RadarConf'23

2023 IEEE RADAR CONFERENCE

May 1 – May 5, 2023 // San Antonio Rivercenter // San Antonio, Texas, USA

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radar2023.ieee-radarconf.org

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IEEE

AESS 50th Anniversary

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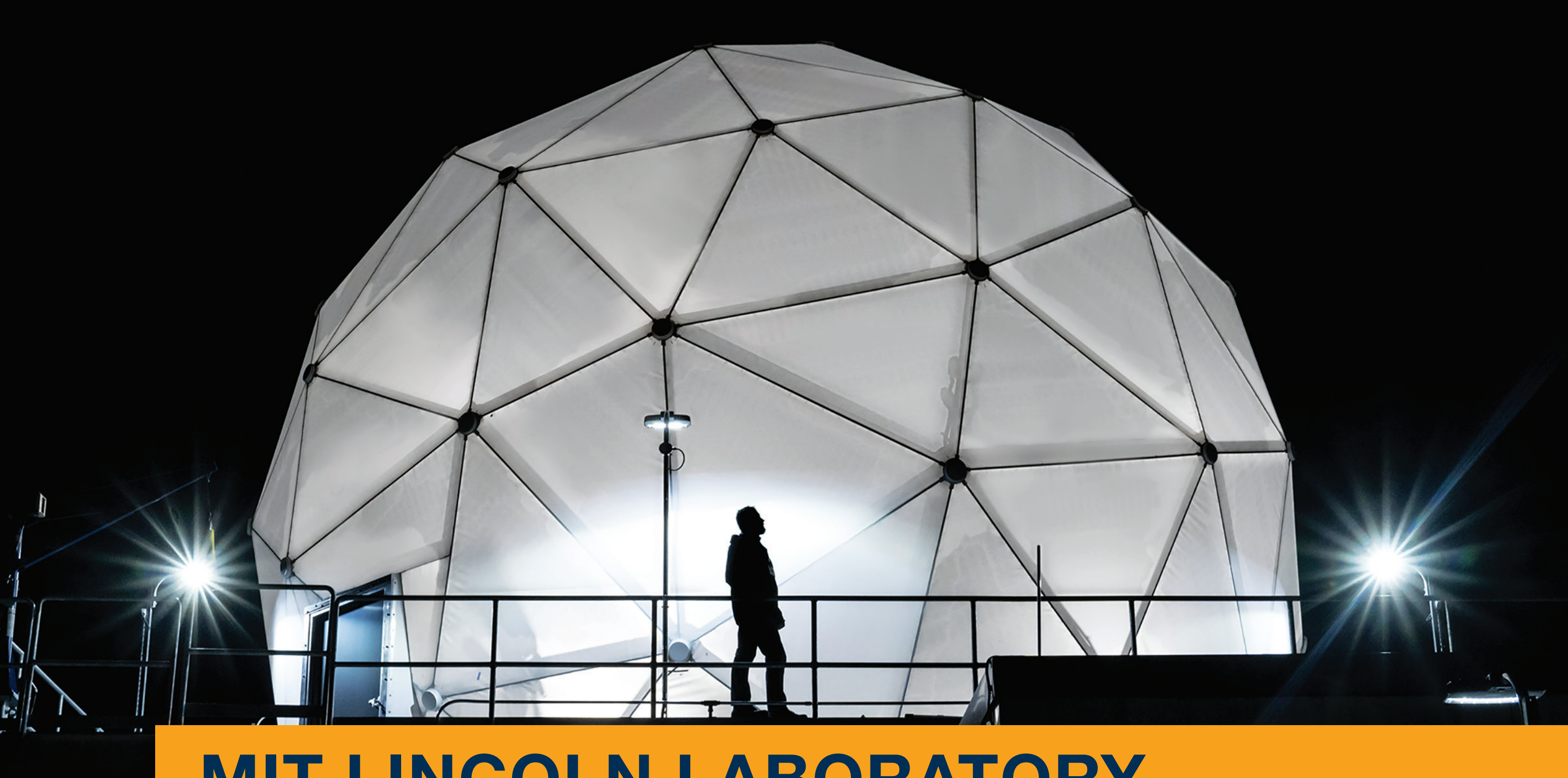

Welcome from the Chairs

It gives us great pleasure to welcome you to the 2023 IEEE Radar Conference to celebrate a Fiesta of Radar Innovations and the 50th anniversary of the Aerospace and Electronic Systems Society (AESS). Our conference is held this year at the River Walk in San Antonio for the first time, jointly sponsored by the AESS and the IEEE Lone Star Section, to foster both a strong technical program and in-person participation to highlight future innovations while keeping with the best traditions and practices of the IEEE and AESS. We are happy to announce in-person briefings and full attendance as we proceed out of the restrictions imposed by the COVID 19 outbreak. We celebrate a Fiesta of Radar Innovations involving the latest radar technologies through plenary talks, special sessions, tutorials, and the Radar Boot Camp. San Antonio is in the heart of Texas within the United States and is known for an eclectic mix of Mexican, German, French, and Old West cultures that combine to create an “only in San Antonio” experience.

The conference kicks off with the Radar Boot Camp, which is supported by educational leaders throughout our research community to cover a wide variety of topics from the history of radar to the latest state-of-the-art applications. Our educational component continues with the tutorial program that offers a combined fifteen lectures and showcases new topics to address technical writing, presentation skills and more. This year’s technical program begins with a presentation from our AESS President, Dr. Mark Davis, celebrating the AESS 50th anniversary as a professional society, followed by our four, premier, plenary speakers that exemplify a diverse perspective of radar topics to include medical science, earth remote sensing, next-generation human ambient intelligence, and the NASA-ISRO Synthetic Aperture Radar Mission. The heart of the technical program highlights original papers describing significant advances in radar technologies, systems, applications and techniques. This year’s conference also celebrates technical excellence from prominent women and minority engineers in the radar field during the Diversity, Equity, and Inclusion (DEI) luncheon, while providing a wide range of student engagements to include the student paper competition and gatherings of the Young Professionals group. Our colleagues’ technical excellence will be celebrated during an award ceremony at the conference banquet.

Finally, we are happy to expand last year’s Industry Panel session with two new sessions to highlight the government and electronic warfare perspectives. The Industry Panel will again take center stage to help bridge the discussion of future radar research and development between academic research and industrial development, thus presenting a confluence of ideas to help us shape the future of radar technology. This panel has also increased industry participation at the conference. At this year’s conference we expand the panel session concept to the newly formed Government and EW Panels, which will add a new perspective to the future of radar technology while increasing participation at the conference. We look forward to your participation and lively discussion covering a wide spectrum of radar topics. We look forward to your participation and seeing you at the Fiesta!

Welcome from AESS

Welcome To 2023 IEEE Radar Conference – the Golden Anniversary of AESS

Mark E Davis, President AESS

Welcome, on behalf of Aerospace & Electronics Systems Society (AESS) Board of Governors, to the 2023 IEEE Radar Conference in San Antonio Texas! We are celebrating the AESS **50th Anniversary** as a professional society, whose technical fields of interest include complex systems for space, air, ocean, and ground-based applications.

Our goal is to engage the worldwide aerospace community including Conferences, Publications, Technical Panels, and Education for our members. At RadarConf23, we are supporting the Radar Summer School, Young Professional gatherings, and Travel Support for students to attend this event. The travel grant is through the **IEEE Michael C. Wicks Radar Student Travel Grant**

To celebrate technical excellence, AESS presents Awards to individuals or groups in recognition of exceptional achievements or significant contributions in our fields of interest. We also conduct interesting and engaging activities for Student Members and Young Professionals at conferences, local chapters, and student branches; and offer merit-based scholarships for Undergraduate and Graduate Student Members. You will be seeing the 2023 awardees at this Conference banquet

The Radar Conference series has historically presented Tutorials to provide our technical interests in Radar Systems, Signal Processing, Sensor Fusion and emerging technologies such as waveform diversity and cognitive radar. These topics have been very successful and are made available in shorter Distinguished Lectures for your Chapters and Industry through the IEEE Learning Network.

One of the major benefits for joining IEEE and AESS is the lower registration costs for these benefits. **Please Join Us** to obtain these membership benefits by signing up at: https://ieee-aess.org

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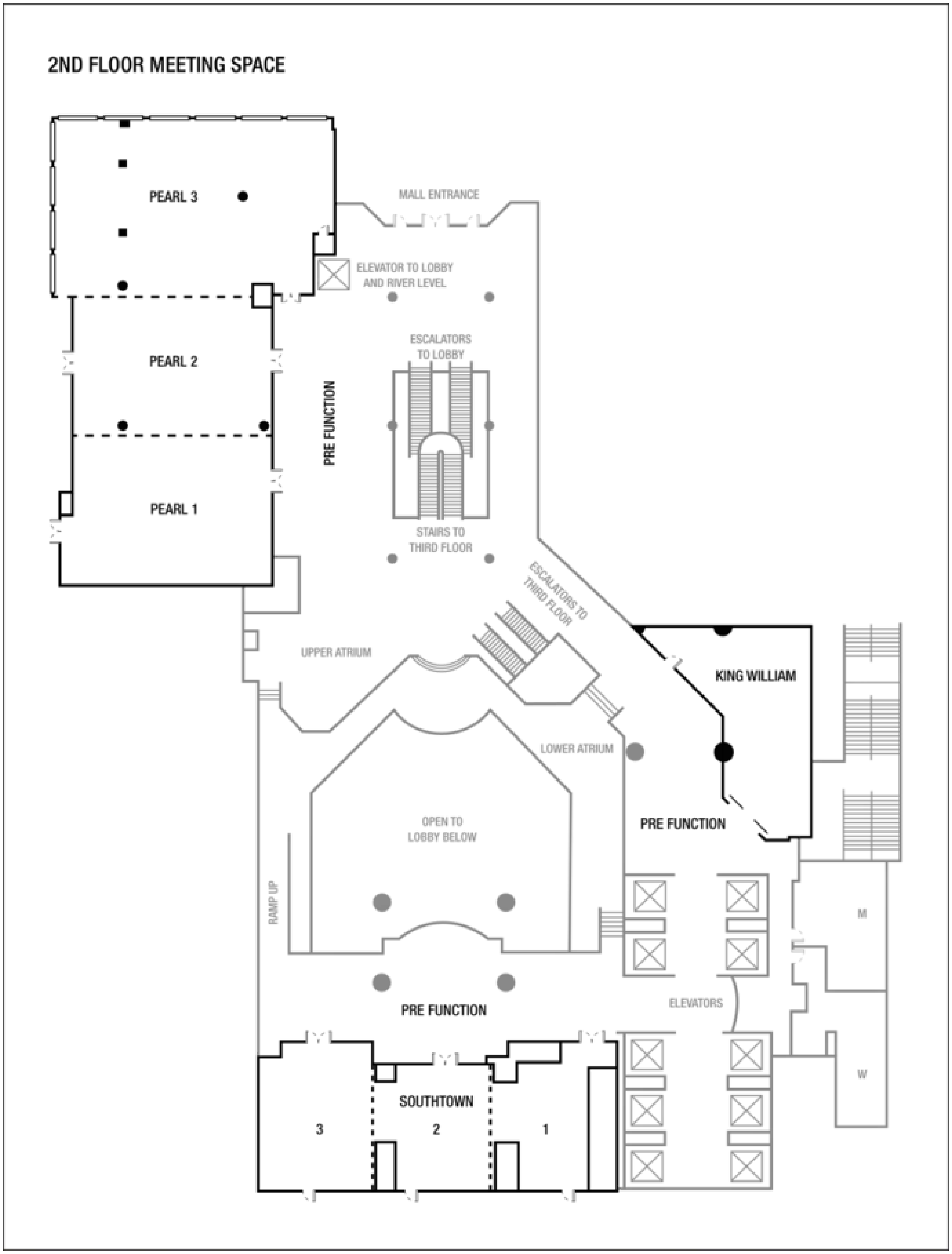

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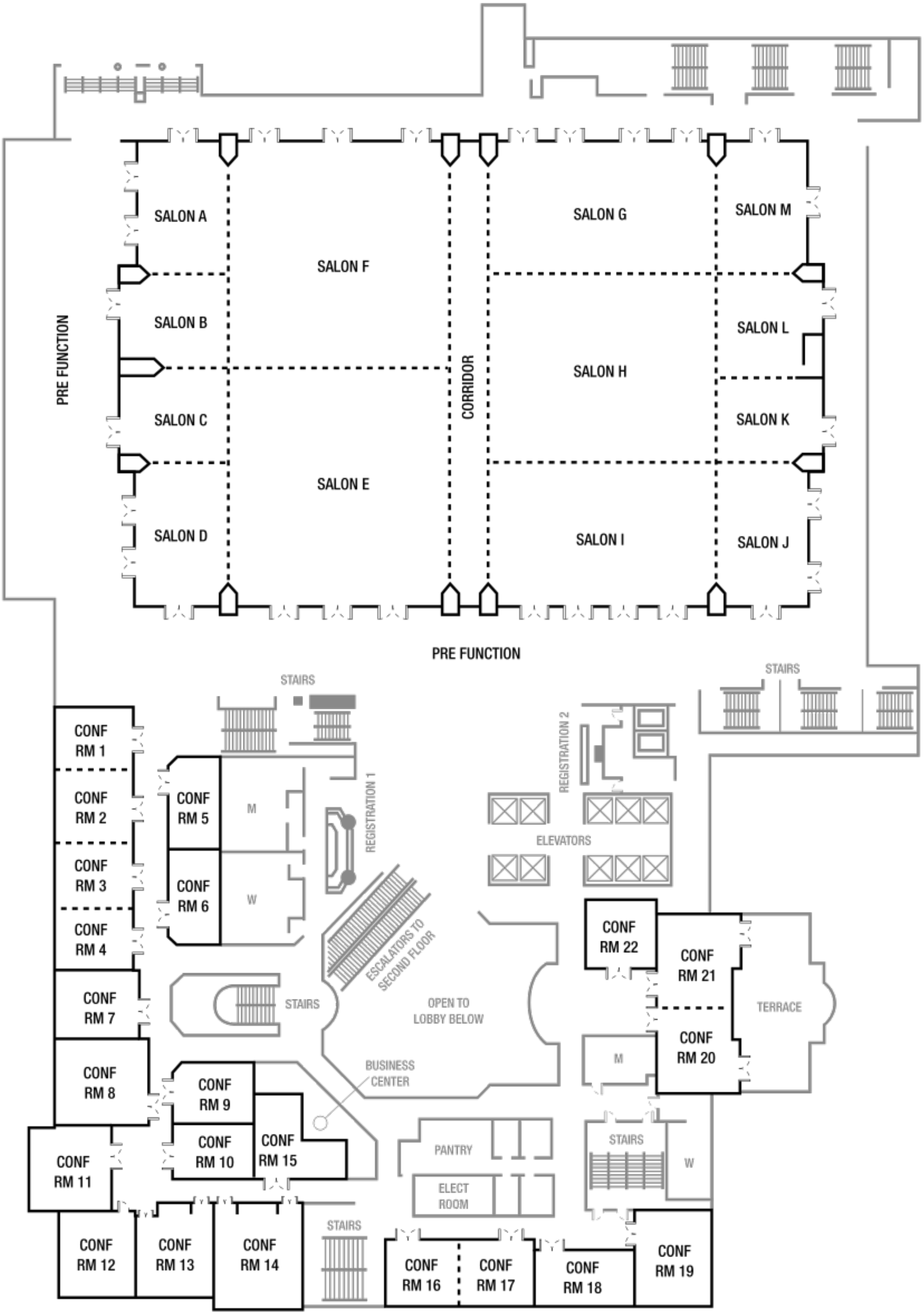

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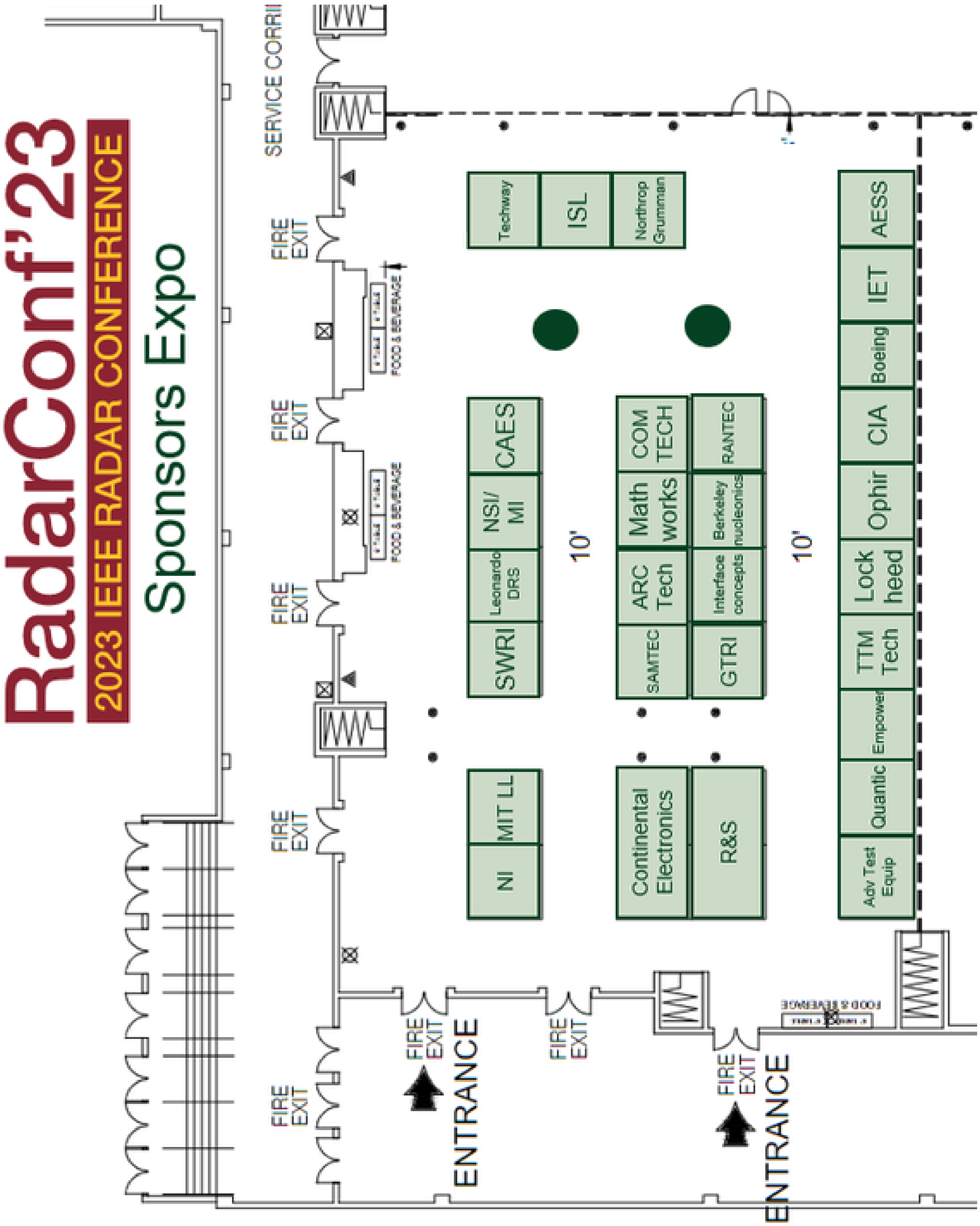

Exhibitor Bingo

Exhibitor Bingo and Prize Drawing!

Bingo: Tuesday and Wednesday in the Expo

Drawing: Wednesday 5pm to 7pm at the Exhibitor Reception

STEP 1

Visit Each Exhibitor and Get a Stamp on your Bingo Card.
Card should be in your conference bag.

Don't forget to take a little time to learn how they are helping Radar Industry

STEP 2

Place your completed Bingo Card in the Golden Raffle Wheel in the Expo Area.

STEP 3

Attend the Exhibitor Reception on Wednesday May 3rd in the Expo from 5pm to 7pm.

A special thanks to our sponsors.
Without you this event would not happen.

Poster Layout

TUESDAY
May 2nd, 12:50-14:20

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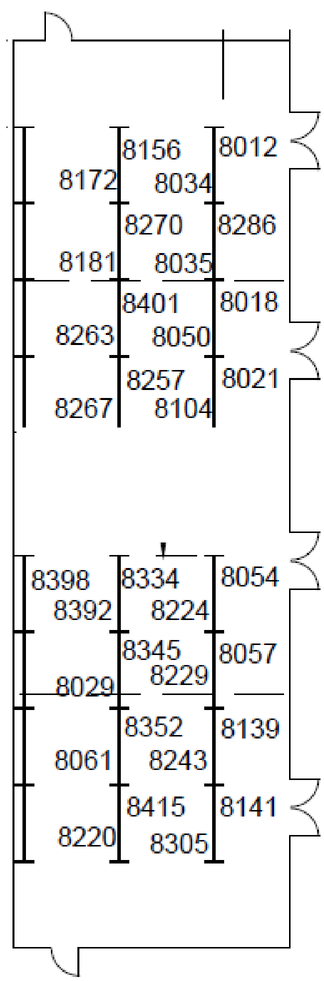
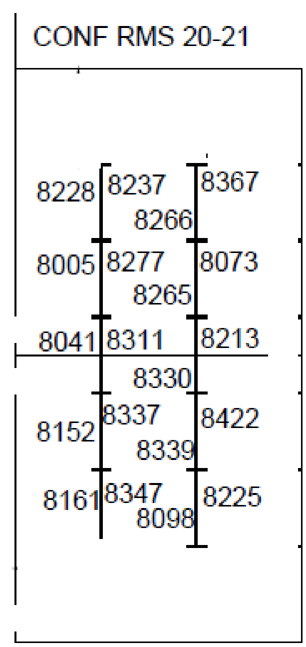
Poster Sessions
- Radar Imaging Methods
- Array Design & Processing
- Waveform Design & Optimization

CONF RMS 1-4



Poster Sessions
- Radar Signal Processing
- Spectrum Sharing & Cognitive Radar



TUESDAY

May 2nd, 14:50-16:20

RadarConf'23

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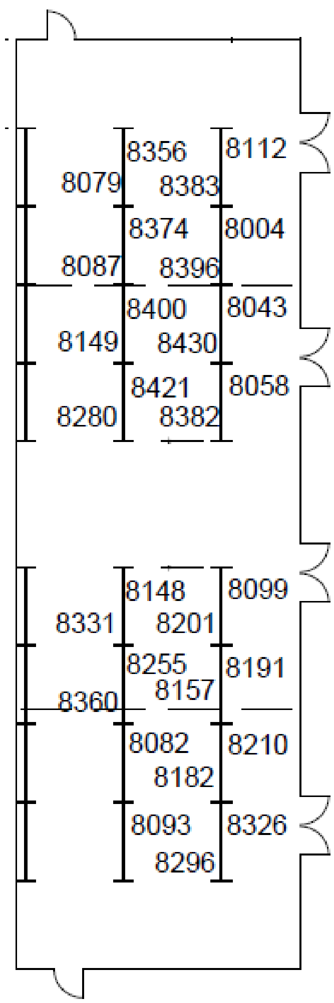
Poster Sessions

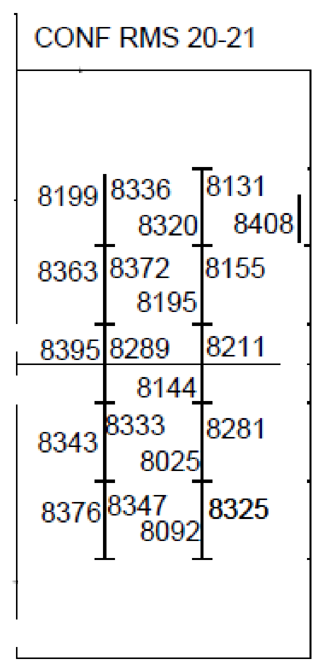
- Machine Learning for Radar
- Classification
- Machine Learning for SAR ATR

CONF RMS 1-4



Poster Sessions

- Radar Technologies
- Multistatic, Networked, & Distributed
- Estimation Techniques



Program at a Glance

Saturday, April 29, 2023

TIME	
8:45 AM	Radar Boot Camp Opening Ceremony *CONF RMS 20-21*
9:00 AM	History of Radar *CONF RMS 20-21*
10:15 AM	Coffee Break
10:30 AM	Introduction to Radar Systems *CONF RMS 20-21*
12:00 PM	Lunch on Your Own
1:30 PM	Estimated and Detection *CONF RMS 20-21*
2:45 PM	Radar Imaging *CONF RMS 20-21*
3:45 PM	Coffee Break
4:15 PM	STAP *CONF RMS 20-21*
5:30 PM	Low Cost GNU Radio Radar Demo *CONF RMS 20-21*

METRON

Sunday, April 30, 2023

TIME	
9:00 AM	Target Tracking *CONF RMS 20-21*
10:15AM	Electronic *CONF RMS 20-21*
11:30 AM	Coffee Break
11:45 AM	Automotive Radar *CONF RMS 20-21*
12:45 PM	Lunch on Your Own
2:30 PM	Low-Cost Radar Demonstrations I *CONF RMS 20-21*
3:30 PM	Coffee Break
4:00 PM	Low-Cost Radar Demonstrations II *CONF RMS 20-21*

METRON

Monday, May 1, 2023

TIME					
7:00 AM	Registration *FOYER*				
8:00 AM	Tutorial: Systematic Filter Design for Tracking Maneuvering Targets *CONF RM 1*	Tutorial: Ultra Wide Band Surveillance Radar *CONF RM 2*	Tutorial: Introduction to Airborne Ground-Moving Target Indicator (GMTI) Radar *CONF RM 3*	Tutorial: Passive Radar on Mobile Platforms – From Target Detection to SAR/ISAR Imaging *CONF RM 4*	Tutorial: Deep Learning Laboratory for Radar Automatic Target Recognition *CONF RM 5*
12:00 PM	Lunch *SALON E*				
1:00 PM	Tutorial: Technical Writing/ Technical Presentations/ Project Management/ Systems Engineering *CONF RM 1*	Tutorial: Active Electronically Scanned Arrays: Fundamentals and Applications *CONF RM 2*	Tutorial: Advanced Radar Detection and Applications *CONF RM 3*	Tutorial: An Overview of Practical Spectrum Sharing Techniques for Radar and Communications *CONF RM 4*	Tutorial: New Illuminators of Opportunity for Passive Radars - Challenges and Opportunities *CONF RM 5*
4:00 PM	Student Paper Competition *CONF RM 6*				
6:30 PM	YP Event *SALON CD*				

Tuesday, May 2, 2023

TIME			
7:00 AM	Registration *FOYER*		
8:00 AM	Exhibit Hall *SALONS A&B (ABF)*		
8:00 AM	General & Technical Chair's Opening Remarks *SALON E (C-E)*		
8:30 AM	Plenary: David G. Long *SALON E (C-E)*		
9:15 AM	Plenary: Paul A. Rosen *SALON E (C-E)*		
10:00 AM	Coffee Break		
10:20 AM	Plenary: Sevgi Gurbuz *SALON E (C-E)*		
11:05 AM	Plenary: Elise Fear *SALON E (C-E)*		
11:50 AM	Lunch *SALONS HI*	DEI Lunch **Ticket Needed** *SALON J (JK)*	TAES Radar Associate Editors and T-RS Editors Meeting **Closed Meeting** *CONF RM 6*
12:50 PM	Poster Session *CONF RMS 20-21*		Poster Session *CONF RMS 1-4*
2:20 PM	Coffee Break		
2:50 PM	Poster Session *CONF RMS 20-21*		Poster Session *CONF RMS 1-4*
4:20 PM	Industry Panel *SALON E (C-E)*		
6:00 PM	Welcome Reception *SALONS A&B (ABF)*		
7:00 PM	RSP Panel Dinner **Closed Meeting** *Salon J*		

Wednesday, May 3, 2023

TIME				
7:00 AM	Registration *FOYER*			
8:00 AM	Exhibit Hall *SALONS A&B (ABF)*			
7:30 AM	Lecture: Integrated Sensing & Communication 1 *SALON D (CD)*	Lecture: Detection & Estimation 1 *SALON E*	Lecture: SAR Automatic Target Recognition *CONF RMS 1-4*	Lecture: Human Monitoring *CONF RMS 20-21*
9:10 AM	Coffee Break			
9:40 AM	Lecture: Advanced Signal Processing Approaches for Next Generation Automotive Radar *SALON D (CD)*	Lecture: Waveform Design *SALON E*	Lecture: AI/ML in Radar *CONF RMS 1-4*	Lecture: Tracking 1 *CONF RMS 20-21*
11:20 AM	Lunch *SALON I (&GH)*			
12:20 PM	Lecture: Micro Doppler & Cognitive Radar - In memory of Dr. Graeme E. Smith *SALON D (CD)*	Lecture: Detection & Estimation 2 *SALON E*	Lecture: Inverse Methods & Applications *CONF RMS 1-4*	Lecture: Advances & Current Trends in Radar Sensing of Physiological Parameters for Human Wellness *CONF RMS 20-21*
2:00 PM	Coffee Break			
2:30 PM	Lecture: Integrated Sensing & Communication 2 *SALON D (CD)*	Lecture: MIMO & Frequency-Diverse Arrays *SALON E*	Lecture: AI Radar Applications 1 *CONF RMS 1-4*	Lecture: Radar Technology & Subsystems *CONF RMS 20-21*
4:10 PM	Government Panel *SALON E*			
6:00 PM	Exhibitor reception *SALONS A&B (ABF)*			
7:00 PM	Banquet Dinner *SALON I (&GH)*			

Thursday, May 4, 2023

TIME				
7:00 AM	Registration *FOYER*			
8:00 AM	Exhibit Hall *SALONS A&B (ABF)*			
7:30 AM	Lecture: Synthetic Aperture Radar for Automotive Applications *SALON D (CD)*	Lecture: Detection & Estimation 3 *SALON E*	Lecture: Passive Radar *CONF RMS 1-4*	Lecture: Distributed Sensing & Communications in Cognitive Radar Network *CONF RMS 20-21*
9:10 AM	Coffee Break			
9:40 AM	Lecture: Advanced Systems and Algorithms for mmWave Radars *SALON D (CD)*	Lecture: Radar Waveform Analysis *SALON E*	Lecture: AI Radar Applications 2 *CONF RMS 1-4*	Lecture: Intelligent Reflecting Surfaces for Next-Generation Radar *CONF RMS 20-21*
11:20 AM	Lunch *Salons GHI*			
12:20 PM	Lecture: Automotive Radar *SALON D (CD)*	Lecture: Multichannel Signal Processing *SALON E*	Lecture: Radar Imaging *CONF RMS 1-4*	Lecture: Tracking 2 *CONF RMS 20-21*
2:00 PM	Coffee Break			
2:30 PM	Lecture: Discrete Optimization for Radar Waveforms *SALON D (CD)*	Lecture: Dual-Function Radar/Communications *SALON E*	Lecture: Space Based Sensors *CONF RMS 1-4*	Lecture: Radar Modeling & Simulation *CONF RMS 20-21*
4:20 PM	EW Panel and Closing *SALON E*			

Friday, May 5, 2023

TIME						
7:00 AM	Registration *FOYER*					
8:00 AM	Tutorial: Micro-Doppler Signatures: Principles, Analysis and Applications *CONF RM 1*	Tutorial: Radar for Health Monitoring: Signal Processing, Systems and Applications *CONF RM 2*	Tutorial: Cognitive EW: An AI Approach *CONF RM 3*	Tutorial: Introduction to Modern Radar Transmitters *CONF RM 4*	Tutorial: Bistatic and Multistatic Radar Imaging *CONF RM 5*	AESS BOG Meeting **Closed Meeting** *CONF RM 20-21*
12:00 PM	AESS BOG Lunch **Closed Meeting** *Pearl 1*					
1:00 PM	AESS BOG Meeting **Closed Meeting** *CONF RM 20-21*					

Saturday, May 6, 2023

TIME	
8:00 AM	AESS BOG Meeting **Closed Meeting** *CONF RM 20-21*
12:00 PM	AESS BOG Lunch **Closed Meeting** *Pearl 1*
1:00 PM	AESS BOG Meeting **Closed Meeting** *CONF RM 20-21*

Plenary Speakers

David G. Long
“Satellite Radar Earth Remote Sensing: Icebergs and Winds”
Brigham Young University

Abstract: Microwave remote sensing extracts environmental information from what is often considered the undesired components of signals encountered in surveillance radar: noise and clutter. Radiometers exploit noise, while remote sensing radars employ clutter to study the Earth. Satellite-based radar sensors, coupled with computer processing offer unique perspectives and measurements of important geophysical processes beyond just imaging. In this talk, I consider applications of satellite radar measurements of the microwave scattering properties of the Earth’s surface. Synthetic Aperture Radar (SAR) make highly detailed backscatter images regardless of the weather or solar illumination conditions. These have both military and civilian applications. However, other types of satellite radar such as altimeters, scatterometers, and weather radars provide unique measurements and perspective. For example, over the ocean radar backscatter is related wind-generated roughness and can be used to measure wind speed and direction. Radar backscatter is particularly sensitive to melt/freeze conditions and can thus be used to map and monitor sea ice and soil conditions. The contrast between ocean and ice scattering enables tracking of major icebergs in Antarctic. Using precise range measurements satellite altimeters measure ocean topography from which ocean currents can be inferred. Satellite weather radars measure rain rates and cloud density. With existing and planned systems, we are in the golden age of satellite radar remote sensing.

Paul A Rosen
“The NASA-ISRO Synthetic Aperture Radar Mission – The Final Stretch Toward a New Capability for Earth Science and Applications”
California Institute of Technology

Abstract: The National Aeronautics and Space Administration (NASA) in the United States and the Indian Space Research Organisation (ISRO) are developing the NASA-ISRO Synthetic Aperture Radar (NISAR) mission, now planned for launch in early 2024. The mission will use synthetic aperture radar to map Earth solid surfaces every 12 days, persistently on ascending and descending portions of the orbit, over all land and ice. The mission’s primary objectives will be to study Earth land and ice deformation, and ecosystems, in areas of common interest to the US and Indian science communities. This single observatory solution with L-band (24 cm wavelength) and S-band (9.4 cm wavelength) imaging radars has a swath of over 240 km at 5-10 m resolution, using full polarimetry where needed. To achieve these unprecedented capabilities, both radars use a reflector-feed system, whereby the feed aperture elements are individually sampled to allow a scan-on-receive capability at both L-band and S-band. The L-band and S-band electronics and feed apertures, provided by NASA and ISRO respectively, share a common 12-m diameter deployable reflector/boom system, provided by NASA. These two radars, which can operate simultaneously, produce prodigious amounts of data even with FPGA-based on-board digital beamforming and filtering to reduce data rates. Given the high data rates and ambitious coverage requirements, new technologies for high-rate Ka-band downlink complement these first-of-a-kind radar systems.

Slowed by the global pandemic, the mission is now approaching its final stage of integration and test. The radar electronics, GNSS unit and solid-state recorder are mounted on an octagonal cylindrical radar instrument structure. This structure, as well as the Ka-band downlink system and associated control electronics finished testing in early March 2023 and are being shipped to India for integration with the ISRO-provided spacecraft bus. The reflector/boom system completed testing in 2022 and will be shipped to India when needed in summer 2023. The integration and test period for the observatory is planned to complete in 2023, with the earliest possible launch date being after the eclipse season for the planned NISAR orbit ends on January 30, 2024. The launch vehicle is ISRO’s GSLV Mark II.

This talk will describe the mission, the measurements, and the technologies and techniques that plans to deliver over 40 Tbits of science and applications data per day to understand our everchanging planet.

Sevgi Gurbuz
"Radar as an Enabling Technology for Next Generation Human Ambient Intelligence"
University of Alabama

Abstract: As technology advances and an increasing number of devices enter our homes and workplace, humans have become an integral component of cyber-physical systems (CPS). One of the grand challenges of cyber-physical human systems (CPHS) is how to design autonomous systems where human-system collaboration is optimized through improved understanding of human behavior. A new frontier within this landscape is afforded by the advent of low-cost, low-power millimeter (mm)-wave RF transceivers, which enables the exploitation of RF sensors almost anywhere as part of the Internet-of-Things (IoT), smart environments, personal devices, and even wearables. RF sensors not only provide sensing capability when other sensors may be ineffective due to environmental factors, but also provide unique spatio-kinematic measurements that are complementary to that of other sensing modalities. Moreover, in indoor environments where privacy is also a driving consideration, RF sensors offer relatively non-intrusive perception capabilities. Consequently, there have been exciting recent advancements in the use of RF sensing for human-computer interaction, remote health monitoring, and smart homes. Since the first research in radar-based human activity recognition over 15 years ago, where the technology was demonstrated in controlled lab settings, now radar can be found in many new devices hitting the market. This includes the Google SOLI sensor in cell phones for non-contact gesture recognition, as well as products under development by Amazon, Vayyar and others for sleep monitoring, vital sign monitoring, and occupancy recognition. However, these applications only begin to touch the surface of the potential for radar-enabled cyber-physical human systems (CPHS). Future intelligent devices equipped with cognitive perception and learning will be able to much more effectively and robustly decipher and respond to complex human behaviors. This talk provides a detailed discussion of current sensing and machine learning challenges, as well as new perspectives that can help us overcome current limitations and pave the way for future radar-enabled interactive environments.

Elise Fear
"Radar-inspired imaging for breast cancer detection"
University of Calgary

Abstract: Biomedical applications at microwave and radio frequencies rely on the differences in permittivity and conductivity of biological tissues. The properties of healthy tissues span a wide range that relates to water content, while diseased tissues such as malignancies typically exhibit increased properties. Leveraging these differences, microwave imaging has been investigated as an alternative method for breast cancer detection and treatment monitoring.

Several approaches have been developed to map the properties of tissues and identify anomalies. Microwave tomography involves measuring signals transmitted through the tissues, then iteratively updating properties of a model until simulations match these measurements. Radar-based approaches involve collecting reflections from tissues, then processing and focusing these reflections to identify anomalies. For both radar and tomography, key challenges are design of a measurement system and interface that enable reliable and rapid collection of data while operating close to the target tissues, developing imaging algorithms capable of detecting anomalies in a complex background, and reconciling the resulting microwave images with clinically available data.

At the University of Calgary, we have developed several generations of prototype systems, focusing on demonstrating the consistency of images collected at different time points, as well as the feasibility of detecting tumors and treatment-related changes. Our most advanced radar-based system implements patient-specific capabilities, scanning the breast with 4 degrees of freedom in sensor positioning to enable consistent collection of data. We leveraged the knowledge gained through experience with this system to develop a novel approach that estimates locally averaged properties of tissues by detecting pulses traveling through the breast. With this approach, we have demonstrated a high degree of similarity between images captured at different time points, as well as symmetry between properties of the right and left breasts. Comparison of the images of right and left breasts of cancer patients has also enabled tracking treatment-related changes. Recently, our team began testing the next generation of this transmission system that features improved resolution. The initial results obtained with this system add to the growing body of work that illustrates the potential of microwave imaging to provide a unique breast imaging solution.

EW Panel

Within the field of artificial intelligence is the emerging research area of using cognitive systems at the edge. Adjacent to the machine learning systems which pretrains on large volumes of data, cognitive systems explore learning in real-time. The decisions made by cognitive systems in complex battle-field scenarios can have life or death consequences.

The panel moderator will facilitate a conversation between industry, academia, and government related to cognitive systems applied to electronic warfare. The diverse set of panelists includes experts in the domains of Cognitive Radar, Cognitive Electronic Warfare, Neuromorphic Computing, and DoD Electronic Warfare. The goal of the panel is to promote future interactions between the radar community and the electronic warfare community.

When: Thursday, May 4, 2023 from 4:20 PM – 5:30 PM
Where: SALONE E

Garrett Hall

Garrett Hall resides in San Antonio, Texas where he works as a Research Engineer at Southwest Research Institute (SwRI). He holds a BS and MS in Electrical Engineering from The University of Texas at San Antonio (UTSA). During his time at UTSA, he published deep learning research in brain-computer interfacing, adversarial examples, and multiagent reinforcement learning. At SwRI, he has served as the principal investigator for multiple internal research programs and continues research as a machine learning expert for signal classification and simulation based decision making.

Karen Haigh

Dr. Karen Haigh is an expert and consultant in Cognitive EW and embedded AI. Her focus is on physical systems with limited communications and limited computation resources that must perform under fast hard- real-time requirements. In September 2021, her book "Cognitive Electronic Warfare: An Artificial Intelligence Approach", was released by Artech House. She received her Ph.D. in from Carnegie Mellon University in Computer Science with a focus on AI and Robotics. Dr. Haigh is a Fellow of the IEEE for contributions to closed-loop control of embedded systems, and a Fellow of AAIA for outstanding achievements in the area of smart homes.

Col. William Young, Jr

Col. William “Dollar” Young, Jr is an accomplished strategist and leader with 27 years in the United States Air Force. He currently commands the 53rd Electronic Warfare Group (EWG) at Eglin Air Force Base. The 53 EWG is responsible for the secure development, testing, and distribution for nearly all mission data software supporting USAF combat aircraft. His organization is the free world’s largest mission data software reprogramming center with nearly 1,000 engineers, operators, analysts, intelligence, and maintenance personnel. Col. Young’s organization also provides survivability assessments for USAF fighter and bomber aircraft.

Col Young was commissioned in 1991 after graduating from the United States Air Force Academy. He earned his wings from Specialized Undergraduate Navigator Training (SUNT). Col Young is a Distinguished Graduate of the US Air Force Weapons School and is a 2006 graduate of the USAF School of Advanced Air and Space Studies (SAASS). He is also a former Air Force Intern with rotations in the Office of the Secretary of Defense, Air Force Operations Group, and the Air Force CHECKMATE Division. Col Young is an Instructor Electronic Warfare Officer with more than 2,400 flying hours in the EA-6B and B-52, including 240 combat hours during Operation ENDURING FREEDOM. He possesses a PhD from MIT, four Masters degrees and a BS in Engineering Science from the USAF Academy.

Steven D. Harbour

Dr. Steven D. Harbour, PhD. Principal Engineer & Scientist, Dayton Engineering Advanced Projects Lab, Avionics Division, SwRI. SME in Artificial Intelligence / Machine Learning, Human Autonomy Teaming, Neuroscience, Electrical & Computer Engineering, Avionics, UAS and Autonomous vehicles. A senior leader, defense research & engineering professional with over 25 years of experience in multiple engineering and aviation disciplines & applications. Leads and performs ongoing basic and applied research projects, including the development of third-generation spiking neural networks (SNNs) and neuromorphic applications to include Human Autonomy Teaming. He has supported the Air Force Research Laboratory Sensors Directorate at Wright-Patterson Air Force Base, Ohio, and at the Air Force Life Cycle Management Center in the ISR / SOF directorate as the Global Hawk Chief of Avionics Engineering and Modernization Programs. USAF test pilot with over 5,000 hours total flying time in F-16, F-4, AT-38, T-37, B-52, and EC-135 aircraft. Flew the MIG-29 as part of the US State Department's military to military visit program under the Nunn-Lugar Act. PhD in Neuroscience (Specializations: Artificial Intelligence & Machine Learning and Neuroergonomics), MS in Aerospace Engineering & Mathematics (Specializations: Avionics, Controls & Displays), BS in Electrical & Computer Engineering (Specializations: Robotics & Feedback Control Systems and Cognition). Dr. Harbour also teaches at the University of Dayton & Sinclair College.

Sevgi Gurbuz

Dr. Sevgi Zubeyde Gurbuz (S'01–M'10–SM'17) received her B.S. and M.Eng. degrees from the Massachusetts Institute of Technology, Cambridge, in 1998 and 2000, respectively, and her Ph.D. degree from the Georgia Institute of Technology, Atlanta, in 2009, all in electrical engineering. She served as a radar-signal processing research engineer in the U.S. Air Force Research Laboratory, Rome, New York, from 2000 to 2004. She is currently an assistant professor of electrical and computer engineering at the University of Alabama, Tuscaloosa Dr. Gurbuz's main focus of research lies in the advancement of RF-enabled Cyber-Physical Human Systems (CPHS), radar signal processing and machine learning algorithms to address the challenges of robust, accurate human micro-Doppler signature analysis, automatic target recognition (ATR) and control of CPHS for automotive, health, human computer-interaction, and defense applications. She has pioneered radar-based American Sign Language (ASL) recognition, for which she was awarded a patent in 2022, and is developing novel, interactive RF sensing paradigms built upon physics-aware machine learning and fully-adaptive (cognitive) radar that provide for unique AI/ML solutions to radar perception problems. She is editor of a recently published book "Deep Neural Networks Design for Radar Applications," and is the author of 8 book chapters, over 25 journal and 85 conference papers. She is the recipient of the 2022 American Association of University Women Research Publication Grant in Medicine and Biology, the 2021 Harry Rowe Mimno Award for Excellence in Technical Communications, the 2020 SPIE Rising Researcher Award, a 2010 Marie Curie Fellowship, and 2010 IEEE Radar Conference Best Student Paper Award. She also serves as a member of the IEEE Radar Systems Panel and is an Associate Editor for the IEEE Transactions on Aerospace and Electronic Systems, IEEE Transactions on Radar Systems, and IET Radar, Sonar and Navigation. Dr. Gurbuz is a Senior Member of the IEEE, and a member of the SPIE and ACM

Kumar Vijay Mishra

Kumar Vijay Mishra (S'08-M'15-SM'18) obtained a Ph.D. in electrical engineering and M.S. in mathematics from The University of Iowa in 2015, and M.S. in electrical engineering from Colorado State University in 2012, while working on NASA's Global Precipitation Mission Ground Validation (GPM-GV) weather radars. He received his B. Tech. summa cum laude (Gold Medal, Honors) in electronics and communication engineering from the National Institute of Technology, Hamirpur (NITH), India in 2003. He is currently Senior Fellow at the United States Army Research Laboratory (ARL), Adelphi; Technical Adviser to Singapore-based automotive radar start-up Hertzwell and Boston-based imaging radar startup Aura Intelligent Systems; and honorary Research Fellow at SnT - Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg. Previously, he had research appointments at Electronics and Radar Development Establishment (LRDE), Defence Research and Development Organisation (DRDO) Bengaluru; IIHR - Hydroscience & Engineering, Iowa City, IA; Mitsubishi Electric Research Labs, Cambridge, MA; Qualcomm, San Jose; and Technion - Israel Institute of Technology.

Dr. Mishra is the Distinguished Lecturer of the IEEE Communications Society (2023-2024), IEEE Aerospace and Electronic Systems Society (AESS) (2023-2024), and IEEE Future Networks Initiative (2022). He is the recipient of the IET Premium Best Paper Prize (2021), U. S. National Academies Harry Diamond Distinguished Fellowship (2018-2021), American Geophysical Union Editors' Citation for Excellence (2019), Royal Meteorological Society Quarterly Journal Editor's Prize (2017), Viterbi Postdoctoral Fellowship (2015, 2016), Lady Davis Postdoctoral Fellowship (2017), DRDO LRDE Scientist of the Year Award (2006), NITH Director's Gold Medal (2003), and NITH Best Student Award (2003). He has received Best Paper Awards at IEEE MLSP 2019 and IEEE ACES Symposium 2019.

Dr. Mishra is Chair (2023-present) of the Synthetic Apertures Technical Working Group of the IEEE Signal Processing Society (SPS) and Vice-Chair (2021-present) of the IEEE Synthetic Aperture Standards Committee, which is the first SPS standards committee. He is the Vice Chair (2021-2023) and Chair-designate (2023-2026) of the International Union of Radio Science (URSI) Commission C. He has been an elected member of three technical committees of IEEE SPS: SPCOM, SAM, and ASPS, and IEEE AESS Radar Systems Panel. Since 2020, he has been Associate Editor of IEEE Transactions on Aerospace and Electronic Systems, where he was awarded Outstanding Editor recognition in 2021. He has been a lead/guest editor of several special issues in journals such as IEEE Signal Processing Magazine, IEEE Journal of Selected Topics in Signal Processing, and IEEE Journal on Selected Areas in Communications. He is the lead co-editor of three upcoming books on radar: Signal Processing for Joint Radar-Communications (Wiley-IEEE Press), Next-Generation Cognitive Radar Systems (IET Press Radar, Electromagnetics & Signal Processing Technologies Series), and Advances in Weather Radar Volumes 1, 2 & 3 (IET Press Radar, Electromagnetics & Signal Processing Technologies Series). His research interests include radar systems, signal processing, remote sensing, and electromagnetics.

Gov't Panel – Radar in Spectrum Challenged World

The ever-increasing demand for spectrum and spectrum congestion has led to auctioning of prime radar spectrum bands to commercial users. This adds additional burden on Radar users because their demand for spectrum is not only increasing but at the same time, they are losing the spectrum to other users. This panel will discuss and debate the many challenges and opportunities to operate, co-exist and share the spectrum with other RF spectrum users.

When: Wednesday, May 3, 2023 from 4:20 PM – 5:30 PM
Where: SALONE E

Hugh Griffths

Hugh Griffiths holds the THALES/Royal Academy of Engineering Chair of RF Sensors at University College London. From 2006-2008 he served as Principal of the Defence College of Management and Technology (DCMT) at the Defence Academy of the United Kingdom, Shrivenham. He received the MA degree in Physics from Oxford University, and the PhD and DSc(Eng) degrees from the University of London. His research interests cover radar, antennas, and signal processing, and he has published over 600 papers, technical articles and books on these subjects.

He served as President of IEEE AES in 2012/2013. He has won a number of awards, including the IEEE AES Nathanson Award (1986), the IET A F Harvey Prize (2013), and the IEEE Picard Medal (2017). Since 2017 he has served as Chair of the Defence Science Expert Committee (DSEC) in the UK Ministry of Defence (broadly equivalent to the Defense Science Board in the US). He was appointed OBE in 2019 for services to engineering, and he was elected Fellow of the Royal Society in 2021.

Vasu D. Chakravarthy

Vasu D. Chakravarthy is a Principal Electronics Engineer at the Air Force Research Laboratories, Sensors Directorate, Electronic Warfare Techniques Development and Analysis Branch., and also serves as an adjunct faculty at Wright State University, Dayton OH. He received his B.S. in Electrical Engineering from the University of Illinois at Chicago, M.S. and Ph.D. in Electrical Engineering from Wright State University. He pioneered a number of new concepts and theories such as Cognitive Jammer, Cognitive EW, and the "Sense-Learn-Adapt" cycle to enable and advance spectrum warfare technologies.

Throughout his career at AFRL, Dr. Chakravarthy's research focus and contribution has been about electromagnetic spectrum (EMS) efficiency and dominance. His present research interest is in advancing the state of art inter-discipline research of AI/ML and signal processing. Dr. Chakravarthy has two patents, written three book chapters and published over 60 papers in peer reviewed conference and journal proceeding. Co-founder and Chair of "AFRL Cognitive RF workshop" from 2010-2016 and Tri-Service EW Complex Emitter Summit (EW CES) from 2022 - present. His research accomplishments earned him induction into AFRL Fellow class of 2020.

Frank Robey

Dr. Frank Robey is a Program Manager in the Strategic Technology Office of the Defense Advanced Research Projects Agency (DARPA) where he is pursuing the advancement of sensor systems and capabilities using signal processing techniques based on firm theoretical foundations.Dr. Robey is on assignment from MIT Lincoln Laboratory. At Lincoln Laboratory he led programs in novel antenna, radar, electronic support, and space-based sensors. These programs included missionapplications of various RF sensors as well as scientific investigations of high-frequency radio propagation and environmental noise in the terrestrial and near-earth environments. Prior assignments include the Reagan Test Site, Kwajalein, Marshall Islands, and the Intelligence Advanced Research Activity (IARPA).Dr. Robey received a doctorate degree in electrical engineering from Washington University, St. Louis. He is a fellow of the IEEE for leadership in the development of advanced radar systems and is perhaps best-known for the commonly-used Adaptive Matched Filter (AMF) detector.

Joshua Weaver

Joshua Weaver is the Director of Spectrum Initiatives and Analysis for the Office of the Undersecretary of Defense for Research and Engineering. His office sponsors and oversees research and development activities to enhance the efficiency and effectiveness of DoD electromagnetic spectrum (EMS) operations. This includes exploring technologies, tools, and processes that improve the DoD's ability to sense, communicate, and achieve effects in congested, constrained, contested, or otherwise complex EMS environments.

Mr. Weaver also serves as the technical authority for the Spectrum Forward Other Transaction Agreement (OTA) with the National Spectrum Consortium; a flexible and collaborative contracting vehicle for executing the Department's spectrum and 5G/Future-G initiatives. He is the Program Manager for the Spectrum Access Research and Development Program which leveraged this OTA to achieve significant advancements in dynamic spectrum access, distributed sensing, interference mitigation and other technologies that enhance the functionality and survivability of DoD EMS operations in increasingly dynamic EMS environments.

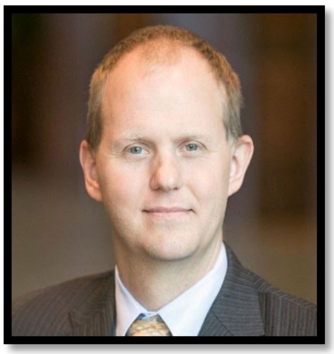
Mr. Weaver co-chairs the Capabilities Working Group under the EMS Senior Steering Group which focuses on activities pertaining to Goal #1 of the EMS Superiority Strategy which is to "Develop Superior EMS Capabilities." He also serves on the Department of Defense Special Spectrum Council to ensure National policy decisions regarding spectrum are sufficiently informed on DoD spectrum needs and the art of the possible in spectrum sharing.

Mr. Weaver is a passionate technologist experienced in agile and novel prototyping strategies that encourage and enable strong collaborations across industry, academia, and Government to develop and field disruptive capabilities.

Industry Panel

Join us for the IEEE Radar Conference Industry Panel… This one-hour moderated discussion brings together experts from across the radar industry. We'll have representatives from a variety of sectors related to radar, including: radar research, radar technology development, system technology, and RF test & measurement. Discussion topics will span the spectrum from advanced RF technologies to advances in digital transformation for test and evaluation. We thank our participants, who include: Lockheed Martin, National Instruments, Northrup Grumman, Continental, MIT-Lincoln Laboratory, and Rohde & Schwarz.

When: Tuesday, May 2, 2023 from 4:20 PM – 5:30 PM
Where: SALONE E



Haydn Nelson

Haydn Nelson a US Navy Veteran he has a great passion for supporting Aerospace and Defense applications. With a Masters in ECE, Haydn has worked in Aerospace and Defense for 18 years across the industry from EW research to deployable embedded systems. Haydn currently manages marketing for Radar and EW applications withing the Aerospace and Defense business unit at NI.

Jeffrey Herd

Dr. Jeffrey Herd is the Leader of the RF Technology Group at Lincoln Laboratory, Massachusetts Institute of Technology (MIT), which develops and demonstrates innovative RF technologies as solutions to emerging needs in radar, electronic warfare, and communications.

Prior to joining the MIT's Laboratory in 1999, Dr. Herd worked in the Sensors Directorate of the Air Force Research Laboratory. While there, he developed phased array antenna technologies, including wideband scanning arrays, multi-frequency antennas, conformal arrays, and digital beamforming arrays. Dr. Herd was a visiting scientist from 1992-1994 at the Institute for Microwave Techniques at the German Aerospace Research Establishment (DLR) in Munich, Germany.

Dr. Herd is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), and served on the Administrative Committee member for the IEEE Antennas and Propagation Society. He was General Chair of the IEEE International Symposium on Phased Array Systems and Technology for the 2013, 2016, and 2019 conferences. From 2012-2014, he served on the National Academy of Sciences panel for Active Scientific Uses of the Radio Spectrum.

Dr. Herd received his BS, MS, and PhD degrees, all in Electrical Engineering, from the University of Massachusetts in Amherst, MA.

Diversity, Equity, and Inclusion (DEI)

As IEEE AESS celebrates its 50th Anniversary, we look forward to the next 50 years of growing and supporting our community through diversity, equity, and inclusion. Join us for lunch on Tuesday May 2! This annual event at the IEEE Radar Conference promotes broader perspectives and collaborations through speakers, panels, and engagement of under-represented groups. Be a part of the 10th annual event and the next 50 years! (Sign up during conference registration. Space is limited, and seats will be reserved on a first come, first served basis.)

When: Tuesday, May 2, 2023 from 11:50 AM – 12:50 PM
Where: SALONE J (JK)

Laura Anitori

Dr. Laura Anitori received her Master of Science degree (cum laude) in Telecommunication Engineering from the University of Pisa, Italy, in 2005 and her Ph.D. degree (cum laude) in Electrical Engineering from the Technical University of Delft, The Netherlands, in 2013. Since 2007 she works at the Radar Technology department of TNO, The Netherlands, where she is senior scientist and program manager of the Defense funded radar research program. She is an IEEE senior member, member of the Board of Governors of AESS, and chair of the AESS Radar System Panel. She is government expert representative for The Netherlands within the European Defence Agency Radar Captech, and Dutch national representative in the NATO Sensors and Electronics Technology (SET) Panel, where she started and coordinates the Woman in SET Working Group. Her significant contributions to NATO were recognized with the SET Early Career Award in 2018, the 2019 SET Panel Excellence Award, and the NATO Scientific Excellence Award in 2022. She serves on several technical program committees and student competition committees at international scientific conferences.

Arik Brown

Dr. Arik Brown received his BS degree in electrical engineering from the Massachusetts Institute of Technology and his M.S. and Ph.D. from the University of Michigan in Computational Electromagnetics with Dr. John Volakis as his advisor. After graduation, Arik worked at Northrop Grumman Mission Systems for 19 years developing advanced system architectures for Radar, EW, Communication and SIGINT systems. At Northrop, Arik received several Trade Secret awards, was a Presidential Leadership Award recipient (2x), and a recipient for the Award for Excellence which is the highest award honor at Northrop Grumman. In 2019, he was awarded the Professional Achievement Award at the Black Engineer of the Year Award Conference.

Arik then served as the Senior Principal Radar Systems Architect for RADA USA; a small defense company focused on ground based Active Electronically Scanned Array (AESA) radars. He was responsible for the strategic application and development of RADA's advanced multi-mission systems for tactical applications involving Counter-UAS, Short Range Air Defense and Active Protection Systems.

Arik has authored several publications and is a leading expert/book author on AESAs (Electronically Scanned Arrays: MATLAB Modeling and Simulation, 2012 and Active Electronically Scanned Arrays: Fundamentals and Applications, 2021). Arik has been appointed to the Board of Governors for the IEEE AESS society and will serve a 3-year term starting in 2023. He currently has rejoined Northrop Grumman and is a NG Fellow working on advanced digital AESA architectures.

Jacqueline A. Fairley

Dr. Fairley is a Senior Research Engineer within the Sensor Artificial Intelligence & Learning Program Office (SAILPO) in the Sensors and Electromagnetic Applications Laboratory (SEAL), at GTRI. She received her Ph.D. in Electrical and Computer Engineering at the Georgia Institute of Technology and completed a postdoctoral fellowship at Emory University in Sleep Medicine and Neuroscience in the Department of Neurology. Her current research focus is the application of artificial intelligence approaches to advance radar technology, sensor resource management, and the utilization of advanced digital signal processing (DSP) techniques to develop airborne radar signal processing algorithms, models, and simulations. Dr. Fairley's professional service endeavors include membership in the IEEE AESS Radar Systems Panel; Treasurer of the IEEE EMBS Atlanta Chapter; and most importantly the establishment and conservation of diversity and inclusion endeavors in STEM.

Jennifer A Watson

Dr. Jennifer A Watson an Assistant Division Head of the Intelligence, Surveillance, and Reconnaissance (ISR) and Tactical Systems Division at MIT Lincoln Laboratory. She joined the Laboratory in 1997 as an associate technical staff member in the Surveillance Techniques Group and began her career developing antenna systems for complex communication environments, with a focus on modeling, development, and field testing. Upon completing her doctoral degree in 2003, she became involved in undersea surveillance work, developing adaptive signal processing approaches for underwater acoustic systems. She combined propagation phenomenology and sensing architectures with novel signal processing techniques to develop and transition capabilities for U.S. Navy programs.

In 2008, Watson transitioned to the Airborne Radar Systems and Techniques Group and was appointed assistant leader in 2010 and leader in 2013. During this time, she led several programs focused on advanced radar and electronic warfare capabilities for ground and maritime surveillance, including adaptive detection and artificial intelligence–enabled exploitation. Under her leadership, the group developed and fielded a series of test beds, including a multichannel Airborne Radar Test Bed to support the development and prototyping of airborne ground surveillance capabilities.

Watson holds BS and MS degrees in electrical engineering from the University of Massachusetts Amherst and a PhD degree in ocean engineering from MIT.

Radar Boot Camp

The Radar Summer School is a brief overview on a wide range of radar topics and is taught by noted radar experts. The school is valuable for those starting a career in radar; as such, there are no prerequisites for attending.

Speakers

Stéphanie Bidon

Stéphanie Bidon received the Dipl.-Ing. degree in aeronautics and the M.S. degree in signal processing from the École Nationale Supérieure d'Ingénieurs de Constructions Aéronautiques, Toulouse, France, in 2004 and 2005, respectively, and the Ph.D. degree and the Habilitation à Diriger des Recherches in signal processing from INP, Toulouse, France, in 2008 and 2015, respectively.

She is currently a Professor with the Department of Electronics, Optronics, and Signal processing at ISAE-SUPAERO, Toulouse, France. Her research is focused on statistical signal processing, particularly with application to radar systems (array signal processing, space-time adaptive processing, dual-function radar-communications systems).

Dr. Bidon is a senior member of the IEEE and serves as an Associate Editor for the IEEE Transactions on Aerospace and Electronic Systems (AES) and the IEEE Transactions on Radar Systems. She has been nominated to the IEEE AES Society Radar Systems Panel (RSP) in 2018 and 2021, where she serves on the Education Committee. She has been recently appointed Vice Chair of the RSP for the next two years.

Hugh Griffiths

Hugh Griffiths holds the THALES/Royal Academy Chair of RF Sensors in the Department of Electronic and Electrical Engineering at University College London, England. From 2006–2008 he served as Principal of the Defence Academy College of Management and Technology. He received the MA degree in Physics from Oxford University in 1975, then spent three years working in industry, before joining University College London, where he received the PhD degree in 1986 and the DSc(Eng) degree in 2000, and served as Head of Department from 2001–2006.

His research interests include radar systems and signal processing (particularly bistatic radar and synthetic aperture radar), and antenna measurement techniques. He serves as Editor-in-Chief of the IET Radar, Sonar and Navigation journal, and was President of IEEE AES for 2102/13. He has published over five hundred papers and technical articles in the fields of radar, antennas and sonar. He has received several awards and prizes, including the IEEE Picard Medal (2017), IET Achievement Medal (2017), the IEEE AES Mimno Award (2015 and 2021), the IET A.F. Harvey Prize (2012) and the IEEE AES Nathanson Award (1996). He is a Fellow of the IET, Fellow of the IEEE, and in 2012 he was elected to Fellowship of the Royal Society (FRS).

Justin Metcalf

Dr. Justin Metcalf received his BS in Computer Engineering from Kansas State University in 2006 where he was a KSU Presidential Scholar. From 2006-2008 he was at the Flight Simulation Labs of Lockheed Martin Aeronautics in Fort Worth, TX. From 2008-2014 he was with the Radar Systems Lab of the University of Kansas, were he obtained an MS in Electrical Engineering in 2011 and a PhD in Electrical Engineering in 2015. He was the recipient of the Richard and Wilma Moore Award for the best departmental MS thesis in 2011-2012. He was a Research Electronics Engineer with the Sensors Directorate of the Air Force Research Laboratory from 2014-2018. He was the chair of the Dayton Chapter of the IEEE Aerospace and Electronic Systems Society from 2016-2018 and won the 2017 IEEE Dayton Section Young Professionals Award. Since 2018 he has been an Assistant Professor with the Electrical and Computer Engineering

Department at the University of Oklahoma, and a member of the Advanced Radar Research Center. He was the recipient of a DARPA Young Faculty Award in 2020 and is currently an Associate Editor for the IEEE Transactions on Aerospace and Electronic Systems and a member of the IEEE AESS Radar Systems Panel. He has published over 50 peer-reviewed publications, including 45 conference papers, 11 journal papers, and 3 book chapters, as well as 1 patent and 5 patent applications pending on topics related to radar signal processing, waveform diversity, radar-embedded communications, and game theory. He has been active in radar/communications research for more than 12 years.

Christ Richmond

Christ D. Richmond is a Professor in the Department of Electrical and Computer Engineering at Duke University where he directs the Signals, Information, Inference, and Learning (SIIL) Group. His research interests include statistical signal and array processing, detection and parameter estimation theory, information theory, machine/deep learning, radar/sonar, communications, and spectral sharing. Prior to joining Duke, he was an Associate Professor in the School of Electrical, Computer, and Energy Engineering at Arizona State University, and prior to that Senior Staff in the Advanced Sensor Techniques Group at the MIT Lincoln Laboratory, and a Visiting Lecturer and Associate of the John A. Paulson School of Engineering and Applied Sciences at Harvard University. Prof. Richmond received the Ph.D. degree in electrical engineering from MIT. He is the recipient of the Office of Naval Research Graduate Fellowship Award, the Alan Berman Research Publications Award, and the IEEE Signal Processing Society Young Author Best Paper Award in the area of Sensor Array and Multichannel (SAM) Signal Processing, and he is a Fellow of the IEEE. He has served as the Technical Chairman of the Adaptive Sensor Array Processing Workshop at MIT Lincoln Laboratory and served as a member of the IEEE Technical Committee on SAM Signal Processing. He served as an Associate Editor for the IEEE Transactions on Signal Processing, and currently serves as a Senior Associate Editor for IEEE Signal Processing Letters, and as a member of the IEEE Aerospace and Electronics Systems Society (AESS) Radar Systems Panel.

Ann Chen

Ann Chen has 15 years of experience in SAR/InSAR algorithm design for earth system science applications. In 2017, she joined the Department of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin as an assistant professor. She is also a faculty member (by courtesy) in the Department of Geological Sciences at UT Austin. She currently leads the Radar Interferometry Group housed in the Center for Space Research. Her group focuses on the development of new satellites, and especially interferometric Synthetic Aperture Radar (InSAR) techniques, for studying natural and induced seismicity, groundwater resources, natural disasters, and permafrost hydrology and carbon storage.

Mike Picciolo

Dr. Mike Picciolo is Senior Technical Director at Anduril Industries, in the Advanced Missions organization. Previously, he was Director of Mission Engineering in the Engineering, Integration and Logistics Division at SAIC. Previously he served as Chief Technology Officer, NSS Division, at ENSCO. Prior, he was the Associate Chief Technologist for Dynetics and Chief Engineer of the Advanced Missions Solutions Group in Chantilly, VA. He has in-depth expertise in Radar, ISR systems, Space Time Adaptive Processing and conducts research in advanced technology development programs. Has deep domain expertise in SAR/GMTI radar, communications theory, waveform diversity, wireless communications, hyperspectral imagery, IMINT, SIGINT, and MASINT intelligence disciplines. He is a member of the IEEE Radar Systems Panel, received the 2007 IEEE Fred Nathanson Radar Engineer of the Year Award, the 2018 IEEE AESS Outstanding Organizational Leadership Award, and founded the IEEE Radar Summer School series.

Scott Goldstein

Dr. Scott Goldstein serves as Chief Scientist, Anduril Industries. He heads the Advanced Missions organization whose charter is to develop cutting edge technology solutions. Previously, he was vice President of Engineering, Integration and Logistics Division at SAIC. Previously he was the Chief Strategy and Technology Officer of ENSCO and Chief Technologist for Dynetics, Inc., and the Manager of the Advanced Missions Solutions Group in Chantilly, VA. He has over 35 years of operational, engineering, leadership and management experience. He has performed fundamental research and development in Radar detection and estimation theory, Space Time Adaptive Processing, as well as in advanced systems concepts involving intelligence sensors, ISR, space superiority capabilities and cyber exploitation. He is a Fellow of the IEEE (for contributions to adaptive detection in radar and communications), a Fellow of the Washington Academy of Sciences and a member of the IEEE Radar Systems Panel. He received the 2002 IEEE Fred Nathanson Radar Engineer of the Year Award.

Shane Flandermeyer

Shane Flandermeyer is a graduate student at the University of Oklahoma's Advanced Radar Research Center (ARRC). His research interests include deep learning, reinforcement learning, radar resource management, and real-time signal processing. He is the recipient of the National Science Foundation (NSF) Graduate Research Fellowship.

Kristine Bell

Kristine Bell is a Senior Fellow at Metron, Inc. and also holds an Affiliate Faculty position in the Statistics Department at George Mason University (GMU). Her technical expertise is in the area of statistical signal processing and multi-target tracking and her current focus is on cognitive and fully adaptive radar, sonar, and electronic warfare systems. She received the B.S. in Electrical Engineering from Rice University in 1985, and the M.S. and Ph.D. from GMU in 1990 and 1995. From 1996-2009, Dr. Bell was an Associate/Assistant Professor in the Statistics Department and C4I Center at GMU. During this time she was also a visiting researcher at the US Army Research Laboratory and the US Naval Research Laboratory. Dr. Bell has served on the IEEE Dennis J. Picard Radar Technologies Medal Selection Committee, the IEEE Jack S. Kilby Signal Processing Medal Selection Committee, the IEEE Aerospace and Electronic Systems Society (AESS) Fellow Evaluation Committee, and the AESS Radar Systems Panel, where she was the chair of the Student Paper Competition Committee. She was the chair of the IEEE Signal Processing Society's Sensor Array and Multichannel (SAM) Technical Committee. She received the GMU Volgenau School of IT & Engineering Outstanding Alumnus Award in 2009 and the IEEE AESS Harry Rowe Mimno Best Magazine Paper Award in 2021. She is a Fellow of IEEE.

David Brown

David Brown is a research engineer in the Defense & Intelligence Solutions Division at Southwest Research Institute (SwRI) where he is the lead engineer for advanced electronic warfare (EW) system research & development. His research interests include applied cognitive EW, including methodologies to push AI/ML algorithms to the sensor edge and smart data compression for congested data transport layers. Prior to joining SwRI, he held a variety of EW related research & development positions and was an adjunct professor at the Georgia Institute of Technology. In addition to engineering experience in EW, David developed experience in practical application of EW as a B-1B aviator. David received undergraduate and graduate training in electrical engineering from Georgia Tech as well as Master of Arts and Master of Divinity from Liberty University. David is a Distinguished

Graduate of the Joint Electronic Warfare Officer School and is the recipient of the AOC EW Pioneer Award and RF Award. He served as the co-chair of the Sensor Open Systems Architecture (SOSA) Low Latency Subcommittee, which focused on EW specific concerns within open architecture systems. David is a senior member of the IEEE.

Alessio Balleri

Alessio Balleri received the Laurea degree in telecommunication engineering (summa cum laude) (five legal years) from the University of Pisa, Italy, in 2004, and the Ph.D. degree in electronic and electrical engineering from the University College London (UCL), London, U.K., in 2010. From February 2010 to March 2012, he was a Research Associate in radar systems with the Department of Electronic and Electrical Engineering, UCL. From June 2004 to December 2004, he was a Visiting Research Scholar with the Department of Electrical and Computer Engineering, University of Illinois at Chicago. He is currently a Reader in radar systems with Cranfield University, Shrivenham, U.K. His research interests include radar and sonar system design, biologically inspired radar and sonar systems, adaptive radar, radar and sonar target classification, target feature extraction, and modeling of radar clutter. Dr. Balleri Guest Coedited a special issue on "Biologically Inspired Radar and Sonar Systems" for the IET Radar, Sonar and Navigation in 2012 and a special issue on "Emerging Radar Techniques" for the EURASIP Journal on Advances in Signal Processing, in 2013. He was the Technical Program Committee Co-Chair for the IET International Radar Conference 2017, Belfast, U.K. and the Technical Co-Chair of the 2020 IEEE International Radar Conference, Washington, DC, USA. He is currently serving as the Special Issue editor for the IET Radar, Sonar & Navigation journal and he has recently been elected as a member of the IEEE AESS Radar System Panel.

Matt Ritchie

Dr. Matthew Ritchie received an MSci degree in physics from The University of Nottingham, in 2008. Following this he completed an Eng.D degree at University College London (UCL), in association with Thales U.K., in 2013. He continued at UCL as a postdoctoral research associate focusing on machine learning applied to multi-static radar for micro-Doppler classification.

In 2017 Dr. Ritchie took a Senior Radar Scientist position at the Defence Science and Technology Laboratories (Dstl) which also involved working as the Team Leader for the Radar Sensing group in the Cyber and Information Systems Division. During his time at Dstl he worked on a broad range of cutting edge RF sensing challenges collaborating with both industry and academia.

As of 2018 he has now taken a academic role at UCL within the Radar Sensing group and was promoted to Associate Professor in 2023. Currently he serves as the Chair of the IEEE Aerospace and System Society (AESS) for the United Kingdom & Ireland, is a Subject Editor-in-Chief for the IET Electronics Letters journal and a Senior Member of the IEEE. He was awarded the 2017 IET RSN best paper award as well as the Bob Hill Award at the 2015 IEEE International Radar Conference

Jon Kraft

Jon Kraft is a senior staff FAE in Colorado and has been with ADI for 16 years. His focus is software-defined radio and aerospace phased array radar. He received his B.S.E.E. from Rose-Hulman and his M.S.E.E. from Arizona State University. He has nine patents issued and one currently pending.

Marshall Bruner

Marshall Bruner is an RF engineer at Ball Aerospace in Westminster, CO where he specializes in electronics design for phased array front-ends as well as the accompanying design and firmware for the digital subsystems. Marshall received his Masters of Science from Colorado State University where his thesis work included designing an FMCW radar system for deployment on a UAS and FMCW signal processing in collaboration with Analog Devices.

Awards Ceremony

RadarConf'23 continues its longstanding tradition of congratulating individuals for outstanding achievements in the fields of AESS. This year, the Awards banquet is scheduled on Wednesday, May 3 at dinner time (7:00 - 10:00 PM).

IEEE Dennis J. Picard Medal

Alberto Moreira
German Aerospace Center (DLR)

For leadership and innovative concepts in the design, deployment, and utilization of airborne and space-based radar systems**.**

2022 IEEE AESS Pioneer Award

Yaakov Bar-Shalom and Henk Blom
University of Connecticut / Delft University of Technology

For development of the Interacting Multiple Model (IMM) approach to multi-model estimation and maneuvering target tracking.

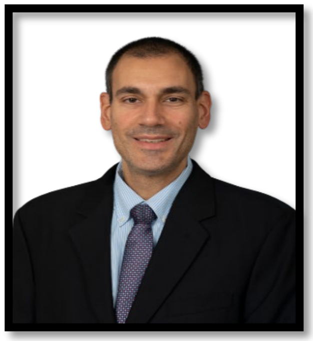
2023 Warren D. White Award

W. Dale Blair
Georgia Tech Research Institute

For contributions to monopulse processing for unresolved objects, tracking of maneuvering targets, and radar resource allocation

AESS Fellows

The IEEE Grade of Fellow is conferred by the Board of Directors upon a person with an extraordinary record of accomplishments in any of the IEEE fields of interest. The total number selected in any one year does not exceed one-tenth of one percent of the total voting Institution membership. Congratulations to the 2022 AESS Class of IEEE Fellows.

Karen Haigh
Haskill Consulting
For contributions to closed-loop control of embedded systems

Anthony Martone
U.S. Army Research Laboratory
For contributions to the development and validation of cognitive radar systems

Khanh Pham
The Air Force Research Laboratory
For leadership in military aerospace decision support systems and strategic small business innovation

Michael Braasch
Ohio University
For contributions to closed-loop control of embedded systems

2023 Fred Nathanson Memorial Radar Award

Justin Garth Metcalf
University of Oklahoma

For contributions to radar embedded communications, spectrum sharing, and cognitive radar.

2023 Industrial Innovation Award

Daniel Harris, Peter A. Lovassy, and Darin T. Dunham
Northrop Grumman / Lockheed Martin / Lockheed Martin

For engineering and implementing System Level Discrimination (SLD) in the Command and Control, Battle Management, and Communications (C2BMC) system. This enhancement significantly decreases the number of interceptors used by engaging weapon systems in the Missile Defense System (MDS) while maintaining engagement performance.

IEEE AESS Distinguished Service Award

Michael Rice
Brigham Young University

For extraordinary leadership as Editor-in-Chief by advancing the prestige of the IEEE Transactions of Aerospace and Electronic Systems through proactive measures to reduce review timelines and at the same time measurably improving quality.

2022 IEEE AESS Early Career Award

Avid Roman-Gonzalez
Business on Engineering and Technology S.A.C.

For contributions to the creation of space technologies in developing countries

2022 IEEE AESS Robert T. Hill Best Dissertation Award

Leonardo Millefiori
CMRE

In recognition of the Ph.D. dissertation “Machine Learning and Data Fusion Methods for Enhanced Maritime Surveillance.

2023 IEEE Michael C. Wicks Radar Student Travel Grant

Michael Wicks was a gifted electronic engineer who had a profound impact on all who met and interacted with him. His dedication to the radar community was well known. He gave freely of his time to serve the IEEE Aerospace & Electronic System Society (AESS) community.

By far his greatest legacy was the profound influence he had on a worldwide generation of radar engineers. His passion for giving back to the AESS and fervor for nurturing the next generation were his motivations when he created the IEEE Michael C. Wicks Radar Student Travel Grant Award.

Thanks to Mike’s donation to seed the IEEE AESS Michael Wicks Fund of the IEEE Foundation, each year graduate students who are lead authors on a paper in the area of radar signal processing accepted for presentation during the annual IEEE Radar Conference can receive travel support to attend the conference and present their research.

Congratulations to the 2022 Michael C. Wicks Award Recipients

Piers Beasley
For the paper “Multi-Band Hybrid Active-Passive Radar Sensor Fusion”

Rodrigo Blazquez
For the paper “Experimental Comparison of Starlink and OneWeb Signals for Passive Radar”

Kainat Yasmneen
For the paper “Estimation of Electrical Characteristics of Complex Walls Using Deep Neural Networks”

Student Paper Finalists


Curated by Luke Rosenberg and Laura Anitori

IEEE RadarConf 2023 student paper finalists which were selected by a committee within the Radar Systems Panel, are recognized for their exceptional content and technical contributions. Finalists are invited to present their work remotely at the conference to a panel of judges from industry and academia. The top three students will receive a cash award and recognition during the banquet awards ceremony on Wednesday, May 3, 2023.

8025 MIMO Radar-Based Rotation Parameter Estimation of Non-Cooperative Space Debris Objects
Christoph Kammel - Friedrich-Alexander-Universität Erlangen-Nürnberg

8061 Waveform Analysis and Digital Predistortion for Modulation-Based Radar Target Simulators
Pirmin Schoeder - Ulm University

8249 Alternative "Bases" for Gradient-Based Optimization of Parameterized FM Radar Waveforms
Bahozhoni White - University of Kansas

8275 Compact Parameterization of Non repeating FMCW Radar Waveforms
Thomas Kramer - University of Kansas

8308 Deep-Layer Training of CNN for SAR with Two-Stage Data Augmentation
Alexander Denton - Naval Postgraduate School

First alternative:

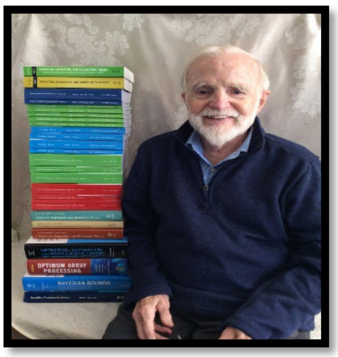
8283 On the Optimality of Spectrally Notched Radar Waveform & Filter Designs
Jonathan Owen - University of Kansas

Second alternative:

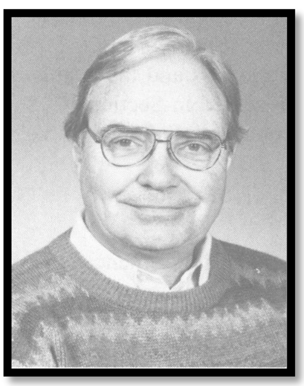
8076 Automotive Radar Interference Avoidance Strategies for Complex Traffic Scenarios
Lizette Lorraine Tovar Torres, Ulm University

In Loving Memory

Graeme E. Smith, an integral member of the RadarConf community and co-chair of the '23 Student Program, passed away in September of last year. Graeme exhibited a strong passion for radar research, teaching, and academics. He always looked forward to establishing new connections and catching up with former colleagues at radar conferences. A special session commemorating Graeme's contributions in the areas of cognitive and micro-Doppler radar will be held on Wednesday, May 3rd, from 12:20-14:00 in Salon D. Additionally, a table will be set up near the registration desk for the duration of the conference, for anyone who would like to leave a memory from their interactions with Graeme or his impact on their research. These notes will be returned to Graeme's family.



Harry L. Van Trees passed away peacefully on December 29, 2022 at the age of 92. He had a distinguished career which spanned a variety of academic, government, and industry positions, and he is widely recognized as one of the founders of the Detection and Estimation Theory body of knowledge. He was the author of numerous textbooks and his four-volume series on “Detection, Estimation, and Modulation Theory” are the classical texts in the area and have shaped the modern fields of radar, sonar, and communications. A table will be set up near the registration desk for the duration of the conference, for anyone who would like to leave a memory from their interactions with Harry or his impact on their research. These notes will be returned to Harry's family.



Ed was a gifted polymath who consistently looked for and contributed to the resolution of technically interesting and challenging problems. He received the S.B. degree in 1945, and the Ph.D. degree in 1950, both from the Massachusetts Institute of Technology, Cambridge, MA, in theoretical physics. He was a staff member at Brookhaven National Laboratory, Upton, NY, from 1950 to 1952, and joined M.I.T. Lincoln Laboratory in 1952, where he was a member of the Senior Staff. His work at Lincoln Laboratory was in the areas of radar detection and estimation, applied seismology, air traffic control, global positioning systems, spread spectrum communications and space-based radar systems analysis. While working in these mission areas, Ed contributed to many diverse topics including the development of linear algebra class libraries, geometry and mapping, stability of towed arrays, and electromagnetic wave propagation through plasma in a magnetic field. Ed was one of the early pioneers in understanding statistically-optimal radar signal processing. With his co-authors, I. Reed and W. Root, Ed developed two seminal monographs, The Detection of Radar Echoes in Noise I and II in 1960, that served to define our modern understanding of radar target detection and parameter estimation. Some notable published works that Ed authored or contributed to during his career include: The Radar Measurement of Range, Velocity and Acceleration, 1961; Matched-Filter Theory for High-Velocity, Accelerating Targets, 1965; Finite Sum Expressions for Signal Detection Probabilities, 1981; An Adaptive Detection Algorithm, 1986; Performance of an Adaptive Detection Algorithm - Rejection of Unwanted Signals, 1989; and A CFAR Adaptive Matched Filter Detector, 1992. Ed’s ability to make challenging analysis in diverse areas is missed.

Tutorials

We are pleased to present a wide selection of tutorials from distinguished academics and professionals around the globe. All tutorials will take place on Monday, May 1st and Friday, May 5th.

Monday Morning (8:00 AM – 12:00 PM)

T1: Systematic Filter Design for Tracking Maneuvering Targets: Getting Guaranteed Performance Out of Your Sensors
Where: CONF RM 1

Description

Although the Kalman filter has been widely applied to target tracking applications since its introduction in the early 1960s, until recently, no systematic design methodology was available to predict tracking performance for maneuvering targets and optimize filter parameter selection. When tracking maneuvering targets with a Kalman filter, the selection of the process noise (e.g., acceleration errors) variance is complicated by the fact that the motion modeling errors are represented as white Gaussian, while target maneuvers are deterministic or highly correlated in time. In recent years, relationships between the maximum acceleration of the target and the variance of the process noise errors were developed to minimize the maximum mean squared error (MaxMSE) in position for multiple filter types. Lower bounds on the variance of the motion modeling errors were also expressed in terms of the maximum acceleration.

This tutorial presents rigorous procedures for selecting the optimal process noise variance for the Kalman filter based on properties of the sensor and target motion model. Design methods are presented for the nearly constant velocity (NCV) Kalman filter with discrete white noise acceleration (DWNA), continuous white noise acceleration (CWNA), or exponentially-correlated acceleration errors (ECAE) and the nearly constant acceleration (NCA) Kalman filter with Discrete Wiener Process Acceleration (DWPA). Filter design for tracking maneuvering targets with linear frequency modulated (LFM) waveforms is also addressed and tracking with LFM waveforms is shown to be significantly better than tracking with a monotone waveform. The application of the design methods to radar tracking is addressed and numerous tracking examples are given. Guidelines on the inclusion of acceleration in your track filter are provided. In other words, guidelines on the use of an NCV Kalman filter versus an NCA Kalman filter are given. The design methods are applied to the Interacting Multiple Model (IMM) estimator and numerous radar tracking examples are used to illustrate the validity of the design methods. The benefit of tracking with LFM waveforms for mode estimation in the IMM estimator is also demonstrated via simulation examples.

T2: Ultra Wide Band Surveillance Radar
Where: CONF RM 2

Description

Ultra Wide Band Surveillance Radar is an emerging technology for detecting and characterizing targets and cultural features for military and geosciences applications. It is essential to have fine range and cross-range resolution to characterize objects near and under severe clutter. This Tutorial contains 5 parts.

- The Early History of Battlefield Surveillance Radar: Battlefield surveillance from manned and unmanned aircraft, along with early experiments in fixed and moving target detection and foliage penetration are covered. Developments in radar technology from MASR, HOWLS, GeoSAR, P3 UWB SAR, and Multibeam MSR enabled our ability to detect fixed and moving objects in dense clutter.

- UWB Phased Array Antenna: Wideband waveforms place a significant demand on the ESA design to maintain gain and sidelobe characteristics. Design of ESA systems with active arrays, time delay steering and digital multiple beamforming will be described.

- UWB Synthetic Aperture Radar (SAR): A brief description of UWB SAR systems will be provided. Techniques developed for ultra-wideband and interferometric image formation will be presented. The impact of regulations on RF spectrum will be illustrated.

- UWB Ground Moving Target Indication: Space time adaptive processing (STAP) has been used for detecting and tracking moving targets in clutter. This section will discuss two approaches for increasing the bandwidth and maintaining geolocat ion accuracy: wideband STAP and Along Track Interferometry.

- New research in Multi-mode Ultra-Wideband Radar: Modern surveillance systems require both SAR and moving target indication (MTI) modes. This section illustrates new technologies for future multimode operation: simultaneous SAR and GMTI in a multichannel radar.

T3: Introduction to Airborne Ground - Moving Target Indicator (GMTI) Radar
Where: CONF RM 3

Description

Airborne Ground-Moving Target Indicator (GMTI) is a radar mode that detects and discriminates moving targets on the ground, such as vehicles and dismounts. This is an important intelligence, Surveillance, and Reconnaissance (ISR) tool particularly for the military and intelligence communities, but also with important application in the civilian and government communities

The tutorial proposed herein will provide an introduction to the physical concepts, processing, performance, features, and exploitation modes that make GMTI radar work, and make it useful. It is intended for scientists, engineers, technicians, or managers who wish to learn more about radar-based detection of moving objects on land and sea surfaces, providing a foundation for system level design, analysis, and performance prediction. Although mathematics will be shown in some parts of the presentation, the lecture will focus on the qualitative significance of the mathematics rather than dry derivations. An undergraduate training in engineering or science is assumed. Some familiarity with signals and systems, modulation, Fourier Transforms, and Digital Signal Processing will be helpful. Liberal use of exampleGMTI data and other processing products will be used to illustrate the concepts discussed. The presentation will be given as four distinct modules, each based on (but enhanced from) presentations developed and given by the presenter in numerous non-public forums to government, military, industry, and academic groups.

T4: Passive radar on mobile platforms – from target detection to SAR/ISAR imaging
Where: CONF RM 4

Description

The purpose of this tutorial is to provide a serious exposition of the state-of-the-art of passiveradar on mobile platform research and development in the context of target detection and imaging. Thetutorial is focused on passive coherent location (PCL) mobile radar placed on different platforms–airborne(airplanes, helicopters, drones, rockets), airlifted (aerostats, drones on wire powered fromground), seaborne (ships, fast boats, submarines), ground (vehicles, lorries, tanks, etc.) and evenspaceborne. The tutorial will commence with a brief theoretical overview via platform discussion, Doppler spread clutter modeling, and Doppler spread clutter cancelation and finishing on demonstratorsand potential applications and use-cases.

Passive radar on mobile platforms know-how is of increasing importance, especially in the context of future System-of-Systems concepts. This four-hour tutorial will impart a thorough technical overview of the current techniques and practices associated with bistatic radar on mobile platforms and ground-based passive radars devoted to SAR/ISAR imaging and progress beyond the rudimentary development of long-established theories.

After an introduction to fundamental principles, geometry, and applications, the tutorial will move on to develop advanced topics. Passive bistatic radar on mobile platforms will receive particular emphasis, given its civilian and military relevance. The tutorial will focus particularly on advanced topics such as (i) passive radar imaging, (ii) passive radar on moving platforms, and (iii) exploitation of the information conveyed by multiple receiving channels providing spatial, frequency, or polarization diversity. In tutoring, the audience will receive a comprehensive treatment of interesting illuminators of opportunity such as FM radio, DVB-T2, and DVB-S/S2, advanced signal processing techniques to compensate for platform movement, analysis of the challenges associated with airborne passive radar, and a thorough grounding in passive SAR/ISAR and GMTI will be established. Over the past few years, the tutors have contributed in the open literature to the emerging domain of Passive Radar on mobile platforms, inclusive of novel simulations and measurements.

In addition to constructing the theoretical narrative fundamental to the advanced pillar topics, a comprehensive set of results will illustrate concepts and aid understanding. Auxiliary advanced topics related to the two pillars will also receive coverage in the tutorial.

T5: Deep Learning Laboratory for Radar Automatic Target Recognition
Where: CONF RM 5

Description

The tutorial focuses on hands-on implementation (laboratory) and theory of machine/deep learning for radio frequency ATR. Utilizing the recently published (July 2020) book by Artech House"Deep Learning for Radar and Communications Automatic Target Recognition," we will present contemporary topics to include research results, technical challenges, and directions of Deep Learning(DL) based object classification using radar data (i.e., Synthetic Aperture Radar / SAR data).

First, the tutorial will present an overview of historical RF ATR research (i.e., template-based approach conducted under DARPA MSTAR (Moving and Stationary Target Acquisition and Recognition) program and limitations of this approach. Second, the tutorial will explore an overview of various machine learning(ML) theories applied to RF data. Examples include the implementation of single target classification(i.e., image chip) and multiple target classifications. The third aspect of the tutorial introduces recent SAR target classification for limited data such as Transfer Learning / Domain adaptation, Few-shot learning (FSL), Low-shot Learning (LSL), and Zero-shot Learning (ZSL). Ancillary concepts include presentation of improving classification accuracy when SAR data are perturbed by intentional/unintentional noise sources. Recent topics of interest such as automatic SAR data labeling technique using active learning will be discussed as well. Throughout the tutorial, we will demonstrate implementation and performance analysis of DL-basedATR on SAR data using ResNet18 model, GoogleColaboratory, and/or TensorFlow from the MSTAR, CVDome, SAMPLE, and North Eastern University RFsignals data. Hence, the tutorial participant would experience the concepts of DL for RF analysis over multiple data set implementations.

Monday Afternoon (1:00 PM – 5:00 PM)

T6: Job Skills Tutorial
Where: CONF RM 1

Description

Overview: This tutorial short course is broken into four “mini” courses that focus on important job skills:

1. Technical Writing–Randy Jost
2. Technical Presentations–Dan Cook and Julie Jackson
3. Project Management–Brittany McCall
4. Radar Systems Engineering–Brian Cordill

Communication, planning, and working in the bigger picture are keys to successfully taking research(and your career!) to the next level.

T7: Introduction to Active Electronically Scanned Arrays
Where: CONF RM 2

Description

Introduction to Active Electronically Scanned Arrays(AESAs)delivers a foundational treatment of AESAs ideal for engineering students and professionals. An overview is provided of the primary subsystems of an AESA. Detailed explanations are provided on the impact of AESAs on mission applications including Radar, Electronic Attack (EA), Electronic Support Measures (ESM), SIGINT and Communications.

A review of AESA fundamentals is covered including topics such as grating lobes, scan loss, instantaneous bandwidth, and 1D, 2D, and conformal array analysis. Comprehensive explorations of key design concepts and fundamentals are provided for subsystems inclusive of antenna array elements, transmit/receive modules, and beamformer including their purpose, functions, and practical design considerations. Performance results for various AESA architectures often found in industry, including analog, subarray, and digital beamforming AES architecture, are discussed. Key advantage of elemental digital beamforming in contrast with analog and subarray beamforming is also provided with an extension to adaptive array nulling for operation in the presence of jamming. With a focus on practical knowledge and applications, this tutorial offers an accessible overview of technology critical to the implementation of collision avoidance in cars, air surveillance radar, communication antennas, and defense technologies. This course is ideal for professionals working with AESAsfor Radar, EW, SIGINT or Communication systems

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T8: Advanced Radar Detection and Applications
Where: CONF RM 3

Description

We teach advanced radar detection from first principles and develop the concepts behind Space-Time Adaptive Processing (STAP) and advanced, yet practical, adaptive algorithms for realistic data environments.

Detection theory is reviewed to provide the student with both an understanding of how STAP is derived, as well as to gain an appreciation for how the assumptions can be modified based on different signal and clutter models. Radar received data components are explained in detail and the mathematical models are derived so that the student can program their own MATLAB or other simulation code to represent target, jammer and clutter from a statistical framework and construct optimal and suboptimal radar detector structures. The course covers state-of-the-art STAP techniques that address many of the limitations of traditional STAP solutions, offering insight into future research trends. Additionally, we cover applications of advanced detection algorithms including modern hardware realizations and other related applications such as COTS-based distributed array STAPbeamforming.

T9: An Overview of Practical Spectrum Sharing Techniques for Radar and Communications
Where: CONF RM 4

Description

The electromagnetic spectrum (EMS) is a precious resource that connects and protects our societies across the globe. Historically this resource was accessed by expensive, purpose-built radio-frequency (RF) systems that operated in well-defined, static frequency allocations. Recent advances in digital radio technology (e.g. software-defined radios, low-cost/high-sample rate analog-to-digital converters, etc.) have made wide swaths of spectrum easily accessible by low-cost, commercially available systems.

This new accessibility has resulted in a heated competition between commercial telecommunications, civil infrastructure, scientific research, and defense interests for access to the finite, limited EMS. Consequently, the spectrum has become increasingly congested with no end in sight for the increasing, insatiable demand by competing users. To mitigate this congestion, it is vital that future users of the spectrum do so in an efficient manner. Therefore, RF systems can no longer depend on static resource allocations (i.e. user separation via frequency or time division). As radar and communication systems pose the greatest demand on spectrum access, their future designs must make use of all degrees-of-freedom (DoFs): time, frequency, space, coding and polarization.

Technologies for efficient radar-communications spectral access can be grouped into two broad categories: co-design and coexistence. Coexistence is a key focus of emerging shared and unlicensed frequency bands (e.g. the Citizens Broadband Radio Service (CBRS) band in the United States), where radar and communications systems must share a set band while incurring limited interference to one another. Coexistence techniques provide efficient spectrum access for spatially distributed users, who may or may not coordinate their access to the shared bands. The second spectrum access technique is co-design. Very often a single platform or system will have multiple datalinks and/or radar systems on-board. Further, advances in arbitrary waveform generation and digital-at-every-element technology have enabled waveform agility and multiple-input multiple-output radar technology, introducing the capability to shape spectrum access along the coding and spatial DoFs. Co-design techniques such as dual-function radar/communications (DFRC) waveforms can reduce the number of RF systems on a platform or system, and a single software-defined RF device can perform both radar and communications.

This tutorial will provide a first-principles examination of the design goals and metrics of both radar and communications. We will explore the motivation and history of spectrum access and examine the practical requirements for utilizing the available DoFs. Specific examples of coexistence and co-design techniques will be explored based on the DoF(s) they use to enable efficient spectrum access. For the co-design problem two distinct families of techniques will be framed and explored in detail: radar-embedded communications via coding diversity and multi-beam emissions from digital arrays. Implications of hardware constraints on these techniques will be illustrated. To narrow the focus radar detection will be the primary radar application.

The target audience is graduate students, researchers, and engineers with a general interest in spectrum-sharing between radar and communications. The tutorial assumes basic knowledge of radar systems and digital communications.

T10: New Illuminators of Opportunity for Passive Radars - challenges and opportunities
Where: CONF RM 5

Description

This tutorial will be pitched so as to present bistatic and multi-static passive radar using novel wideband illuminators of opportunity in an advanced format. The tutorial will focus on developing the grounding of advanced principles and concepts that are, and will be, of high relevance to the field.

This tutorial will be of high value to scientists and engineers working with passive radar technology, representatives of the military, government and industry, and to other postgraduates involved in the field of radar as well as seasoned practitioners. Our goal is the delivery of modern advanced topics in an accessible format. By the conclusion of the tutorial, participants will have acquired a deep appreciation of core advanced topics relating to passive radar using new wideband illuminators of opportunity, such as WiFi, 5G/6G, DVB-S and STARLINK, and the required signal processing techniques. The tutorial will include different standards comparison, challenges, opportunities and limitations analysis with focus on modern applications for using wideband IoOs in passive radars, e.g., target detection, classification, SAR/ISARimaging that participants would not have accrued through self-study of recently published literature. Representative examples will be used throughout the tutorial to aid understanding. Worked examples with interactive participation will ensure a lively tutorial for the full duration.

Friday Morning (8:00 AM – 12:00 PM)

T11: Micro-Doppler Signatures: Principles, Analysis and Applications
Where: CONF RM 1

Description

The micro-Doppler analysis is the study of the time-varying Doppler frequencies from multiple moving scattering centers of targets. Over the past few years, the potential of micro-Doppler signature analysis has been demonstrated in different areas of radar signal processing such as enhanced target detection, characterization and tracking, in a plethora of applications including condition monitoring, urban and airspace surveillance, healthcare, automotive, and manufacturing. Combined with the recent advances in machine learning and artificial intelligence, micro-Doppler analysis is a powerful tool to perform automatic target recognition

This tutorial is broadly divided into two parts. In the first part, the fundamentals of the phenomenology of micro-Dopplersignatures and related signal processing will be introduced with reference to the canonical cases of rigid bodies, then extended to non-rigid bodies. In the second part, different applications of radar micro-Doppler signature analysis will be presented with reference to a common classification framework, either using more conventional extracted features or neural networks. These advanced applications will include micro-Doppler for UAVs classification, micro-Doppler-based ballistic threats discrimination, micro-Doppler in Industry 4.0 and AgriTech, hand gesture recognition and vital sign monitoring, and human activities classification targeting continuous actions in a sequence. An overview of the main techniques and of some of the open datasets available in the literature that can support research in this direction will also be provided.

T12: Radar for Health Monitoring: Signal Processing, Systems and Applications
Where: CONF RM 2

Description

Radar-based health monitoring meets the requirements of a non-disturbing,ubiquitous-use, all-weather, penetrable, privacy-preserving sensing. This has led to the emergence of a rich set of useful and interesting radar-based healthcare applications ranging from clinical to home care, sports training to automotive, and forensic to rescue operations. Unlike wearable sensors, a small-footprint radar measures physiological signals from human body without any mechanical contact with the human skin. Compared to vision sensors (e.g., cameras), radar signals are capable of penetrating clothing without raising any privacy concerns.
Lately, there has been a focus on radar-based sensing for more complex applications such as patient/neonatal monitoring in intensive care units, general wards, emergency department triage, motion correction in magnetic resonance/computed tomography imaging, respiratory gating in radiation oncology. Radar practitioners are also striving to achieve accurate and robust biometrics in complex challenging environments such as crowded spaces, dynamic body motions, through-wall sensing, and drone-borne radars. This requires exploiting techniques such as sensor fusion, complex array deployments, multiple wavelengths, and advanced signal processing algorithms.
This tutorial will introduce the audience to the latest developments and technologies pertaining to radar remote sensing for physiological measurements, including robust measurement techniques, novel systems, new datasets, and testbeds/platforms in healthcare applications. We will highlight the latest trends in research on signal processing and systems for emerging healthcare applications including plethysmography, THz sensing, and sensor fusion. A tutorial on emerging healthcare applications will be highly relevant for participants from diverse backgrounds-academia, industry, and government-all of whom have active interest and stake in enabling smart health in the new era at commercial and military levels. The scope of the tutorial is two-fold. First, it provides an overview of the state-of-the-art radar-based health applications. Secondly, it covers theoretical aspects of several emerging problems in this area from system and signal processing perspectives Therefore, apart from specific aspects covered here, this tutorial is also highly relevant to researchers looking for a broad overview of challenges and solutions in the area.

T13: Cognitive EW: An AI Approach
Where: CONF RM 3

Description

This tutorial will present an overview of how AI can be used in EW. They will describeopportunities for using AI in situation assessment and electronic support (ES), and decision-making techniques for electronic protect (EP), electronic attack (EA), and electronic battle management (EBM). We will present AI techniques from Situation Assessment, Decision Making, and Machine Learning, and discuss tradeoffs.

We will describe approaches to the important issue of real-time in-mission machine learning, and evaluation approaches that demonstrate that a cognitive system that learns how to handle novel environments. The tutorial is intended to be a voice track to the 2021 book Cognitive ElectronicWarfare: An Artificial Intelligence Approach (Artech US and Artech UK). Our intended audience is RF people--experts in EW, cognitive radio, and/or cognitive radar--who want to learn more about how and where to use AI. Our goal is to help triage and guide EW system designers in choosing and evaluating AI solutions. Cognitive EW is one of these critical advances that will determine the outcomes of future battles.

T14: Radar Transmitters
Where: CONF RM 4

Description

This tutorial on radar transmitters will address a broad range of issues including system-level design, vacuum-tube technologies and supporting hardware (such as power supplies, exciters, and modulators), solid-state device technologies, and related spectrum issues facing transmitter designers.

System-level design topics will include the topology of the transmitter as well as the individual components comprising the topology. While great strides have been made in solid-state transmitters, tube technology will be part of high-power radars for the foreseeable future. Different types of tubes, such as TWT’s, CFA’s, and Klystrons, will be addressed, including a discussion of how they function and why they are used in radar particular applications. Supporting hardware such as power supplies, exciters, and modulators will also be covered. In the solid-state arena, the different types of devices, such as GaN, will be discussed in terms of how they are used in power amplifier designs. The classes of power amplifiers will be overviewed in terms of biasing, output versus input, and output spectral characteristics. Required supporting components such as output filters will be discussed in this context. Combiners and phase matching issues and techniques for connecting individual power amplifiers for increased power output and efficiency will be overviewed. Practical aspects of transmitter operation will be discussed. The session will conclude with a discussion on areas of research related to current transmitter issues. Emissions, desirable and undesirable, in terms of different types of power amplifiers will be covered. Active array topology and design will be presented. Finally, an overview of the move toward software-defined transceivers will be presented.

T15: Bistatic and Multistatic Radar Imaging
Where: CONF RM 5

Description

SAR/ISAR images have been largely used for earth observation, surveillance, classification and recognition of targets of interest. The effectiveness of such systems may be limited by a number of factors, such as poor resolution, shadowing effects, interference, etc. Moreover, both SAR and ISAR images are to be considered as two-dimensional maps of the real three-dimensional object.

Therefore, a single sensor may produce only a two-dimensional image where its image projection plane (IPP) is defined by the system-target geometry. Such a mapping typically creates a problem for the image interpretation, as the target image is only a projection of it onto a plane. In addition to this, monostaticSAR/ISAR imaging systems are typically quite vulnerable to intentional jammers as the sensor can be easily detected and located by an electronic counter-measure (ECM) system. Bistatic SAR/ISAR systems can overcome such a problem as the receiver can act covertly due to the fact that it is not easily detectable by an ECM system, whereas multi-static SAR/ISAR may push forward the system limits both in terms of resolution and image interpretation and add to the system resilience.

Technical Program – Tuesday, May 2

8:00 - 8:30
General & Technical Chair's Opening Remarks
Room: SALON E (C-E)

8:30 – 9:15
Plenary Speaker: David G. Long, *Brigham Young University*
Room: SALON E (C-E)

Satellite Radar Earth Remote Sensing: Icebergs and Winds
David G. Long
Brigham Young University
Microwave remote sensing extracts environmental information from what is often considered the undesired components of signals encountered in surveillance radar: noise and clutter. Radiometers exploit noise, while remote sensing radars employ clutter to study the Earth. Satellite-based radar sensors, coupled with computer processing offer unique perspectives and measurements of important geophysical processes beyond just imaging. In this talk, I consider applications of satellite radar measurements of the microwave scattering properties of the Earth's surface. Synthetic Aperture Radar (SAR) make highly detailed backscatter images regardless of the weather or solar illumination conditions. These have both military and civilian applications. However, other types of satellite radar such as altimeters, scatterometers, and weather radars provide unique measurements and perspective. For example, over the ocean radar backscatter is related wind-generated roughness and can be used to measure wind speed and direction. Radar backscatter is particularly sensitive to melt/freeze conditions and can thus be used to map and monitor sea ice and soil conditions. The contrast between ocean and ice scattering enables tracking of major icebergs in Antarctic. Using precise range measurements satellite altimeters measure ocean topography from which ocean currents can be inferred. Satellite weather radars measure rain rates and cloud density. With existing and planned systems, we are in the golden age of satellite radar remote sensing.

9:15 – 10:00
Plenary Speaker: Paul A. Rosen, *California Institute of Technology*
Room: SALON E (C-E)

The NASA-ISRO Synthetic Aperture Radar Mission – The Final Stretch Toward a New Capability for Earth Science and Applications
Paul A. Rosen
California Institute of Technology
The National Aeronautics and Space Administration (NASA) in the United States and the Indian Space Research Organisation (ISRO) are developing the NASA-ISRO Synthetic Aperture Radar (NISAR) mission, now planned for launch in early 2024. The mission will use synthetic aperture radar to map Earth solid surfaces every 12 days, persistently on ascending and descending portions of the orbit, over all land and ice. The mission's primary objectives will be to study Earth land and ice deformation, and ecosystems, in areas of common interest to the US and Indian science communities. This single observatory solution with L-band (24 cm wavelength) and S-band (9.4 cm wavelength) imaging radars has a swath of over 240 km at 5-10 m resolution, using full polarimetry where needed. To achieve these unprecedented capabilities, both radars use a reflector-feed system, whereby the feed aperture elements are individually sampled to allow a scan-on-receive capability at both L-band and S-band. The L-band and S-band electronics and feed apertures, provided by NASA and ISRO respectively, share a common 12-m diameter deployable reflector/boom system, provided by NASA. These two radars, which can operate simultaneously, produce prodigious amounts of data even with FPGA-based on-board digital beamforming and filtering to reduce data rates. Given the high data rates and ambitious coverage requirements, new technologies for high-rate Ka-band downlink complement these first-of-a-kind radar systems.

Slowed by the global pandemic, the mission is now approaching its final stage of integration and test. The radar electronics, GNSS unit and solid-state recorder are mounted on an octagonal cylindrical radar instrument structure. This structure, as well as the Ka-band downlink system and associated control electronics finished testing in early March 2023 and are being shipped to India for integration with the ISRO-provided spacecraft bus. The reflector/boom system completed testing in 2022 and will be shipped to India when needed in summer 2023. The integration and test period for the observatory is planned to complete in 2023, with the earliest possible launch date being after the eclipse season for the planned NISAR orbit ends on January 30, 2024. The launch vehicle is ISRO's GSLV Mark II.

This talk will describe the mission, the measurements, and the technologies and techniques that plans to deliver over 40 Tbits of science and applications data per day to understand our everchanging planet.

10:00 – 10:20
Coffee Break

10:20 – 11:05
Plenary Speaker: Sevgi Gurbuz, *University of Alabama*
Room: SALON E (C-E)

Radar as an Enabling Technology for Next Generation Human Ambient Intelligence
Sevgi Gurbuz
University of Alabama
As technology advances and an increasing number of devices enter our homes and workplace, humans have become an integral component of cyber-physical systems (CPS). One of the grand challenges of cyber-physical human systems (CPHS) is how to design autonomous systems where human-system collaboration is optimized through improved understanding of human behavior. A new frontier within this landscape is afforded by the advent of low-cost, low-power millimeter (mm)-wave RF transceivers, which enables the exploitation of RF sensors almost anywhere as part of the Internet-of-Things (IoT), smart environments, personal devices, and even wearables. RF sensors not only provide sensing capability when other sensors may be ineffective due to environmental factors, but also provide unique spatio-kinematic measurements that are complementary to that of other sensing modalities. Moreover, in indoor environments where privacy is also a driving consideration, RF sensors offer relatively non-intrusive perception capabilities. Consequently, there have been exciting recent advancements in the use of RF sensing for human-computer interaction, remote health monitoring, and smart homes. Since the first research in radar-based human activity recognition over 15 years ago, where the technology was demonstrated in controlled lab settings, now radar can be found in many new devices hitting the market. This includes the Google SOLI sensor in cell phones for non-contact gesture recognition, as well as products under development by Amazon, Vayyar and others for sleep monitoring, vital sign monitoring, and occupancy recognition. However, these applications only begin to touch the surface of the potential for radar-enabled cyber-physical human systems (CPHS). Future intelligent devices equipped with cognitive perception and learning will be able to much more effectively and robustly decipher and respond to complex human behaviors. This talk provides a detailed discussion of current sensing and machine learning challenges, as well as new perspectives that can help us overcome current limitations and pave the way for future radar-enabled interactive environments.

11:05 – 11:50
Plenary Speaker: Elise Fear, *University of Calgary*
Room: SALON E (C-E)

Radar-inspired imaging for breast cancer detection
Elise Fear
University of Calgary
Biomedical applications at microwave and radio frequencies rely on the differences in permittivity and conductivity of biological tissues. The properties of healthy tissues span a wide range that relates to water content, while diseased tissues such as malignancies typically exhibit increased properties. Leveraging these differences, microwave imaging has been investigated as an alternative method for breast cancer detection and treatment monitoring.

Several approaches have been developed to map the properties of tissues and identify anomalies. Microwave tomography involves measuring signals transmitted through the tissues, then iteratively updating properties of a model until simulations match these measurements. Radar-based approaches involve collecting reflections from tissues, then processing and focusing these reflections to identify anomalies. For both radar and tomography, key challenges are design of a measurement system and interface that enable reliable and rapid collection of data while operating close to the target tissues, developing imaging algorithms capable of detecting anomalies in a complex background, and reconciling the resulting microwave images with clinically available data.

At the University of Calgary, we have developed several generations of prototype systems, focusing on demonstrating the consistency of images collected at different time points, as well as the feasibility of detecting tumors and treatment-related changes. Our most advanced radar-based system implements patient-specific capabilities, scanning the breast with 4 degrees of freedom in sensor positioning to enable consistent collection of data. We leveraged the knowledge gained through experience with this system to develop a novel approach that estimates locally averaged properties of tissues by detecting pulses traveling through the breast. With this approach, we have demonstrated a high degree of similarity between images captured at different time points, as well as symmetry between properties of the right and left breasts. Comparison of the images of right and left breasts of cancer patients has also enabled tracking treatment-related changes. Recently, our team began testing the next generation of this transmission system that features improved resolution. The initial results obtained with this system add to the growing body of work that illustrates the potential of microwave imaging to provide a unique breast imaging solution.

11:50 – 12: 50
Lunch
Room: SALONS HI

11:50 – 12: 50
DEI Lunch
Room: SALON J (JK)

11:50 – 12: 50
TAES Radar Associate Editors and T-RS Editiors Meeting
Closed Meeting
Room: CONF RM 6

12:50 – 14:20
Radar Signal Processing
Poster Session
Room: CONF RMS 20-21
Session Chairs: Patrick McCormick and Braham Himed

8265: A Robust Framework to Design Optimal Radar Deployment for Range-Based Target Localization Technique
Augusto Aubry{2}, Prabhu Babu{1}, Antonio De Maio{2}, Ghania Fatima{1}, Nitesh Sahu{1}
{1}Indian Institute of Technology Delhi, India; {2}Università degli Studi di Napoli Federico II, Italy
In this paper, the problem of designing optimal positions of monostatic radars composing a multiplatform network is pursued. Leveraging the CRB of the target position based on radar range measurements, two figures of merit (independent of actual target location) are considered. Specifically, a broad area where the target is likely to be present is considered, and either the trace of the CRB averaged over the grid points sampling the surveillance area or the maximum trace of CRB over the mentioned grid points is minimized. A framework based on block majorization-minimization is proposed to deal with the formulated resource allocation problems.

8330: Two-Stage Clutter Suppression Method for Human Detection Using FMCW Radar
Jihye Kim, Sohee Lim, Jaehoon Jung, Seong-Cheol Kim
Seoul National University, Korea
This paper proposes a two-stage clutter suppression method to correctly determine the position of human subjects in a clutter-rich indoor environment. First, the micro-movement information is utilized to detect the vital signs of human subjects and suppress static clutters. However, vibrating electronic devices such as a fan and a desktop computer, which are non-static clutters, can impede the human detection. Therefore, to separate human subjects from these non-static clutters, the velocity information is used to extract meaningful features. Finally, experimental results showed that the proposed method can detect the human position while suppressing both kinds of clutter signals.

8339: Robust Adaptive Pulse Compression Algorithm for Targets with Straddling

Chen Ning, Jing Tian, Shanling Zheng, Biao Zhang, Wei Cui
Beijing Institute of Technology, China

The existing iterative adaptive filtering algorithms based on the minimum mean square error (MMSE) criterion can effectively suppress range-Doppler sidelobes of targets and unveil targets in multi-target scenarios. However, these iterative adaptive filtering algorithms suffer from deteriorated performance in the presence of targets with range-Doppler-straddling when using linear frequency modulation (LFM) waveforms. To suppress sidelobes when straddling occurs, this paper presents a robust adaptive pulse compression algorithm based on straddling-robust self-calibration iterative adaptive filtering (SR-SCIAF). The received signal model considering range-Doppler-straddling effects are firstly established and then the SR-SCIAF algorithm is introduced based on the MMSE criterion. During the iterative processing, SR-SCIAF can reduce the modelling mismatch by estimating straddling offsets and compensating the corresponding phase mismatch. Simulation results demonstrate that SR-SCIAF provides good robustness against straddling effects and can effectively suppress range-Doppler sidelobes of targets with straddling in multi-target scenarios.

8098: A Novel Partial Coherent Detection Algorithm for Over-the-Horizon Radar

Haoqi Wu, Luxin Dong, Jianfeng Ding, Zhihang Wang, Zishu He, Ziyang Cheng
University of Electronic Science and Technology of China, China

This paper addresses the partial coherent target detection problem for over-the-horizon (OTH) radar in Gaussian noise and clutter environment. The Gaussian distribution is adopted to model the noise and clutter based on the lowrange resolution characteristic of OTH radar. The novel partial coherent detector is proposed in the presence of partial coherent signals. To be more concrete, by using the generalized likelihood ratio test (GLRT), we develop the partial coherent detector and two special forms, i.e., coherent detector and noncoherent detector. The performance of the proposed detectors is evaluated and compared by using the simulated partial coherent signals data. The numerical results show that the partial coherent detector performs better than the coherent detector and noncoherent detector. The constant false alarm rate (CFAR) properties of the proposed detectors can be verified by simulation.

8367: Theoretical and Experimental Analysis of the Supposed Stealthiness of Noise Radar

Mikko Heino{2}, Jaakko Marin{2}, Kai Hiltunen{1}, Matias Turunen{2}, Taneli Riihonen{2}
{1}Patria Group, Finland; {2}Tampere University, Finland

This paper investigates the feasibility of one of noise radar's supposed main benefits, the proposed low probablity of intercept (LPI) due to the wideband pseudorandom noise signal being undetectable. The performance of both the noise radar and the intercepting receiver are first studied theoretically through stochastic signal analysis with multi-channel cross-correlating receivers, accompanied by simulation studies with realistic noise-modulated FM-signals and OFDM noise signals. The results are confirmed by a real measurement of an operating noise radar with an intercepting two-channel receiver both from mainlobe and sidelobe directions. It is shown that the interceptor with a correlation receiver has a significant SNR benefit in detecting the signal of the noise radar compared to the noise radar's own detection, even though the radar can utilize the exact knowledge of the transmit signal. This leads to 100-fold detection ranges compared to the radar's operation range rendering the supposed undetectability invalid. The main stealth benefit of noise radars is concluded to be the interceptor's inability to accurately predict the purpose of the detected wideband noise waveform.

8073: Surveillance Performance of Digital Radars in Non-Uniform Target Behavior

Jameson Morgan{2}, Brian Rigling{1}
{1}University of Dayton, United States; {2}Wright State University, United States

Surveillance radar systems generally do not use knowledge of the operating environment target behavior to adapt operation. We demonstrate the feasibility and benefit of adapting digital radar operation using such knowledge. A simulated environment is configured with a priori knowledge to generate training data that allows a neural network to accurately predict which area of the environment to illuminate. The simulated environment explores the most rewarding solution to different possible states and the neural network generalizes from the training data. The results obtained show improvement over the state of practice and demonstrate the feasibility of the proposed solution approach.

8213: A Study of Practical Radar-Based Nighttime Respiration Monitoring at Home

Yindong Hua, Zongxing Xie, Fan Ye
State University of New York at Stony Brook, United States

In this paper, we focus on the high quality home-based sleep data acquisition and respiration monitoring. We conduct comparisons among four typical sensors and find the best place for sensors is on the side of the bed considering both accuracy (2.65 bpm error) and fastening efforts. In that process, we further discovery that the range bin tracking is a key factor to impact the accuracy when extracting the respiration from the phase. In addition, although both data can be a good source to get the respiration, the amplitude data is easier to locate the rough range of the target and the phase data is more sensitive to the body movement.

8422: FMCW Radar-Based Vital Signal Monitoring Technique Using Adaptive Range-Bin Selection

Mingeon Shin, Yongchul Jung, Jongho Kim, Kwangseok Choi, Kwangho Lee, Haram Ju, Kang-Il Cho, Sungho Lee

Korea Electronics Technology Institute, Korea

This paper aims to propose a signal processing technique for non-contact sensing of vital signs such as respiration and heart-rate using FMCW radar. Existing studies have limitation of only detecting vital signs for a fixed target, but in this study, we propose vital signs sensing technique for a moving target. We propose a novel algorithm that tracks the optimal distance information through the correlation between the distance information from the moving target and the magnitude and energy density of the phase information that responds to vital signs. The novel algorithm is based on signals from FMCW radar sensors that can extract range information from moving objects. The proposed algorithm is verified through a compact module through a 60GHz commercial FMCW radar sensor and a radar signal processor. The experimental results show that the proposed algorithm has a 4.5 bpm error in heart rate, while conventional techniques have an error of 11.4 bpm.

8225: Doppler Signature Analysis of Perturbed Target Motion in Over-the-Horizon Radar

Yimin Zhang{2}, Braham Himed{1}

{1}Air Force Research Laboratory, United States; {2}Temple University, United States

Target geo-location is an important task in over-the-horizon radar. A useful approach is based on the Doppler signatures of the micro-multipath signals which reveal target motion and enable target state estimation. Target Doppler signatures, however, are sensitive to irregular target motions due to, for example, turbulence, thereby further complicating the Doppler signature analyses. In this paper, we consider the Doppler signatures of micro-multipath signals for a target that moves with a constant altitude but its azimuth velocity and altitude are perturbed. We analyze the effect of such velocity and altitude variations in the resulting Doppler signatures. The nominal Doppler frequency and the Doppler frequency difference are estimated using the spectrogram of the received micro-multipath signal and its self-stationarized result, respectively.

12:50 – 14:20
Spectrum Sharing & Cognitive Radar
Poster Session
Room: CONF RMS 20-21
Session Chairs: Faruk Uysal and Kristin Bing

8041: Time-Based Geolocation and Main Beam Estimation of an Airborne Rotating Radar for Spectrum Sharing

Laurence Mailaender, Alex Lackpour

Peraton Labs, United States

Dynamic spectrum sharing between airborne radars and 5G cellular networks has the potential for granting additional RF spectrum to cellular networks. A spectrum sharing controller can use estimates of the radar's location and beam orientation to anticipate and mitigate RF interference events over a large geographic area. However, localization of the radar is complicated by airborne radar's relatively narrow beamwidth and time-varying waveform. We introduce the Rotating Beam Time-of-Arrival (RB-TOA) algorithm to jointly estimate the radar's location and antenna main beam orientation. Each RF sensor measures the peak time when the radar's main beam maximally couples with the sensor's antenna; these time estimates are then combined at a sensor fusion server and the radar's main beam orientation and location are jointly solved using a gradient descent algorithm. We show that the RB-TOA algorithm rapidly converges to a geolocation accuracy that is 50x better than the performance of a two-antenna angle-of-arrival algorithm (AoA) for the same number of sensors.

8152: Modeling and Impact of Cellular Uplink Aggregate Interference on Radar Performance

Masoud Farshchian{3}, Harris Zebrowitz{2}, Amy Baker{2}, Frederick Howard{1}

{1}Defense Information Systems Agency, Defense Spectrum Organization, United States; {2}MITRE Corporation, United States; {3}MITRE Corporation, Empyreal Waves, LLC, United States

This paper presents the results of a study to evaluate the suitability of statistical electromagnetic compatibility (EMC) analysis techniques developed on the Advanced Wireless Services 3 (AWS-3) to assess the impact of cellular network aggregate interference on DoD radar. To perform this assessment the impact of aggregate emissions from cellular networks is evaluated as a combined function of radar system parameters, cellular geometric pattern, and the aggregate interference probability density function (PDF) and power spectral density (PSD). A key contribution of this paper – which is also applicable to radar clutter modeling – is a new method to generate stochastic in-phase and quadrature (I/Q) samples using an augmented zero-memory non-linear (A-ZMNL) transformation that improves upon the limitation of the current ZMNL techniques, and simultaneously matches both the long tail PDF for very low shape factors, and the very sharp drop-off PSD of the orthogonal frequency division multiplexing (OFDM) based emissions. We show via Monte-Carlo simulation that the potential impact of the interference could be more severe than that predicted by AWS-3 EMC analysis techniques.

8228: False Target Detection in OFDM-Based Joint RADAR-Communication Systems
Antonios Argyriou
University of Thessaly, Greece
Joint RADAR communication (JRC) systems that use orthogonal frequency division multiplexing (OFDM) can be compromised by an adversary that re-produces the received OFDM signal creating thus false RADAR targets. This paper presents a set of algorithms that can be deployed at the JRC system and can detect the presence of false targets. The presence of a false target is detected depending on whether there is residual carrier frequency offset (CFO) beyond Doppler in the received signal, with a Generalized Likelihood Ratio Test (GLRT). To evaluate the performance of our approach we measure the detection probability versus the false alarm rate through simulation for different system configurations of an IEEE 802.11-based JRC system.

8161: A Cognitive Jamming Decision-Making Method for Multi-Functional Radar Based on Threat Assessment
Gengchen Xu, Yujie Zhang, Weibo Huo, Jifang Pei, Yin Zhang, Haiguang Yang
University of Electronic Science and Technology of China, China
Multi-function radar (MFR) plays an important role in modern battlefield, and the cognitive jamming decision-making method for MFR is the key technology to effectively interfere MFR, which is of great research significance. In order to effectively interfere MFR, a cognitive jamming decision-making method based on threat assessment is proposed in this paper. Firstly, the problem of jamming decision-making is modeled as a Markov decision process with reward. Creatively, rewards will be given by a track-based threat assessment model, by which the jamming strategies are able to fit the real-time requirements of electronic countermeasures. Finally, the Q-Learning algorithm is used to solve the problem and derive the optimal jamming strategy. Experiment results show that the proposed jamming strategy is more effective in reducing the threat of MFR to the target. Compared with the present methods, the proposed approach has advantages in real-time performance and effectiveness of jamming decision-making, and has more practical value.

8237: Smart Interference Signal Design to a Cognitive Radar
Bosung Kang{4}, Vikram Krishnamurthy{2}, Kunal Pattanayak{2}, Sandeep Gogineni{3}, Muralidhar Rangaswamy{1}
{1}Air Force Research Laboratory, United States; {2}Cornell University, United States; {3}Information Systems Laboratories Inc., United States; {4}University of Dayton, United States
This paper addresses an adversarial inference problem involving cognitive radars. The game theoretic framework described in this paper comprises “us” and an “adversary”. Our goal is to design an external interference signal that confuses the adversary radar with given information of the signals of the radar. The optimization problem is formulated such that the signal power of the designed interference is minimized while enforcing the probability that the signal-to-clutter-plus-noise ratio (SCNR) of the radar exceeds a certain SCNR level to be less than a specified threshold. The resulting problem is a challenging optimization problem since the constraint is based on a probability density function (PDF), which is non-differentiable. By taking an expected value of the SCNR, the problem is relaxed to a convex problem using the semidefinite relaxation. The simulation results verify the performance of the designed interference using the high-fidelity modeling and simulation tool, RFView.

8277: Pulse-to-Pulse Circuit Reconfiguration in Spectrum Sensing Radar
Trevor Van Hoosier, Jordan Alexander, Austin Egbert, Justin Roessler, Charles Baylis, Robert J. Marks II
Baylor University, United States
Because the wireless spectrum is becoming increasingly congested due to re-allocation of radar frequencies for spectrum

sharing, radar systems need to be able to adapt and change operating frequency quickly in response to interference. In a cognitive radar capable of spectrum sharing, reconfigurable transmitter circuitry allows the output power to be reoptimized to maximize detection range. Real-time reconfiguration has been accomplished through real-time impedance tuners that have been implemented using a software-defined radio controller with intelligent optimization algorithms. With a new, fast plasma-switch impedance tuner, a complete evaluation of the output power for a single tuner setting can be performed during the on-time of a pulse. We have placed the plasma-switch tuner under control of a spectrum-sharing software-defined radio platform to demonstrate circuit reconfiguration upon changing operating frequency and bandwidth on a pulse-to-pulse basis. The ability to reconfigure the transmitter amplifier load impedance allows the radar to detect targets at greater ranges while maximizing the signal-to-interference-plus-noise ratio by evading potential interference.

8311: Priority-Based Task Scheduling in Dynamic Environments for Cognitive MFR via Transfer DRL
Sunila Akbar{2}, Raviraj S. Adve{2}, Zhen Ding{1}, Peter W. Moo{1}
{1}Defence Research and Development Canada, Canada; {2}University of Toronto, Canada
A radar resource management (RRM) module manages the available radar resources by first prioritizing and then scheduling the tasks. Apart from scheduling the tasks as per their priorities, the task scheduler of a cognitive radar requires the scheduling to be adaptable to the changing environment. We formulate a general model for the distributions of task parameters, specifically, task priorities and delay tolerance, to ensure priority-based task scheduling. We develop the use of transfer learning (TL) within a deep reinforcement learning (DRL) framework to address the challenge of adaptability to a varying environment.

8337: Smart Noise Jamming Power Adjustment Using Exploratory Deep Deterministic Policy Gradient
Yujie Zhang, Weibo Huo, Cui Zhang, Jifang Pei, Yin Zhang, Yulin Huang
University of Electronic Science and Technology of China, China
Smart noise jamming is an emerging barrage jamming and plays an essential role in electronic countermeasures (ECM). To improve the interference effectiveness of smart noise, in this paper, an exploratory deep deterministic policy gradient (EDDPG) algorithm is proposed to continuously adjust the multi-step jamming power. Firstly, multi-step jamming power adjustment is modeled as a Markov decision process (MDP). Subsequently, average jamming-to-signal ratio (JSR) at multi-functional radar (MFR) receiver is chosen as the evaluation indicator to assess the performance of multi-step noise. Moreover, the principle of noise jamming power allocation is analyzed, and a reinforcement learning framework is developed to continuously adjust multi-step jamming power. Finally, numerical results are provided to verify the validity of the proposed method.

8347: Run-Time Monitors Design for Adaptive Radar Systems: A Practical Framework
Pepijn Cox, Mario Coutiño, Giuseppe Papari, Ahmad Millad Mouri Sardarabadi, Laura Anitori
TNO Netherlands Organisation for Applied Scientific Research, Netherlands
Adaptivity in multi-function radar systems is rapidly increasing, especially when moving towards fully adaptive, cognitive radar systems. However, the large number of available system configurations makes the rigorous verification and certification process during the testing phase, deployment, and after hardware and software upgrades, challenging, if not infeasible. To alleviate the verification process, run-time verification can be applied to oversee the correct function of a system during its operation. The application of run-time verification into a radar system is not straightforward. The goal of this paper is to introduce a framework to identify, characterize, and map the various aspects necessary for implementing run-time verification for (components of) multi-function radar systems. The proposed framework can be used by radar practitioners and researchers for applying run-time-verification to adaptive, re-configurable radar systems. In addition, we discuss how run-time verification can be leveraged to gather new insights from operational data to improve functionalities in upcoming update cycles and present an example of a verifier designed using the introduced framework.

8266: Joint Transmit Design with Interference Management for Radar and Communication Coexistence System
Ziyu Liu{1}, Junhui Qian{1}, Yuanyuan Lu{1}, Jinru Zhang{1}, Peng Xu{1}, Hu Mao{2}
{1}Chongqing University, China; {2}Guangdong Hongxin Technology Co., LTD, China
In this paper, we propose a new high-performance spectrum sharing configuration method for radar communication spectrum coexistence system. The controlled degrees of freedom are the transmit matrix of communication system and radar transmit vector. In order to maximize the signal to interference noise ratio (SINR) under the conditions of transmission energy, the similarity of radar and radar reference transmit vector, and achievable communication system rate constraints,

this paper presents a new algorithm based on the derived local design, which is less computationally complex than the traditional alternating convex transform method. Numerical results demonstrate the advantages of the solution proposed in this paper.

8005: Range-Doppler Spoofing in OFDM Signals for Preventing Wireless Passive Emitter Tracking
Antonios Argyriou
University of Thessaly, Greece
Passive emitter tracking (PET) algorithms can estimate both the range and Doppler of a wireless emitter when it uses orthogonal frequency division multiplexing (OFDM). In this paper we are interested to prevent this from happening by an unauthorized receiver (URx). To accomplish that we introduce in the transmitted signal a \textit{spoofing signal} that varies across subcarriers and successive OFDM symbols. With this technique the emitter is not only able to spoof its actual range and Doppler (allowing covert communication in terms of these two parameters), but is also capable of producing additional false emitter signatures to further confuse the URx. To evaluate the performance of our approach we calculate the range-Doppler response at the URx for different system configurations of an 802.11-based system.

12:50 – 14:20
Radar Imaging Methods
Poster Session
Room: CONF RMS 1-4
Session Chairs: Brian Rigling and Fabiola Colone

8012: Analysis of Keller Cones for RF Imaging
Anurag Pallaprolu, Belal Korany, Yasamin Mostofi
University of California, Santa Barbara, United States
Imaging still objects with off-the-shelf WiFi transceivers is challenging. The interaction of object edges with the incoming wave, dictated by the Geometrical Theory of Diffraction and the Keller cones, presents new possibilities for imaging with WiFi via edge tracing. In this paper, we bring a comprehensive understanding to the impact of different parameters on the Keller cones and the corresponding edge-based imaging, thereby developing a foundation for a methodical imaging system design. We consider the impact of parameters such as curvature of a soft edge, edge orientation, distance to the receiver grid, transmitter location, etc., on edge-based WiFi imaging.

8286: Multichannel Radar Forward-Looking Superresolution Imaging Considering Large Platform Speed
Rui Chen, Wenchao Li, Kefeng Li, Yongchao Zhang, Jianyu Yang
University of Electronic Science and Technology of China, China
To achieve forward-looking imaging of multichannel radar with large platform speed, a superresolution scheme is proposed in this paper. In the scheme, the azimuth dechirp processing is performed firstly, and then the Doppler frequency correction is conducted to eliminate the effect of platform velocity. At last, the iterative adaptive approach(IAA) is used to restore the Doppler spectrum and then realize forward-looking superresolution imaging. Simulation results are given to illustrate the effectiveness of the proposed scheme.

8018: MIMO-SAR Image Antialiasing for Cascaded mmWave Radar Sensor
Kang Liu{2}, Yuanhui Zhang{2}, Yu Cao{2}, Xiangcheng Zhu{2}, Qiyang Ge{2}, Fan Zhang{1}, Shunan Wang{1}, Zhijian Zhang{1}
{1}Andar Technologies, China; {2}China Jiliang University, China
This paper presents a cascaded mmWave Radar sensor system, which is able to generate MIMO SAR imaging. Two techniques are proposed in this paper, calibration and antialiasing. Since the cascaded radar has a big aperture, the data capture time is significantly reduced by $M\times N$ times, M and N are the number of Tx and Rx channels of the cascaded radar sensor, which enables real time SAR imaging acquisition. In order to generate focused SAR imaging, the calibration of cascaded radar is necessary. Furthermore, an antialiasing technique is proposed to enhance the SAR image by reducing the ghost image bands. The proposed algorithm is evaluated by both simulation and real data processing. The experimental results show that MIMO-SAR image by our cascaded Radar sensor has the potential in real time applications.

8021: Three-Dimensional Initial Imaging Result of Chinese Gaofen-3 Satellite Based on CS-TomoSAR
Jing Feng, Shuang Jin, Jingjing Zhang, Hui Bi

Nanjing University of Aeronautics and Astronautics, China
For the Gaofen-3 (GF-3) dataset with few available images, due to the low image resolution and large baseline intervals, traditional methods fail to achieve accurate 3-D reconstruction of interested area. With the help of multi-signal compressed sensing (MCS) theory, this paper introduces a novel processing workflow to achieve 3-D reconstruction of Chinese GF-3 Satellite dataset. This paper uses the GF-3 dataset to generate high-resolution 3-D point cloud of Chinese Beijing area, demonstrating the potential of GF-3 satellite for 3-D imaging.

8034: Shadow-Oriented Tracking Method for Multi-Target Tracking in Video-SAR
Xiaochuan Ni{2}, Yuan Song{1}, Xu Zhan{2}, Zhenyu Yang{2}, Lanwei Guo{1}, Dongqiong Xiong{1}, Xiaoling Zhang{2}, Tianjiao Zeng{2}
{1}Sichuan Province Engineering Research Center for Broadband Microwave Circuit High Density Integratio, China; {2}University of Electronic Science and Technology of China, China
This work focuses on multi-target tracking in Video synthetic aperture radar. Current methods have limited accuracy as they fail to consider shadows' characteristics and surroundings fully. To solve these, we propose a shadow-oriented tracking method. To avoid false tracking, a pre-processing module is proposed to enhance shadows. To avoid missed tracking, a detection method based on deep learning is designed to learn shadows' features, thus increasing positive detection. A recall module is designed to recall missing shadows. Experiments on measured data demonstrate that, compared with other methods, SOTrack achieves much higher tracking accuracy.

8035: A Model-Data-Driven Network Embedding Multidimensional Features for Tomographic SAR Imaging
Yu Ren, Xiaoling Zhang, Xu Zhan, Jun Shi, Shunjun Wei, Tianjiao Zeng
University of Electronic Science and Technology of China, China
This work focuses on tomoSAR imaging based on multi-dimensional features. Current DL-based tomoSAR imaging network use an unfolding network to mimic the iterative calculation of the classical compressive sensing (CS)-based methods and process each range-azimuth unit individually. Faced with the problem of insufficient utiliza-tion of multi-dimensional features in the imaging process, a two-dimensional deep unfolding imaging network is constructed. On the basis of it, we consider adding two 2D processing modules to perform azimuth-height slices and distance-height slices, respectively, to add multi-dimensional features into the tomoSAR imaging procedure. Meanwhile, to train the proposed multi-feature-based imaging network, we construct a tomoSAR simulation dataset consisting entirely of simulation data of buildings. Experiments verify the effectiveness of the proposed method.

8050: Multipass Circular SAR 3D Imaging via Lq-Based Complex Approximate Message Passing Algorithm
Weixing Yang, Daiyin Zhu
Nanjing University of Aeronautics and Astronautics, China
Multipass circular synthetic aperture radar (MCSAR) three-dimensional (3D) imaging is a challenging problem. For anisotropic scattering observation targets, the strategy of subaperture incoherent 3D imaging is generally adopted. In subaperture 3D target reconstruction, the L1/2-based complex approximate message passing (CAMP) reconstruction algorithm combined with the Bayesian information criterion (BIC) is proposed in this paper. Compared with the target reconstruction algorithm in elevation with multipass circular SAR data, such as the L1 norm-based method, the clear observed target 3D image with fewer desultory points can be obtained by the proposed method.

8104: Autofocusing of THz SAR Images by Integrating Compressed Sensing Into the Backprojection Process
Yevhen Ivanenko, Viet Thuy Vu, Mats I. Pettersson
Blekinge Institute of Technology, Sweden
The THz frequency spectrum provides an opportunity to explore high-resolution synthetic-aperture-radar (SAR) short-range imaging that can be used for various applications. However, the performance of THz SAR imaging is sensitive to phase errors that can be caused by an insufficient amount of data samples for image formation and by path deviations that can be practically caused by SAR platform vibrations, changes in speed, changes in direction, and acceleration. To solve the former problem, an improved interpolation procedure for backprojection algorithms has been proposed. However, to make these algorithms efficient in handling the latter problem, an additional autofocusing is necessary. In this paper, we introduce an autofocusing procedure based on compressed sensing that is incorporated into the backprojection algorithm. The reconstruction is based on the following calculated parameters: windowed interpolation sinc kernel, and range distances between SAR platform and image pixels in a defined image plane. The proposed approach is tested on real data, which

was acquired by the 2πSENSE FMCW SAR system through outdoor SAR imaging.

8156: Synthetic Aperture Radar Imaging from Sub-Nyquist Samples by Using Deep Priors of Image
Hongyang An, Ruili Jiang, Haowen Zuo, Junjie Wu, Zhongyu Li, Jianyu Yang
University of Electronic Science and Technology of China, China
In this paper, we propose an imaging method from sub-Nyquist sampled data based on deep priors of SAR images. First, we use a generative flow network to model the deep prior information of the images based on the existing SAR image datasets. Then, the pre-trained network modeling deep prior information of images is embedded in a typical compressed sensing method, i.e., the Iterative Shrinkage-Thresholding Algorithm (ISTA), to replace the sparse shrinkage function of it. Meanwhile, in order to improve the accuracy and convergence speed of reconstruction, we used the subsampled echo data to fine-tune the iterative parameters of the embedded ISTA method. The results of the experiments show that through the use of the deep prior information of the images, this method can accurately reconstruct non-sparse SAR images from the subsampled echoes, even if only a few echo samples are available.

8270: RCS-Based Imaging of Extended Targets for Classification in Multistatic Radar Systems
Sruti S{1}, Anil Kumar A{2}, Giridhar K{1}
{1}Indian Institute of Technology Madras, India; {2}TCS Research, India
Low-complexity composite RCS imaging of extended targets is developed using ISAR-oriented approach in a distributed multistatic radar system. The algorithm employs a floating grid-based formulation to overcome the exact time and phase alignment shortcomings in the fusion of measurements. Bistatic radar cross-section (RCS) values estimated using a robust recovery technique are fused to obtain a comprehensive RCS image. This image is also utilized to derive the synthetic shape which gives a notion of the dimension of the target. The unique multistatic RCS images and the synthetic shapes derived for different extended targets provide discriminatory features for accurate target classification.

8401: Resource Allocation and Optimization of Multi-UAV SAR System
Zi Guan, Zhichao Sun, Junjie Wu, Jianyu Yang
University of Electronic Science and Technology of China, China
In this paper, a multi-UAV SAR system with one UAV operating as receiving node and multiple UAVs operating as transmitting nodes is proposed. The proposed system gains better multi-angle featured imaging performance and higher target recognition ability. The multi-UAV SAR system contains a large number of UAV nodes, the imaging performance of the system is closely related to the configuration, power and bandwidth of the nodes, so the system resources need to be reasonably allocated to achieve the optimal comprehensive performance of the system. The system resource allocation is modeled as a constrained multi-objective optimization problem (MOP) considering the spatial configuration, transmit power and frequency band allocation of the UAVs and is solved by multi-objective particle swarm optimization (MOPSO) method to provide satisfactory imaging performance concerning the diversity of observation angle, resolution performance and image quality.

8257: K-Space Signal Occupancy of Starlink Signals and Their Applications in Passive Radar Imaging
Diego Cristallini, Rodrigo Blázquez-García, Daniel O'Hagan
Fraunhofer Fraunhofer Institute for High Frequency Physics and Radar FHR, Germany
In this paper, the possibility to exploit Starlink satellites as illuminators of opportunity for passive inverse synthetic aperture radar is investigated. Specifically, the \textit{always on} beacon signals transmitted by Starlink satellites are considered as a reliable source of illumination. Although these signals are inherently narrow-band, their potential reception over long times (e.g. few minutes), and the corresponding significant variations of the aspect angle to a target during such times, allows the exploitation of beacon signals for Doppler radar tomography. To this end, the \textit{slow-time} K-space signal occupancy of Starlink beacon signals is derived and it is shown how the K-space can be filled in. The possibility to utilise simultaneously multiple beacon signals originating from multiple Starlink satellites is also investigated.

8172: Adaptive Dynamic Regularization Super-Resolution Imaging Method of Forward-Looking Scanning Radar Based on Data-Depended
Mengxi Feng, Yin Zhang, Xingyu Tuo, Shuifeng Yang, Deqing Mao, Yongchao Zhang, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China
Non-convex Lp regularization method has been applied in airborne scanning radar forward-looking imaging, but the

selection of parameter p is troublesome if it should be manually chosen. To select an appropriate parameter p based on the data property, a data-depended dynamic regularization method is proposed. The iteratively reweighted algorithm is employed to solve the Lp norm minimization and updating the parameter p in each iteration. Simulation results demonstrate the performance of the proposed adaptive superresolution imaging method. The proposed method can determine the regularization parameter depending on the echo data, which improves the adaptivity of the traditional Lp regularization method.

8181: Quantitative Investigation of Imaging Quality vs. Radar Position Errors in Millimeter-Wave SAR

Qi Wen, Siyang Cao
University of Arizona, United States

Millimeter wave (mmWave) imaging has promising potential for many applications because of its fine resolution, object-penetration capabilities, and all-weather, all-day work- ing conditions. Combined with low-cost mmWave radars, the synthetic aperture radar (SAR) technique enables flexible, cost- effective, mmWave imaging solutions. This paper experimentally investigates how SAR imaging quality depends on in-aperture position errors. We emulate a wide range of position errors with root-mean-square values ranging from 1 mm up to 256 mm, covering between a fraction and a few tens of the wavelengths at 77 GHz. The presented results provide useful guidance for designing portable mmWave SAR systems that can benefit from flexible and low-cost motion tracking solutions.

12:50 – 14:20
Array Design & Processing
Poster Session
Room: CONF RMS 1-4
Session Chairs: Andre Bourdoux and Michael Picciolo

8054: A General Efficient Design Method for Optimum Nonuniform Array Pattern Synthesis

Ruitao Liu{2}, Bing Wang{1}, Wenqiang Wei{2}, Xianxiang Yu{2}, Guolong Cui{2}
{1}Science and Technology on Electronic Information Control Laboratory, China; {2}University of Electronic Science and Technology of China, China

This paper focuses on the research of a general optimization framework applying to the placement of both two types of nonuniform arrays, thinned array (TA) and sparse array (SA). We introduce the optimization problems that aim to minimize array factor (AF) peak sidelobe level (PSLL), also involving a number of practical constraints. To tackle the resultant non-convex optimization problems, we propose a modified iterative coordinate descent (MICD) method to split original problems into multiple independent one-dimensional subproblems. In each iteration, the redundant calculation is removed to improve the efficiency of the algorithm. Finally, numerical simulations are provided to verify the effectiveness of the proposed method.

8057: Avian Radar System Using Phased Array Radar Technologies

Jiangkun Gong{3}, Deren Li{3}, Jun Yan{3}, Huiping Hu{2}, Deyong Kong{1}
{1}Hubei Economic University, China; {2}Wuhan Geomatics Institute, China; {3}Wuhan University, China

Since the flight accident of U.S. Airways Flight 1549 in 2009, commercial avian radar systems for detecting birds mainly employing marine radar technologies, began to propagate rapidly. We propose an avian radar using the wingbeat corner reflector effect, and pulse-Doppler phased array radar technologies. Results indicated that the detection ranges are 10 km & 20 km, far longer than the 2 km & 6 km reported by the Federal Aviation Administration (FAA), with the detection response time (DRT) of 30 ms, much shorter than the reported 5 s. Therefore, there is a need to review the avian radar systems design.

8139: Cylindrical Distributed Coprime Conformal Array for 2-D DOA and Polarization Estimation

Mingcheng Fu, Zhi Zheng, Yizhen Jia, Bang Huang, Wenqin Wang
University of Electronic Science and Technology of China, China

In this paper, we devise a novel cylindrical conformal array, termed cylindrical distributed coprime conformal array (CDCCA), for two-dimensional (2-D) direction-of-arrival (DOA) and polarization estimation. The proposed CDCCA avoids the lag redundancies between two adjacent linear subarrays of cylindrical conformal array, and increases the unique lags number in its difference coarray. Moreover, it provides a larger array aperture than the exiting cylindrical conformal arrays under the same number of sensors. Therefore, the CDCCA configuration can resolve a larger number of sources and provide a higher

estimation accuracy. Numerical results demonstrate its superiority in comparison to several existing conformal arrays.

8141: Reduced-Dimension Subspace Detector Design for FDA-MIMO Radar in Sample-Starved Scenarios

Bang Huang{1}, Wenqin Wang{1}, Weijian Liu{2}, Mingcheng Fu{1}, Zhi Zheng{1}
{1}University of Electronic Science and Technology of China, China; {2}Wuhan Electronic Information Institute, China

This paper focuses on the detection of a point-like target in sample-starved environments with Gaussian interference, which includes strong main-lobe interference and weak thermal noise for frequency diverse array multiple-input multiple-output (FDA-MIMO) radar. At the design stage, the target signature is only partially known and assumed to lie in a known subspace. To solve the sample-starved problem, we adopt a reduced-dimension method to decrease the requirement of training data via pre-multiplying test and training data by a suitable matrix representing the signal subspace. Then, the generalized likelihood ratio test criterion is applied to come up with a reduced-dimension subspace detector. Numerical results validate the effectiveness of proposed detector.

8224: A Narrowband Criterion for Arrays of General Geometry

Mark Leifer
Ball Aerospace, United States

This paper derives the bandwidth that signals should be limited to, by filtration or frequency binning, to ensure that they are narrowband and are processed correctly by typical array processing algorithms (e.g., for interference nulling or angle of arrival estimation). The narrowband condition is defined as the maximum bandwidth signal that can be fully described by a single significant eigenvalue of the array covariance matrix. A simple closed-form expression for this bandwidth is derived that applies to arrays of arbitrary geometry and that clearly indicates how the bandwidth scales with array geometry and with signal SNR.

8229: Matched Filtering Performance Analysis for Massive MIMO Radar with One-Bit Quantization

Minglong Deng, Haoqi Wu, Ziyang Cheng, Jiaheng Wang, Zishu He
University of Electronic Science and Technology of China, China

In this paper, we investigate the performance of matched filtering (MF) for massive MIMO radar with one-bit ADCs. Firstly, we show that in the context of white Gaussian noise, the MF output of one-bit quantized received signals of massive MIMO radar is asymptotically Gaussian. Then, statistical characteristics, including mean and covariance matrix, of the MF output are derived, respectively. More importantly, using the fact that massive MIMO radar has a large number of measurements (i.e., the number of samples in space/frequency/time domains), we provide approximate probabilistic distribution of the MF output, which is capable of making the signal processing algorithms of one-bit MIMO radar low in complexity. Moreover, based on the above approximations, the performance gap between one-bit and traditional infinite-bit MIMO radars is mathematically derived. Finally, from the perspective of target detection and beamforming, representative simulations are conducted to demonstrate the performance of massive MIMO radar with one-bit ADCs.

8243: On the Relationship Between PRI Staggering and Sparse Arrays

Rachel J. Chang, Daniel B. Herr, Jonathan W. Owen, Patrick M. McCormick, Shannon D. Blunt, James M. Stiles
Radar Systems Lab, University of Kansas, United States

It is well known that pulse repetition interval (PRI) staggering can expand the unambiguous Doppler domain, though doing so can likewise increase Doppler sidelobes unless the staggering sequence is carefully designed. Within this context of stagger sequence selection we consider the intuitively related notion of sparse array design in the spatial domain. In so doing, the spatial co-array concept is examined for PRI staggering, along with physically meaningful boundaries of each domain and co-array attributes observed to be useful for staggering selection.

8305: Knowledge-Aided Sea Clutter Suppression Based on Echo State Network

Jianfeng Ding, Haoqi Wu, Zhihang Wang, Zishu He, Ziyang Cheng
University of Electronic Science and Technology of China, China

This paper studies the knowledge-aided sea clutter suppression based on echo state network (ESN). Aiming at the problem that the sea clutter suppression based on time series by ESN has poor suppression effect under the condition of high sea state and low signal-to-clutter ratio (SCR), We propose the knowledge-aided sea clutter suppression methods based on frequency spectrum and power spectrum by ESN. Sea clutter suppression is achieved by learning the sea clutter characteristics under the prior conditions through ESN. We use the measured datasets of IPIX radar for experimental

verification, and the results show that the proposed methods can effectively suppress the sea clutter in different sea states and even detect the target with lower SCR.

8334: Direction Finding in Partly Calibrated Arrays Using Sparse Bayesian Learning
Yihan Su, Guangbin Zhang, Tianyao Huang, Yimin Liu, Xiqin Wang
Tsinghua University, China
Direction finding in partly calibrated arrays, a distributed array with errors between subarrays, receives wide studies. Existing sparse recovery methods solve a complex semi-definite programming (SDP) problem, which has high time and space complexity. We consider to introduce sparse Bayesian learning (SBL) to partly calibrated arrays instead. In a SBL framework, we formulate a sparse recovery problem with self-calibration on errors, and derive the closed-form iterations to solve the problem. Simulations verify the feasibility of our proposed method and less time complexity than existing sparse recovery methods.

8345: SF-ESPRIT: An Efficient 3D Localization for MIMO SFCW Radars Using Space-Frequency Array
Achanna Anil Kumar, Rokkam Krishna Kanth, Andew Gigie, Tapas Chakravarty, Arpan Pal
TCS Research, India
In this paper, the problem of 3D localization of multiple point targets with Multiple Input Multiple Output (MIMO) Stepped Frequency Continuous Wave (SFCW) radar is considered. We propose to combine the channel response of the virtual Uniform Rectangular Array (vURA) obtained by scanning at uniformly spaced frequency points to form a larger array referred as Space-Frequency (SF) array. Towards estimating jointly the azimuth, elevation and range of multiple targets with this SF-array, we propose a new ESPRIT based algorithm which we refer to as SF-ESPRIT. The localization capability of SF-ESPRIT largely depends upon the number of frequency scanning points, and further possess the ability to localize far more targets than the dimension of the vURA. In addition, the inter-element spacing requirement of vURA is also greatly relaxed. We show that with this proposed approach one can obtain much better localization performance with fewer elements than the standard existing methods. Appropriate numerical results are presented to corroborate these findings.

8352: Gridless DOA Estimation for Automotive Millimeter-Wave Radar with a Novel Space-Time Network
Yanjun Zhang, Jun Tao, Yan Huang, Lvhongkang Lan, Jiang Liu, Xinyu Guan
Southeast University, China
Direction of arrival (DOA) estimation of radio wave is required in many practical applications, and is a key technology in target detection of millimeter wave radar. In this paper, a new space-time network (STNet) is proposed, which models DOA estimation as a regression task to solve the off-grid problem and achieve the effect of gridless estimation.We design a space feature processing module (SFPM) and a time feature processing module (TFPM), which extract features from the covariance matrix of the received signal and the original received signal respectively. Through such processing, we retain sufficient information, obtain more features for the regression task, and ensure the estimation effect of using a small number of snapshots. The experimental will be presented to demonstrate the performance of STNet.

8415: Arctic Over-the-Horizon Radar Receive Array Design Considerations
Ryan Riddolls
Defence Research and Development Canada, Canada
An Arctic over-the-horizon radar system should be located so that the boundary of the aurora borealis lies at one-half its maximum range. At this location, the ionosphere reflection point is generally outside the aurora and auroral backscatter clutter arrives from close to the horizon. The optimal depth of an AOTHR two-dimensional receive array for clutter mitigation is given by the spread of the clutter spatial autocorrelation. Endfire element spacing is limited by the appearance of grating lobes at the horizon.

8392: Coprime Visible Regions Assisted Angle Unfolding for Sparse Esprit
Lifan Xu, Shunqiao Sun
University of Alabama, United States
In many applications, such as automotive radar for autonomous vehicles, a sparse linear array (SLA) is more attractive than a uniform linear array (ULA). SLAs not only make hardware costs lower to design antenna arrays with a large aperture but also reduce the mutual coupling among antenna elements. When estimation of signal parameters via rational invariance techniques (ESPRIT) is applied on SLAs with shift among subarrays being larger than half wavelength, there would be

ambiguities in the field of view (FoV) of the sensor array due to angle folding. In this paper, we present novel SLA geometry with non-uniform subarrays that do not necessarily have a centrally symmetric geometry, and corresponding coprime FoV aided approach to do the angle unfolding. The main goal of the sparse array design is to increase the array aperture size using fewer sensors while maintaining shift invariant geometry. By carefully designing the shifts among these sparse subarrays following a coprime relationship, the angles can be resolved uniquely by a consistent comparison of the angle estimations reported separately by different shifted subarrays.

12:50 – 14:20
Waveform Design & Optimization
Poster Session
Room: CONF RMS 1-4
Session Chairs: Shannon Blunt and Laura Anitori

8029: Unimodular Sequence Set Design for MIMO Radar Ambiguity Function Shaping

Wenyan Wei, Yinsheng Wei
Harbin Institute of Technology, China

This manuscript presents a method to design a unimodular sequence set with a desired ambiguity function for MIMO radar. We first extend the idea that designing transmit signal with an ambiguity function that exhibits low values in specific range-Doppler bins can suppress clutter to the case of MIMO radars and formulate the design problem. The limited-memory Broyden-Fletcher-Goldfarb-Shanno (L-BFGS) method is employed to solve the problem. We also devise a way to employ FFT in calculating the objective function and gradient. Numerical experiments demonstrate that the proposed method is superior to the existing method.

8061: Waveform Analysis and Digital Predistortion for Modulation-Based Radar Target Simulators

Pirmin Schoeder, Vinzenz Janoudi, Tim Petersohn, Timo Grebner, Christian Waldschmidt
Universität Ulm, Germany

With the help of radar target simulators radar systems can be tested and validated. Modulation-based radar target simulators offer a cost-effective simulation capability, but suffer from nonlinearities. This paper analyzes the waveform that is employed in typical radar scenarios by the radar target simulator. The signal statistics are used to define a required back-off in order to remain in the linear region of the radar target simulator. A digital predistortion scheme is presented that allows to increase the power of the modulation signal without increasing the nonlinearities. The predistortion scheme can be implemented fully in software, without additional hardware or measurement equipment. Measurements with a 77GHz radar sensor are presented to verify the derived signal theory and digital predistortion scheme.

8220: Learned Complex Circle Manifold Network for MIMO Radar Waveform Design

Kai Zhong{2}, Jinfeng Hu{1}, Ye Yuan{2}, Gangyong Zhu{1}, Xianxiang Yu{1}, Guolong Cui{1}
{1}University of Electronic Science and Technology of China, China; {2}Yangtze Delta Region Institute Quzhou, University of Electronic Science and Technology of China, China

The waveform design for transmit beampattern with constant modulus constraint (CMC) is a key technology in Multiple Input Multiple Output (MIMO) radar systems. Usually, the existing methods mainly include two categories: classical statistical modeling methods, most of which relax the problem with performance degradation; and conventional data-driven Deep Neural Networks (DNNs) without considering the characteristic of CMC. We notice that the CMC can be geometrically interpreted as restricting the solution to a Complex Circle Manifold (CCM), then the model-driven Learned CCM Network (LCCM-Net) is proposed, where the gradient descent algorithm is unfolded as the network layer. Different from the existing methods, the proposed method considers both the characteristic of CMC without relaxation and adaptively adjust the stepsize by the network. Compared with the existing methods, the proposed method can achieve 0.654 dB SINR gain enhancement with 1 magnitude computational cost decreasing.

8263: Joint Design of OFDM Sequences and Mismatch Filter Under Spectral Constraints

Jinyang He, Wanpeng Huang, Ziyang Cheng, Huiyong Li, Zishu He
University of Electronic Science and Technology of China, China

The OFDM sequences with low correlation sidelobe level (CSLL) is desired in many 5G wireless systems. The OFDM sequences and mismatch filter are jointly designed by maximizing the weighted merit factor (WMF) of the cross-correlation between the OFDM sequences and mismatch filter under the constraints of spectra, where MF refers to the ratio of the central lobe energy to the sum of all other lobes. To solve the nonconvex problem, we devise an efficient alternating optimization (AltOpt) algorithm. Numerical simulations are provided to demonstrate the effectiveness of the proposed algorithms.

8267: Reinforcement Learning for Radar Waveform Optimization

Mario Coutiño, Faruk Uysal
TNO Netherlands Organisation for Applied Scientific Research, Netherlands

Recently, it has been shown that reinforcement learning (RL) is able to solve decision-based problems through a series of action-observation-reward cycles. In this paper, we pose the problem of constrained waveform optimization as a sequential decision problem and show how it can be solved by an RL agent. The proposed RL-based method is an alternative to mix-integer optimization, evolutionary algorithms, and Bayesian optimization, which is capable of dealing directly with a variable parameter space dimension while considering designs with different processing algorithms in the (optimization) loop. To illustrate the effectiveness of the proposed method, we demonstrate the optimization of an agent's policy capable of defining the number of pulses as well as their duration and modulation parameters of radar waveform while optimizing an user-defined figure of merit.

8398: Waveform Selection for FMCW and PMCW 4D-Imaging Automotive Radar Sensors

Nazila Karimian Sichani{2}, Moein Ahmadi{2}, Ehsan Raei{2}, Mohammad Alaee-Kerahroodi{2}, Mysore R. Bhavani Shankar{2}, Esfandiar Mehrshahi{1}, Seyyed Ali Ghorashi{3}
{1}Shahid Beheshti University, Iran; {2}Université du Luxembourg, Luxembourg; {3}University of East London, United Kingdom

The emerging 4D-imaging automotive MIMO radar sensors necessitate the selection of appropriate transmit waveforms, which should be separable on the receive side in addition to having low auto-correlation sidelobes. TDM, FDM, DDM, and inter-chirp CDM approaches have traditionally been proposed for FMCW radar sensors to ensure the orthogonality of the transmit signals. However, as the number of transmit antennas increases, each of the aforementioned approaches suffers from some drawbacks, which are described in this paper. PMCW radars, on the other hand, can be considered to be more costly to implement, have been proposed to provide better performance and allow for the use of waveform optimization techniques. In this context, we use a block gradient descent approach to designing a waveform set that is optimized based on weighted integrated sidelobe level in this paper, and we show that the proposed waveform outperforms conventional MIMOFMCW approaches by performing comparative simulations.

14:20 – 14:50
Coffee Break

14:50 – 16:20
Radar Technologies
Poster Session
Room: CONF RMS 20-21
Session Chairs: Lorenzo Lo Monte and Alfonso Farina

8199: Fast Prototyping of Nonlinear Passive Tags for Location Detection Using Harmonic Radar

Leya Zeng{2}, Dan Fazzini{1}, Robert Fazzini{1}, Steven Johnson{1}, Changzhi Li{2}
{1}Ballocator, LLC, United States; {2}Texas Tech University, United States

This paper proposes a novel passive nonlinear tag design, fabrication, and tests using a second-order harmonic system with various antenna configurations. The tag's antennas were fabricated using conductive materials, and the Schottky diode's performance was greatly enhanced based on its nonlinearity. The detective distance of up to 6.7 ft of the tags was tested using a benchtop setup of a 7.9 GHz transmitter and a 15.8 GHz receiver antenna without any signal amplification. The lightweight and miniature tags have great potential for extensive applications in locating objects.

8363: Dual-Polarized Microstrip-Fed Slot Antenna Design with Dual-Notch Filtering for Ultra-Wideband Communications

Naser Parchin{2}, Mostafa Elsayed{3}, Julien Le Kernec{3}, Ahmed Amar{1}
{1}Ain Shams University, Egypt; {2}Edinburgh Napier University, United Kingdom; {3}University of Glasgow, United Kingdom

This paper aims to discuss the characteristics of a dual-port/dual-polarized MIMO slot antenna system with dual band filtering for ultra-wideband (UWB) wireless communications. Its structure contains a pair of modified arc shaped radiation stubs with a shared ground plane in a planar form. The stubs also contain W-shaped and open-ended rectangular slots. The ground plane of the suggested design contains an open-ended circular slot. The results indicate that the antenna operates at frequencies 3–10.7 GHz, fully covering the UWB spectrum. Additionally, two notched-band filtering characteristics have been achieved at 5.5 and 7.5 GHz to fully suppress the interfaces from other wireless systems such as WLAN and downlink of X-band satellite communication. The introduced design is examined in terms of its fundamental characteristics. It has been determined that sufficient scattering parameters, 3D radiations, efficiency, and gain levels are all achievable with the planned UWB antenna design. The proposed antenna system meets the requirements well for MIMO and diversity applications.

8395: RFSoC-Based Design and Implementation of a Direct RF FMCW Radar Altimeter

Victor Bursucianu, Abdessamad Amrhar, Jean-Marc Gagné, Rene Jr. Landry
LASSENA, École de Technologie Supérieure, Canada

This paper presents the novel design architecture and implementation of a Direct RF Sampling Radar Altimeter based on the RFSoC from Xilinx. This architecture only uses RF filters and Power Amplifiers in the RF front end reducing considerably its SWaP-C (Size, Weight, Power and Cost). All the radar signal generation and range processing are done inside the FPGA. The lab test was done with certified equipment (Alt-8000), presented at the end, and shows that the radar altimeter respects the accuracy requirements of the DO-155 and presents an error identical to the ALT-8000 error on the simulated altitude.

8343: 6-Bit CMOS Phase Shifter and Attenuator Based on Time-Modulation for Ku-Band Phased Array Applications

Shiwei Wu{3}, Hongliang Zhao{1}, Chong He{2}, Dongwei Pang{3}, Yan Wang{3}, Qi Xia{4}, Zongming Duan{1}
{1}East China Research Institute of Electronic Engineering, China; {2}Shanghai Jiao Tong University, China; {3}University of Science and Technology of China, China; {4}University of Texas at San Antonio San, Armenia

Quasi-single sideband time modulation (QSSB-TM) topology is adopted to design high precision 6-bit phase and amplitude circuit in 0.13-um CMOS technology. The excellent amplitude and phase performance are realized with QSSB-TM circuit composed of a 90o power divider, two 180o phase shifters and a 0o Wilkinson power divider in 14-18GHz. The max root mean square (RMS) phase error is 0.2o in the 6-bit phase shifter mode. The max RMS amplitude error is 0.63dB in the 6-bit attenuator mode. The chip size is 1.5mm*1.7mm (2.55mm2).

8376: A High Performance Computing Architecture for Real-Time Digital Emulation of RF Interactions

Mandovi Mukherjee, Nael Mizanur Rahman, Coleman Delude, Joseph Driscoll, Uday Kamal, Jongseok Woo, Jamin Seo, Sudarshan Sharma, Xiangyu Mao, Payman Behnam, Sharjeel Khan, Daehyun Kim, Jianming Tong, Prachi Sinha, Santosh Pande, Tushar Krishna, Justin Romb
Georgia Institute of Technology, United States

A high performance architecture for emulating real-time radio frequency systems is presented. The architecture is developed based on a novel compute model and uses near-memory techniques coupled with highly distributed autonomous control to simultaneously optimize throughput and minimize latency. A cycle level C++ based simulator is used to validate the proposed architecture with simulation of complex RF scenarios.

8336: Beampattern Design for Radars with Reconfigurable Intelligent Surfaces

Emanuele Grossi, Luca Venturino
Università degli Studi di Cassino e del Lazio Meridionale, Italy

We consider a radar architecture where an illuminator composed of few sources is used as a feeder for a (passive) reconfigurable intelligent surface (RIS), so as to mimic the behavior of a multiple-input multiple-output (MIMO) radar composed of as many active elements as the RIS. In this framework, we study the problem of beampattern design in the space-frequency domain, and we propose to choose the source signals and the RIS adjustable phases in order to minimize the weighted squared error between the desired (amplitude) beampattern and the synthesized one. A low complexity iterative algorithm is proposed to solve the resulting non-convex least square problem. An example is provided to show the merits of the proposed approach.

14:50 – 16:20
Multistatic, Networked, & Distributed
Poster Session
Room: CONF RMS 20-21
Session Chairs: Mateusz Malanowski and Christ Richmond

8320: Multi-Domain Resource Scheduling for Surveillance Radar Anti-Jamming Based on Q-Learning

Tao Yang{1}, Ye Yuan{2}, Wei Yi{1}
{1}University of Electronic Science and Technology of China, China; {2}Yangtze Delta Region Institute Quzhou, University of Electronic Science and Technology of China, China

This paper proposes a multi-domain resources scheduling strategy based on Q-Learning for surveillance radar anti-jamming. As its core, the surveillance radar accomplishes detection tasks and avoids potential active jamming by intelligently selecting the radar transmit parameters of spatial (i.e., beam position), frequency, and energy (i.e., dwell time and transmit power) domains. The resources scheduling is formulated as a sequential decision problem in the context of unknown prior information about environments and enemy jammers. To describe this decision problem mathematically, we build a detailed Markov decision process (MDP) model and establish the corresponding reward function regarding the performance of the radar detection, low interception and the penalty after intercepted. A Q-Learning based solution is presented to find the optimized action strategy of the formulated model accordingly. Simulation results show that the proposed strategy can improve the radar detection performance while reducing the risk of interception by the enemy.

8372: Multi-Sensor Adaptive Birth for Labeled RFS Filters Using Bistatic Range-Only Measurements

Anthony Murray, Alex Withers, Anthony Trezza, Donald Bucci Jr.
Lockheed Martin, United States

Recently, a Monte Carlo importance sampling-based approach has been established to achieve scalable, multi-sensor, measurement adaptive track initialization for labeled random finite set filters. However, previously suggested proposal distributions require every sensor’s measurement function to have a differentiable inverse in the observable dimensions of the target’s state space. This paper provides an alternative proposal distribution for Monte Carlo importance sampling-based, multi-sensor, measurement adaptive track initiation that is not restricted to invertible measurement functions. The solution for a bistatic range-only measurement function is provided, and simulation results are shown to verify the efficacy of the solution.

8195: Multi-Band Hybrid Active-Passive Radar Sensor Fusion

Piers Beasley, Matthew Ritchie
University College London, United Kingdom

In this paper the topic of joint active and passive (hybrid) radar sensing is introduced and the theoretical benefits are outlined. An experimental hybrid radar setup is presented where a low-cost Software Defined Radio (SDR) based radar system is used for hybrid sensing of targets using active and Passive Bistatic Radar (PBR). Experimental results are presented for simultaneously sensing using an active 2.4 GHz sensing mode and 690 MHz Digital Video Broadcasting — Terrestrial (DVB-T) based PBR sensing mode. The detection performance of each sensor and a joint sensor performance are evaluated, where the joint sensing performance is found to exceed that of the individual sensors alone. The ability to reduce active radar transmissions, but still retain a reasonable detection performance, is investigated using experimental data and the case is made for adaptive behaviour in order to exploit the benefits available to hybrid radars.

8289: Decentralized Multi-Target Tracking for Netted Radar Systems with Non-Overlapping Field of View

Cong Peng, Haiyi Mao, Yue Liu, Lei Chai, Wei Yi
University of Electronic Science and Technology of China, China

In this paper, a robust and high-accuracy decentralized fusion strategy is proposed for multi-target tracking (MTT) in netted radar systems with non-overlapping field of view (FoV). Each radar in the network runs a local Probability Hypothetical Density filter with the decentralized consensus protocol to reduce communication bandwidth and eliminate information inconsistency among nodes. In the above process, the most critical core is an effective fusion strategy. Our proposed method adopts the geometric covariance intersection (GCI) rule to improve fusion accuracy. However, the standard GCI fusion is not suitable for this case because it only focuses on the targets within the intersection of radar FoVs. Consider that, we extend the weights to be a set of state-dependent weights instead of scalars to perform GCI fusion in a more robust manner. Furthermore, the radar FoVs are always unknown and time-varying in practical scenarios. We combine a clustering

algorithm based on highest posterior density to maintain a good fusion performance. The Gaussian Mixture implementations is presented. Numerical simulation is designed to demonstrate the efficacy of the proposed method.

8144: Long-Distance Bistatic Measurements of Space Object Motion Using LOFAR Radio Telescope and Non-Cooperative Radar Illuminator

Konrad Jędrzejewski{3}, Mateusz Malanowski{3}, Krzysztof Kulpa{3}, Mariusz Pożoga{2}, Andrzej Modrzewski{1}, Michal Karwacki{1}

{1}PIT-RADWAR S.A., Poland; {2}Space Research Centre, Polish Academy of Science, Poland; {3}Warsaw University of Technology, Poland

The paper presents the concept and results of experiments devoted to verifying empirically the potential capability of long-distance space object observation by radar system employing an astronomical LOFAR (LOw-Frequency ARray) radio telescope and a non-cooperative radar illuminator operating in a VHF band. The large antenna array of one of the LOFAR radio telescopes was used as a surveillance receiver to collect weak echo signals reflected from space objects, while the reference signal was recorded by a simple software-defined radio receiver located near the radar illuminator. A dedicated object motion compensation procedure has been applied to detect high-speed space targets in low-Earth orbit. The results of the conducted experiments confirm the possibility of detecting space objects employing the antenna arrays used in the LOFAR radio telescopes and signals emitted by non-cooperative radars to illuminate space objects.

8333: Satellite Orbit Refinement Based on Passive Bistatic Radar Measurements

Mateusz Malanowski, Konrad Jędrzejewski, Krzysztof Kulpa

Warsaw University of Technology, Poland

The paper presents the concept and its empirical validation of the use of passive bistatic radar based on the LOFAR radio telescope and commercial digital radio DAB+ illuminator for orbit parameter refinement. The orbit parameter update is based on minimizing the errors of bistatic range and velocity measurements in several points of the orbit, visible by the LOFAR receiver.

14:50 – 16:20
Estimation Techniques
Poster Session
Room: CONF RMS 20-21
Session Chairs: Jim Day and Jacqueline Fairley

8025: MIMO Radar-Based Rotation Parameter Estimation of Non-Cooperative Space Debris Objects

Christoph Kammel, Ingrid Ullmann, Martin Vossiek

Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

This paper presents an approach to determine the rotation parameters of a non-cooperative space debris object by extracting, localizing and tracking the target's dominant scatterers with a millimeter-wave MIMO radar system. An unscented Kalman filter tracks the scatterer positions over several processing intervals and is therefore able to estimate the rotation period of the target as well as the position and orientation of its rotation axis. On the one hand, the proposed algorithm is validated by realistic simulations. On the other hand, the filter performance under different rotation parameters is evaluated by different measurements in the laboratory.

8092: Covariance Matrix Estimation with Kronecker Structure Constraint for Polarimetric Detection

Jiaheng Wang, Yalong Wang, Haoqi Wu, Zhihang Wang, Jun Li
University of Electronic Science and Technology of China, China

With the Kronecker product structure constraint, this paper proposes a covariance matrix (CM) estimation method in the Compound-Gaussian (CG) sea clutter background. We assume the CG clutter in different polarization channels has different textures, which is different from the existing Kronecker structure-based CM estimation methods for polarimetric target detection. Based on the maximum likelihood (ML) criterion, we obtain the fixed point equation of the CM and solve it by an iterative algorithm. The proposed method is referred to as the Kronecker-based maximum likelihood estimate (KMLE), and the relevance of KMLE to the existing estimation methods is also discussed. For the performance assessment, we demonstrate the estimation accuracy of KMLE by presenting the normalized mean-square error (NMSE), and the detection performance is assessed by inserting the estimated CM into the test statistic of the texture-free generalized likelihood ratio test (TF-GLRT) detector. Through simulations with the synthetic and real sea clutter, we verify that KMLE outperforms other estimation methods when the training samples are limited.

8131: A SPICE-TV Super-Resolution Method for Scanning Radar

Jiawei Luo, Yongchao Zhang, Yin Zhang, Shuifeng Yang, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

Recently, the sparse iterative covariance fitting estimation (SPICE) method has been proposed for airborne radar super-resolution imaging, which offers higher azimuth resolution but poor target contour construction ability. In this paper, a SPICE-TV super-resolution method is proposed to handle this problem. First, the scanning radar angular superresolution problem is transformed into a convex optimization problem that relies on the sparse covariance fitting criterion and the total variation (TV) regularization constraint. On the one hand, the weighted sparse norm of SPICE is employed to improve azimuth resolution due to its sparse property. On the other hand, the TV norm is introduced to reconstruct the target contour because it can well keep the target edge information. This convex optimization problem is then solved by CVX. The proposed method has a higher resolution than the traditional TV method. Moreover, it has the ability to reconstruct the target contour compared with the traditional SPICE method. The simulation verifies the superiority of the proposed method.

8155: Multipath Model Order Selection for Non-Line of Sight Radar Localization in Urban Environment

Ba-Huy Pham{2}, Olivier Rabaste{2}, Jonathan Bosse{2}, Israel Hinostroza{3}, Thierry Chonavel{1}
{1}Lab-STICC, CNRS UMR 6285, IMT Atlantique, France; {2}ONERA, France; {3}SONDRA, CentraleSupélec, France

In urban environment, Non-Line of Sight (NLOS) target position can be determined by exploiting reflections on surrounding building, for instance using Matched Subspace Filter (MSF). However, it has been shown that the MSF output exhibits strong localization ambiguities when the different positions share one or more multipaths in common. This ambiguity phenomenon is all the more exacerbated since the zones in the research domain are not illuminated by the same number of paths. In this paper, the well-known Bayesian Information Criterion (BIC) is introduced in order to deal with this problem. Besides, we propose a multipath selection procedure in order to select the relevant model of for each position under test based on the Orthogonal Least Squares (OLS) algorithm combined with BIC as a stopping rule. These solutions, applied on both simulated and experimental data, show a better localization results compared to classic localization scheme.

8211: Iterative Adaptive Approach Based on Long-Time Coherent Integration Outputs

Zicheng Kong, Jing Tian, Chen Ning, Wei Cui
Beijing Institute of Technology, China

Wideband radar systems have excellent target detection and recognition performance because of high range resolution. However, range migration occurred in long-time coherent processing and range-Doppler sidelobes may deteriorate the performance of wideband radar systems seriously. To address the two problems above, a fast iterative adaptive approach based on long-time coherent integration outputs is proposed for wideband range-Doppler imaging. The proposed algorithm first correct range migration by Keystone transform and then suppress sidelobes of targets based on the long-time coherent integration outputs within a small processing window around mainlobes. The computational complexity of the proposed method can be further reduced thanks to employing a threshold criterion and exploiting the structure of the covariance matrix. The performance of the proposed algorithm is demonstrated by numerical examples.

8281: An Accurate and Efficient Two-Step Velocity Estimation Method for Moving Targets for Airborne Forward-Looking Scanning Radar

Jiahao Shen, Deqing Mao, Yin Zhang, Wenjing Wang, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

Relative velocity estimation is a key challenge for moving target detection in current forward-looking scanning radar-aerial collision avoidance systems. Since the conventional methods suffer from low precision or heavy computation load for fast-moving target motion estimation, this paper proposes an accurate and efficient two-step estimation method that improves the efficiency and accuracy. To improve the estimation efficiency, the first step utilizes Radon transform to narrow the velocity interval which reduces the number of searches. The second step is devoted to fine searching the velocity interval by the minimum entropy criterion, which ensures high estimation accuracy. In the search process, a two-point interpolation method is proposed to reduce the search time and further improve the estimation efficiency. Theoretical and simulation experimental analyses provide qualitative and quantitative evaluations of the efficiency and accuracy of the proposed method.

8325: Worst-Case Centre-Frequency Estimation

Robby McKilliam, Vaughan Clarkson, Troy Kilpatrick
Whipbird Signals, Australia

This paper analyses the centre-frequency estimator proposed by Lank, Reed, and Pollon. This estimator is popular in practical applications due to its robustness and computational simplicity. Under a bandwidth constraint, the worst-case behaviour of the estimator is shown to occur when the underlying signal consists of two sinusoids separated by the bandwidth. This worst-case behaviour provides upper bounds on the estimators error and corresponding confidence intervals when the underlying signal is unknown. The upper bounds are useful in applications such as electronic support where the specific form of received signals may not be known.

8408: Fast Iterative Adaptive Approach Based on 2-D Matched Filter Outputs for RFPA Signal

Jia Wei, Fengyu Wang, Yizhe Pan, Jing Tian, Wei Cui
Beijing Institute of Technology, China

Random frequency and pulse repetition interval agile (RFPA) signals have excellent performance on low probability of intercept (LPI) and anti-jamming. However, due to the random characteristics of RFPA signals, their matched filter (MF) outputs suffer from high range-Doppler sidelobes, which seriously deteriorate weak targets detection performance. The iterative adaptive approach based on matched filter (MF-IAA) is proved to be effective in suppressing sidelobes, but it has a heavy computational burden. To solve these problems, we propose a fast MF-IAA method based on the 2-D MF outputs within a small processing window (MF-FWIAA). The simulation results show that MF-FWIAA can effectively suppress the range-Doppler sidelobes of RFPA signals with low computational complexity.

14:50 – 16:20
Machine Learning for Radar
Poster Session
Room: CONF RMS 1-4
Session Chairs: Sevgi Gurbuz and Hugh Griffiths

8112: Detection of Close-Proximity Automotive Targets Using LSTM

Vinay Kulkarni, V.V. Reddy, Avinash Dixit
International Institute of Information Technology, Bangalore, India

Constant false alarm rate (CFAR) detector is widely used in automotive radar for target detection from the range- Doppler (RD) map. Due to the large target size relative to the range resolution of the radar, the target response is spread in the RD map. Presence of multiple closely-situated targets add to the challenge of precisely identifying the number of targets present in the scene. Multiple detections provided by CFAR in such scenarios pose challenge to the identification of the actual number of targets. We propose two LSTM-based networks to resolve the number of targets present in the scene. The performance of the proposed networks is presented in comparison with Resnet-50.

8004: FMCW Radar Sensing for Indoor Drones Using Variational Auto-Encoders

Ali Safa{3}, Tim Verbelen{1}, Ozan Çatal{1}, Toon Van de Maele{1}, Matthias Hartmann{2}, Bart Dhoedt{1}, André Bourdoux{2}

{1}IDLab, Ghent University, imec, Belgium; {2}imec, Belgium; {3}imec, Katholieke Universiteit Leuven, Belgium

This paper investigates unsupervised learning of low-dimensional representations from FMCW radar data, which can be used for multiple downstream tasks in a drone navigation context. To this end, we release a first-of-its-kind dataset of raw radar ADC data recorded from a radar mounted on a flying drone in an indoor environment, together with ground truth detection targets. We show that, by utilizing our learned representations, we match the performance of conventional radar processing techniques while training our models on different input modalities such as range-doppler maps, range-azimuth maps, or raw ADC samples of only two consecutively transmitted chirps.

8043: Neural Network LFM Pulse Compression

Jabran Akhtar

Norwegian Defence Research Establishment, Norway

Matched filtering plays an important role in radar systems as the established pulse compression technique. This article puts forwards an alternative machine learning based technique for the matched filtering process assuming the incoming signal is oversampled. The aim is to replace the convolutional operation with a small fully connected feedforwarding neural network and attain an additional increase in the range resolution. The paper demonstrates how such a neural network design can be constructed and a practical training approach is presented. The results are compared against traditional matched filtering and target detection methods showing a clear advantage of trained neural networks for the pulse compression procedure and as a mean to construct inventive mismatched filters.

8058: Radar-Based Object Classification in ADAS with Hardware-Aware Nas and Input Region Scaling

Daan Schalk{2}, Fons van der Sommen{1}, Willem Sanberg{2}

{1}Eindhoven University of Technology, Netherlands; {2}NXP Semiconductors, Netherlands

This paper presents a radar-based object classification algorithm for an ADAS context with contributions on two key aspects: an improved input data selection process and new neural network designs to perform the classification. The network designs are optimized via a customized Hardware-aware Neural Architecture Search process (HA-NAS) that optimizes a network for both task accuracy and execution efficiency on specific hardware. We extend and describe these novel design techniques for adaption towards radar data, which is relatively less explored than for camera or LiDAR data. Our proposed region-of-interest selection process normalises the spatial coverage of object spectra for increased input data consistency. Our NAS algorithm automatically explores variations and combinations of state-of-the-art manual designs and produces Paretocurves of optimal solutions that offer performance trade-offs and design insights. Candidate networks are evaluated automatically on real embedded hardware to measure their efficiency. Our methodology generates architectures that are 2x faster or 2% more accurate than the reference state of the art network.

8099: Aircraft Marshaling Signals Dataset of FMCW Radar and Event-Based Camera for Sensor Fusion

Leon Müller{3}, Manolis Sifalakis{2}, Sherif Eissa{1}, Amirreza Yousefzadeh{2}, Paul Detterer{2}, Sander Stuijk{1}, Federico Corradi{1}

{1}Eindhoven University of Technology, Netherlands; {2}imec, Netherlands; {3}imec, Eindhoven University of Technology, Netherlands

Radar sensors are used as an alternative or complementary modality to camera vision for many applications. Gesture recognition for command control is a commonly explored application. Nevertheless, there is a lack of benchmarking datasets for comparing different algorithms for sensory fusion. This work addressed this problem by providing a newly collected dataset of 11 full-body gestures representing aircraft marshalling signals. Moreover, we present a new encoding strategy capable of highly reducing the data rate from FMCW radars. As a result, we demonstrate a significant (>76\%) radar data rate reduction while retaining most of the accuracy (<2\% accuracy loss). Finally, we demonstrate early sensory fusion with binary radar data and a Dynamic Vision Sensor (DVS), achieving higher accuracy than each modality alone. To the best of our knowledge, this is the first demonstration of sensory fusion of radar and DVS camera data aimed at classifying human gestures using only binary sensorial information.

8191: Improving the Robustness of Automotive Gesture Recognition by Diversified Simulation Datasets

Nicolai Kern, Julian Aguilar, Pirmin Schoeder, Christian Waldschmidt

Universität Ulm, Germany
In automotive scenarios, traffic gestures are subject to a wide range of extrinsic variations such as rotation or translation. While radar-based gesture recognition is advantageous with respect to bad weather and lighting, it is challenging to provide radar datasets that cover all the possible variations sufficiently. This in turn can lead to failure or reduced accuracy of a classifier. The paper investigates the impact of such dataset deficiencies and demonstrates that data augmentation from radar simulations mitigates the adverse effects on classification accuracy, making the gesture recognition more robust.

8210: Association of Camera and Radar Detections Using Neural Networks
Konstantinos Fatseas{2}, Marco Bekooij{1}
{1}NXP Semiconductors, Netherlands; {2}Univesity of Twente, Netherlands
Automotive radar and camera fusion relies on linear point transformations from one sensor's coordinate system to the other. However, these transformations cannot handle non- linear dynamics and are susceptible to sensor noise. Furthermore, they operate on a point-to-point basis, so it is impossible to capture the characteristics of an object as a whole. This paper introduces a method that performs detection-to-detection association by projecting heterogeneous object features from the two sensors into a common high-dimensional space. We associate 2D bounding boxes and radar detections based on the Euclidean distance between their projections. Our method utilizes deep neural networks to transform feature vectors instead of single points. Therefore, we can leverage real-world data to learn non- linear dynamics and utilize several features to provide a better description for each object. We evaluate our method against a traditional rule-based method, showing that it improves the accuracy of the association algorithm and it is more robust in complex scenarios with multiple objects.

8326: Histogram-Based Deep Learning for Automotive Radar
Maxim Tatarchenko, Kilian Rambach
Bosch Center for Artificial Intelligence, Germany
There are various automotive applications that rely on correctly interpreting point cloud data recorded with radar sensors. We present a deep learning approach for histogram-based processing of such point clouds. Compared to existing methods, the design of our approach is extremely simple: it boils down to computing a point cloud histogram and passing it through a multi-layer perceptron. Our approach outperforms state-of-the-art approaches on the task of automotive radar object type classification. It is also robust to noise that often corrupts radar measurements, and can can deal with missing features of single radar reflections. Finally, the design of our approach makes it more interpretable than existing methods, allowing insightful analysis of its decisions.

8383: Time-Sensitive and Distance-Tolerant Deep Learning-Based Vehicle Detection Using High-Resolution Radar Bird's-Eye-View Images
Ruxin Zheng{2}, Shunqiao Sun{2}, Hongshan Liu{2}, Teresa Wu{1}
{1}Arizona State University, United States; {2}University of Alabama, United States
High-resolution radar bird's-eye-view (BEV) obtained from radar range-azimuth spectra through a polar-to-Cartesian coordinate transform contains targets' geometric information that can be learned by deep neural networks for object detection. Compared to radar point clouds, there is no information loss in radar BEV. Unlike RGB images, radar BEVs are single-channel grayscale images with unique characteristics such as inconsistent resolution and SNR. Therefore, directly implementing an image-based object detection network is not an optimal solution for object detection using radar BEV. We propose a Temporal-fusion, Distance tolerant single stage object detection Network, termed as, TDRadarNet, to robustly detect vehicles up to 100 meters under various driving scenarios. DRadarNet leverages historical radar frames to exploit temporal features and separates far and near fields to address inconsistent resolution in radar frames. With qualitative and quantitative results, we show that TDRadarNet achieves 68.9% in precision and 66.8% in recall, and 67.8% in F1-score, which outperforms the state-of-the-art image-based object detection networks by 10.6%, 17.1%, and 14.1%.

8396: Complex SincNet for More Interpretable Radar Based Activity Recognition
Sabyasachi Biswas{1}, Cemre Omer Ayna{1}, Sevgi Zubeyde Gurbuz{2}, Ali C. Gurbuz{1}
{1}Mississippi State University, United States; {2}University of Alabama, United States
Most of the current radio frequency activity classification techniques employ a two-stage process. First, generating the micro-Doppler spectrograms or range-Doppler videos. Then, use this with machine learning (ML) techniques. In this paper, we propose a more interpretable complex-valued CNN to directly classify human activities from the complex-valued raw radar data. The 1D slow-time radar data is used as input, and the complex sinc function is used as first layer of the proposed

model. For verification, an ASL dataset consisting of 15 activity classes is selected. Enhanced results are observed compared to standard CNN models applied on the Micro-Doppler spectrogram images.

8430: Scanning Radar Scene Reconstruction with Deep Unfolded ISTA Neural Network

Juezhu Lai, Ding Yuan, Jifang Pei, Deqing Mao, Yin Zhang, Xingyu Tuo, Yulin Huang
University of Electronic Science and Technology of China, China

This paper proposes a new learning-based approach, an improved ISTA-based deep unfolding network, to reconstruct the scene information from the scanning radar echoes. Different from the traditional analysis-based method, we established the deep unfolded scene reconstruction network based on the structure of ISTA. It can learn the optimal network parameters through the input radar data, which avoids the manual selection of parameters in the traditional method.Besides, we apply a loss function to ensure the effectiveness of the sparse transformation, so that the method can recover target information from scanning radar echoes in various complex scenes.

8382: AI-Based Human Detection and Localization in Heavy Smoke Using Radar and IR Camera

Hovannes Kulhandjian{1}, Alexander Davis{1}, Lancelot Leong{1}, Michael Bendot{1}, Michel Kulhandjian{2}
{1}California State University, Fresno, United States; {2}Rice University, United States

One of the main challenges that currently firefighters are facing in search and rescue operations is battling the heavy smoke inside a space that needs to be searched for people and animals. In this work, we develop an integrated system composed of two unique sensing mechanisms that are capable of real-time detection and localization of humans and animals in deep smoke with the intention to improve the situational awareness of firefighters on the scene. We make use of data from a micro-Doppler sensor and an infrared camera and train a deep convolutional neural network (DCNN) algorithm to localize a human in dense smoke in real time. Experimental results reveal that the proposed system can detect a human in heavy smoke with an average of 98% accuracy.

14:50 – 16:20
Classification
Poster Session
Room: CONF RMS 1-4
Session Chairs: Chalise Batu and Daniel Rabideau

8201: Semi-Supervised Active Learning for Radar Based Object Classification Using Track Consistency

Johannes Benz, Christian Weiss, Axel Acosta Aponte, Gor Hakobyan
Robert Bosch GmbH, Germany

The development of machine learning (ML) models requires large amounts of labeled data. For real world, safety critical automotive applications such as radar based perception, the dataset must contain various and rare corner cases. The straightforward approach of measuring and manually labeling large amounts of data to capture such corner cases is often infeasible or impractical. Thus, approaches for efficiently selecting and labeling the relevant data are essential for ML-based radar applications. In this paper, we propose a method for semi-supervised learning (SSL) for radar object type classification. We use the track consistency of tracked radar objects as a constraint to generate high-quality labels for the vast portions of the unlabeled dataset. We extend the proposed SSL approach with active learning that considers the object relevance, such that the most relevant data with the least accurate auto-labels are selected for human labeling. We show that the proposed approach achieves a saving of more than 80% of human labeling costs based on auto-labeling and relevant data selection.

8157: Transductive Prototypical Attention Network for Few-Shot SAR Target Recognition

Xuelian Yu, Sen Liu, Haohao Ren, Lin Zou, Yun Zhou, Xuegang Wang
University of Electronic Science and Technology of China, China

This paper proposes a novel few-shot SAR method named Transductive Prototypical Attention Network. At first, a region awareness-based feature extractor is designed to focus on regions of interest, laying the foundation for few-shot SAR target recognition. Secondly, a cross-feature spatial attention module is proposed to improve the discriminativeness of features. Finally, a transductive prototype reasoning algorithm that differs from inductive learning enables more robust inference, iteratively updates the class prototype with test samples. Experimental results on MSTAR dataset demonstrate the robustness and superiority of our proposed method for few-shot SAR target recognition.

8182: Group-Wise Feature Fusion R-CNN for Dual-Polarization SAR Ship Detection

Xiaowo Xu, Xiaoling Zhang, Tianwen Zhang, Jun Shi, Tianjiao Zeng, Zikang Shao
University of Electronic Science and Technology of China, China

Ship detection in synthetic aperture radar (SAR) images is a hot pot in the remote sensing (RS) field. However, most existing deep learning (DL)-based methods only focus on the single-polarization SAR ship detection without leveraging the rich dual-polarization SAR features, which poses a huge obstacle to the further model performance improvement. One problem for solution is how to fully excavate polarization characteristics using a convolution neural network (CNN). To address the above problem, we propose a novel group-wise feature fusion R-CNN (GWFF R-CNN) for dual-polarization SAR ship detection. Different from raw Faster R-CNN, GWFF R-CNN embeds a group-wise feature fusion module (GWFF module) into the subnetwork of Faster R-CNN, which enables group-wise feature fusion between polarization features and multi-scale ship features. Finally, the experiments on the dual-polarization SAR ship detection dataset (DSSDD) demonstrate that GWFF R-CNN can yield a ~4.1 F1 improvement and a ~2.9 average precision (AP) improvement, compared with Faster R-CNN.

8296: An Optical Image-Aided Approach for Zero-Shot SAR Image Scene Classification

Yanjing Ma, Jifang Pei, Xing Zhang, Weibo Huo, Yin Zhang, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

Most existing SAR image scene classification methods cannot effectively identify the scene categories without training samples, which seriously affects the classification performance of these unseen categories. A framework of optical image-aided zero-shot SAR image scene classification is established, including feature extraction, joint feature compatibility and calibration classification module. Specifically, the feature extraction module is employed to sufficiently extract features from optical and SAR images. The joint feature compatibility module can maximize the compatibility between extracted features. Based on the compatibility score, the calibration classification module combines superposition calibration and one-versus-all classifier, and finally achieves good performance in classification for zero-shot SAR scene. Experimental results based on multi-modal remote sensing scene classification (MRSSC) dataset have shown the superiority of the proposed method on zero-shot SAR image scene classification.

8356: Multi-Scale Dense Networks for Ship Classification Using Dual-Polarization SAR Images

Jinglu He{1}, Wenlong Chang{1}, Fuping Wang{1}, Ying Liu{1}, Chenglu Sun{2}, Yinghua Li{1}
{1}Xi'an University of Posts and Telecommunications, China; {2}Xi'an Xiangteng Microelectronics Technology Co., LTD, China

The general convolutional neural networks (CNNs) for ship classification using SAR images cannot fully explore the SAR ship feature representations, which limits its potentials for better classification performance. This paper proposes a novel multi-scale framework for the CNNs to further improve the ship classification performance with dual-polarization SAR images. Particularly, the deep features with different spatial scales are fused to acquire multi-scale global representations, which are integrated by the group bilinear pooling and will further be processed by multiple classifiers. Extensive experiments demonstrate the robustness and superior performance of the proposed method on the OpenSARShip datasets.

8374: LSTM Framework for Classification of Radar and Communications Signals

Victoria Clerico{2}, Jorge González-López{1}, Gady Agam{1}, Jesús Grajal{2}
{1}Illinois Institute of Technology, United States; {2}Information Processing and Telecommunications Center, Universidad Politécnica de Madrid, Spain

While radar and communications signal classification are usually treated separately, they share similar characteristics, and the methods applied in one domain can be potentially applied in the other. We propose a simple and unified scheme for the classification of radar and communication signals using Long Short-Term Memory (LSTM) neural networks. This proposal provides an improvement of the state of the art on radar signals where LSTM models are starting to be applied within schemes of higher complexity. To date, there is no standard public dataset for radar signals. Therefore, the data used in our systematic evaluations will be made available publicly and will facilitate a standard comparison between methods.

8400: Classification of Traffic Signaling Motion in Automotive Applications Using FMCW Radar

Sabyasachi Biswas, Benjamin Bartlett, John Ball, Ali C. Gurbuz
Mississippi State University, United States

ADAS includes sensors such as Radar, Lidar, or Camera to make vehicles aware of their surroundings. These ADAS

systems are presented to a wide variety of situations in traffic, such as upcoming collisions, lane changes, intersections, sudden changes in speed, and other common instances of driving errors. In these circumstances, it is much more common for a person to be tasked with directing vehicles via gesturing. In this study, we present a new dataset collected of traffic signaling motions using mmWave radar, camera, Lidar and motion-capture system. The dataset is based on those utilized in the American traffic system.

8421: SAR ATR Under Limited Training Data via MobileNetV3

Chenwei Wang, Siyi Luo, Lin Liu, Yin Zhang, Jifang Pei, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

In recent years, deep learning has been widely used to solve bottleneck problems of synthetic aperture radar (SAR) automatic target recognition (ATR). However, most current methods rely heavily on large training samples and have many parameters which lead to failure under limited training samples. Therefore, we try to use a lightweight network for SAR ATR under limited training samples, which has fewer parameters, less computational effort, and shorter inference time than normal networks. Through experiments and comparisons under the moving and stationary target acquisition and recognition (MSTAR) dataset, the lightweight network is validated to have excellent recognition performance on limited training samples and be very computationally small.

8148: Reinforcement Learning Approach for a Cognitive Framework for Classification

Kilian Barth, Stefan Brüggenwirth
Fraunhofer Fraunhofer Institute for High Frequency Physics and Radar FHR, Germany

In this work, we introduce a reinforcement learning approach for a cognitive framework for classification. It is designed for a system with a perception-action cycle based on partially observable Markov decision processes. This framework utilises a sequence of different waveforms to identify a target. The system is devised for an environment, which in practise will differ from the environment it will be employed to. As a consequence, the classification performance is reduced. At this point, the learning approach leverages the knowledge such that the system can learn from experience and improve its performance. The framework is tested on a scenario with electromagnetic models, showing a noticeable improvement in comparison to the framework without learning capability.

8255: Extended Target Reconstruction of Airborne Real Aperture Array Radar by Adaptive Hybrid Regularization

Deqing Mao, Xingyu Tuo, Jianan Yan, Yulin Huang, Yongchao Zhang, Haiguang Yang, Jianyu Yang
University of Electronic Science and Technology of China, China

Hybrid regularization methods can be applied in airborne real aperture array radar (RAAR) to improve its angular resolution by combining the advantages of different regularization norms. However, the scale information of the extended targets cannot be accurately obtained because its reconstructed performance is related to the selected regularization parameters. In this paper, to accurately observe the scale information of extended targets, an adaptive hybrid regularization (AHR) method is proposed by a data-adaptive reweighted strategy. First, the generalized sparse (GS) regularization norm and the generalized total variation (GTV) regularization norm are combined to enhance the angular resolution and scale information of extended targets simultaneously. Second, a data-adaptive reweighted strategy is proposed to reduce the number of selected regularization parameters. Finally, simulations are carried out to verify the reconstructed performance of the proposed method. Based on the proposed AHR method, the scale information of the extended targets can be accurately obtained by adaptively selecting proper regularization parameters.

8082: TripleM:Multidimensional Feature Separation of Multiple Gestures in Multi-Person Scenarios Based on FMCW Radar

Han Jiang, Hongyang An, Haoyu Li, Junjie Wu, Zhongyu Li, Jianyu Yang
University of Electronic Science and Technology of China, China

Remarkable process has been made in hand gesture recognition based on radar sensors. However, existing research are mostly conducted for only one hand gesture in the sensor's field of view, leading to limitations in some practical scenarios when multiple gestures exist simultaneously.In this paper, we propose a method to estimate the number of multiple gestures precisely in multi-persons scenarios firstly, then separates the mixed blind source signals to acquire each individual motion signal. Finally, we extract multidimensional features for each separated gesture. Extensive experiments are carried out based on commercial frequency modulated continuous wave (FMCW) single-input multi-output (SIMO) millimeter-wave

radar system to verified the effectiveness of this approach.

8093: Achieving Efficient and Realistic Full-Radar Simulations and Automatic Data Annotation by Exploiting Ray Meta Data from a Radar Ray Tracing Simulator

Christian Schüßler, Marcel Hoffmann, Vanessa Wirth, Björn Eskofier, Tim Weyrich, Marc Stamminger, Martin Vossiek
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Ray meta data is collected during the simulation process to achieve the following: Efficient simulation of full radar cubes (Angle/MIMO, Doppler, Range) using only a single ray tracing run for one antenna pair and for one single chirp. Further, ray meta data is used to decompose the signal into its parts. This makes direct labeling of multi-path or specific object arts possible. Simulations are compared with real measurements and some example applications are demonstrated.

14:50 – 16:20
Machine Learning for SAR ATR
Poster Session
Room: CONF RMS 1-4
Session Chairs: Julie Jackson and Lars Ulander

8079: Deep Open World SAR Target Recognition with Regular Polytope Networks

Brent Thomson{2}, Matthew Scherreik{1}
{1}Air Force Research Laboratory, United States; {2}Brigham Young University, United States

Traditional synthetic aperture radar (SAR) automatic target recognition (ATR) algorithms assume that all target labels are available during training, and that the number of targets does not change. Open world recognition (OWR) addresses these limitations by rejecting unknown targets at test time and later adding them to the class library. OWR models have been proposed for generic visual tasks, but SAR ATR has been largely unexplored. We employ a regular polytope network as a deep feature extractor and study its effectiveness for open world SAR ATR. We present initial results to motivate future work on deep open world SAR ATR.

8087: Incremental Learning in Synthetic Aperture Radar Images Using Openmax Algorithm

Amir Hosein Oveis{2}, Elisa Giusti{1}, Selenia Ghio{1}, Giulio Meucci{2}, Marco Martorella{2}
{1}CNIT, RaSS National Laboratory, Italy; {2}Università di Pisa, CNIT, RaSS National Laboratory, Italy

In real-time real-world scenarios, an automatic target recognition (ATR) system may encounter new samples from unseen classes continually. Retraining a neural network by using the new and all the previous samples, whenever new data is received, imposes a considerable computational cost. Instead, incremental learning aims at learning new knowledge while preserving previous knowledge with an emphasis on computational time and storage resources. In this paper, we employ the Openmax method, which has been initially introduced for open set recognition in optical images, to assist a convolutional neural network (CNN) in incremental learning scenarios with SAR images. The new set for fine-tuning the network is constituted of the unknown samples recognized by the Openmax method together with exemplars from the old classes. Our real data analysis to validate the proposed method is performed on radar images of man-made targets from the well-known Moving and Stationary Target Acquisition and Recognition (MSTAR) dataset.

8149: A Tailored cGAN SAR Synthetic Data Augmentation Method for ATR Application

Gustavo F. Araujo{1}, Renato Machado{1}, Mats I. Pettersson{2}
{1}Aeronautics Institute of Technology, Brazil; {2}Blekinge Institute of Technology, Sweden

This article proposes a method to simulate Synthetic Aperture Radar (SAR) images, so that targets belonging to classes of interest appear on image chips with specific aspect angles, i.e., depression and azimuth angles. Images synthesized by Electromagnetic Computing (EMC) are used to train a Conditional Generative Adversarial Network (cGAN). Two synthetic image chips of the same class and depression angle, but separated by two degrees in azimuth, are used as input to the cGAN. The cGAN predicts the image of the same class and depression angle whose azimuth angle correspond to the bisector of the two input chips. An experiment using the SAMPLE dataset was performed to evaluate the quality of the image prediction. Running through a total of 100 training epochs, the cGAN converges reaching the minimum Mean Squared Error (MSE) after 74 epochs. The results demonstrate that the proposed method is promising for applications in Automatic Target Recognition (ATR).

8280: SAR Ship Detection Based on an Improved CNN with IoU-FL and Attention Mechanism

Zhenghua Ze, Gang Li, Jianghong Han, Xueqian Wang, Riti Waqi
Tsinghua University, China

In this paper, we propose an improved convolutional neural network (CNN) based on a novel intersection over union (IoU)-embedded-focal loss (IoU-FL) and a convolutional block attention module (CBAM). During the regression process, a novel IoU-embedded-focal loss (IoU-FL) is proposed to mitigate the imbalance problem in bounding box regression (BBR). Moreover, three CBAM modules are embedded in the backbone of the network to refine different level semantic feature maps and suppress unnecessary background ones for multi-scale targets detection.

8331: HA-SARSD: An Effective SAR Ship Detector via the Hybrid Attention Residual Module

Nanjing Yu{1}, Haohao Ren{2}, Tianmin Deng{1}, Xiaobiao Fan{1}
{1}Chongqing Jiaotong University, China; {2}University of Electronic Science and Technology of China, China

The all-day and all-weather characteristics of the synthetic aperture radar (SAR) images make them be widely applied in the maritime monitoring field. Recently, ship detection algorithms based on the convolution neural networks (CNNs) are hot research topics. However, owing to the indistinctive ship features and complex backgrounds, it is difficult to detect ships precisely via SAR images. Moreover, it is challenging to balance the detection effect and the inference speed. Therefore, a novel hybrid attention-synthetic aperture radar ships detector (HA-SARSD) based on the You Only Look Once version 5 (YOLOv5) algorithm is proposed in this paper. The local hybrid attention residual module (LHARM) is designed to optimize the feature extraction ability. Owing to the abundant channels in the deep-level feature, LHARM is developed in the fifth layer of HA-SARSD. Experimental results on Large-Scale SAR Ship Detection Dataset-v1.0 (LS-SSDD-v1.0) and SSDD datasets show that HA-SARSD optimizes the SAR ship feature extraction ability and obtains the balance of detection effect and speed.

8360: Benchmarking Convolutional Neural Network Backbones for Target Classification in SAR

Denisa Qosja, Simon Wagner, Stefan Brüggenwirth
Fraunhofer Fraunhofer Institute for High Frequency Physics and Radar FHR, Germany

With the recent developments in the field of deep learning, various neural networks have been proposed to increase the detection accuracy of targets in radar data and beyond. A prominent network, named ConvNext has achieved state-of-the-art results in computer vision. In this paper, its performance on SAR is aimed to be evaluated and compared to its predecessors over three distinct SAR datasets. A thorough comparison shows the superiority of ConvNext in the target recognition task in SAR. Furthermore, several augmentations are exploited to enhance the size of training set and evaluated to show whether they fit in the radar domain.

14:50 – 16:20
Machine Learning for SAR ATR
Poster Session
Room: CONF RMS 1-4
Session Chairs: Julie Jackson and Lars Ulander

16:20 – 18:00
Industry Panel
Room: SALON E (C-E)

Jeffrey Herd
Lincoln Laboratory, Massachusetts Institute of Technology

Haydn Nelson
National Instruments

Bill Kardine
Rohde and Schwarz

Mike Pochettino
Northrup Grumman

18:00 – 19:00
Welcome Reception
Room: SALONS A&B (ABF)

19:00 – 22:00
RSP Panel Dinner
Closed Meeting
Room: Salon J

7:30 – 9:10
Integrated Sensing & Communication 1
Room: SALON D (CD)
Session Chairs: Christos Masouros and Taneli Riihonen

8110: On the Impact of Phase Noise on Monostatic Sensing in OFDM ISAC Systems

Musa Furkan Keskin{2}, Carina Marcus{3}, Olof Eriksson{3}, Henk Wymeersch{2}, Visa Koivunen{1}
{1}Aalto University, Finland; {2}Chalmers University of Technology, Sweden; {3}Veoneer Sweden AB, Sweden

Phase noise (PN) can become a major bottleneck for integrated sensing and communications (ISAC) systems towards 6G wireless networks. In this paper, we consider an OFDM ISAC system with oscillator imperfections and investigate the impact of PN on monostatic sensing performance by performing a misspecified Cramer-Rao bound (MCRB) analysis. Simulations are carried out under a wide variety of operating conditions with regard to SNR, oscillator type (free-running oscillators (FROs) and phase-locked loops (PLLs)), 3-dB bandwidth of the oscillator spectrum, PLL loop bandwidth and target range. The results provide valuable insights on when PN leads to a significant degradation in range and/or velocity accuracy, establishing important guidelines for hardware and algorithm design in 6G ISAC systems.

8194: Full-Duplex Analog Beamforming Design for mm-Wave Integrated Sensing and Communication

Ao Liu{1}, Taneli Riihonen{2}, Weixing Sheng{1}
{1}Nanjing University of Science and Technology, China; {2}Tampere University, Finland

This paper considers the beamforming design for integrated sensing and communication (ISAC) application at millimeter-wave (mm-wave) analog array system. Particularly, addressed to the ISAC challenges stemming from the full-duplex operation, the proposed method suppresses the self-interference (SI) and enables co-existence of multiple simultaneous beams for both communications and sensing purposes. The proposed analog beamformers maximize the beamforming gain at the sensing direction while maintaining beamforming gain at the communications direction(s), as well as mitigating the potential reflection from the environment by optimizing the low sidelobe combined radar pattern. Simulation results demonstrate the effectiveness of the proposed method in terms of gain, sidelobe level, SI cancellation and sensing performance.

8322: OFDM Based WiFi Passive Sensing: A Reference-Free Non-Coherent Approach

Francesca Filippini{1}, Marco Di Seglio{1}, Carlo Bongioanni{1}, Paul V. Brennan{2}, Fabiola Colone{1}
{1}Università degli Studi di Roma La Sapienza, Italy; {2}University College London, United Kingdom

WiFi based passive sensing is attracting considerable interest in the scientific community for both research and commercial purposes. In this work, we aim at taking a step forward in an endeavor to achieve good sensing capabilities employing compact, low-cost, and stand-alone WiFi sensors. To this end, we resort to a reference-free non-coherent signal processing scheme, where the presence of a moving target echo is sought by detecting the amplitude modulation that it produces on the direct signal transmitted from the WiFi access point. We first validate the proposed strategy against simulated data, identifying advantages and limitations. Then, we apply the conceived solution on experimental data collected in a small outdoor area with the purpose of detecting a small cooperative drone.

8378: Compensating Power Amplifier Distortions on Radar Signals via Waveform Design

Ehsan Raei, Mohammad Alaee-Kerahroodi, Mysore R. Bhavani Shankar, Bjorn Ottersten
Université du Luxembourg, Luxembourg

This paper aims to study the distortion effect of Power Amplifiers (PAs) on radar waveforms in terms of Integrated Sidelobe Level in Single Input and Single Output (SISO) radar systems. To this end, we consider Memory Polynomial (MP) model as behavior of the PA which considers both non-linearity and memory distortions. Then, we consider minimizing the auto-correlation of the PA output in the baseband as a design metric for compensating the distortion effect of the PA. In this regard, we proposed an algorithm based on Coordinate Descent (CD) method to design an M-ary Phase Shift Keying (MPSK) waveform, which is a discrete phase waveform. Finally, in the numerical results, we evaluate the performance of the proposed method and compare it with Digital Predistortion (DPD) method as a conventional approach for compensating the distortion effect of PA.

8399: Radar-Communications Waveform Co-Design Over-the-Air Using the WISCANet SDR Network

Shammi A. Doly, Alex R. Chiriyath, Andrew Herschfelt, Jacob Holtom, Shankarachary Ragi, Daniel W. Bliss
Arizona State University, United States

Many waveform co-design studies demonstrate theoretical performance enhancements but only sometimes provide a clear path toward implementing a tractable solution. To address this limitation, we developed a waveform co-design technique to maximize the joint radar-communications network's joint performance and a computationally tractable method for optimizing it. This waveform co-design technique is based on the theory of \textit{partially-observable Markov decision processes} (POMDPs), which we solve using the approximate dynamic programming approach called \textit{nominal belief-state optimization} (NBO). Using our WISCANet over-the-air experimental radio testbed, we implement a simple radar-communications system and demonstrate this waveform design and optimization technique in pseudo-real-time, over-the-air demonstrations. We further extend the problem by proposing a real-time waveform optimization solution using the Kalman Filter in a dynamic environment.

7:30 – 9:10
Detection & Estimation 1
Room: SALON E
Session Chairs: Fulvio Gini and Piotr Samczynski

8045: Particular DDM Codes for Online Phase Shifter Calibration in Automotive MIMO Radar

Mayeul Jeannin{1}, Oliver Lang{2}, Dian Tresna Nugraha{3}, Farhan Bin Khalid{1}, André Roger{1}, Mario Huemer{2}
{1}Infineon Technologies AG, Germany; {2}Johannes Kepler University, Austria; {3}PT Infineon Technologies Batam, Indonesia

This paper presents a new subset of DDM codes for MIMO FMCW slow-time phase coding. As opposed to classical DDM variations targeting the problem of Tx ambiguity, this new DDM subset enables the estimation of a particular phase shifter imbalance directly from the operational data without interrupting radar detections. Most importantly, the estimation is performed online with multiple Tx transmitting simultaneously. This paper is part of a broader study on the possibility of digitalizing part of the calibration circuitry of an automotive radar device.

8119: Multistatic Radar Data Fusion for Detection with Reduced Transmit Power Consumption

Dilan Dhulashia, Matthew Ritchie
University College London, United Kingdom

This paper presents a comparison of the detection performance of two multistatic radar detection methods, each with a different communications capacity. The methods are tested over different scenarios and the power requirements to obtain similar detection performance to a monostatic radar are analysed. The scenarios simulated are in two-dimensional space and the multistatic system considered is comprised of a single transmit and three distributed receive nodes. It is shown data fusion at a lower level of abstraction can lead to better detection performance in multistatic systems and power resource savings relative to a monostatic system are given.

8170: Non-Cooperative Distributed Detection via Federated Sensor Networks

Domenico Ciuonzo{2}, Apoorva Chawla{1}, Pierluigi Salvo Rossi{1}
{1}Norwegian University of Science and Technology, Norway; {2}Università degli Studi di Napoli Federico II, Italy

In this work we tackle distributed detection of a non-cooperative target by federating two wireless sensor networks. The objective is to capitalize the diversity achieved on both sensing and reporting phases. When the target is present, sensors observe an unknown signal with attenuation depending on the (unknown) distance between the sensor and the target position, embedded in symmetric and unimodal noise. The fusion center receives quantized sensor observations through error-prone binary symmetric channels and is in charge of performing a more-accurate global decision. The resulting problem is a two-sided parameter testing with nuisance parameters (i.e., the target position) present only under the alternative hypothesis. After introducing the generalized likelihood ratio test for the problem, we develop a novel fusion rule corresponding to a generalized Rao test, to reduce the computational complexity. The aforementioned rules are compared in terms of performance and computational complexity, showing the appeal of the latter and the benefit of federation assessed.

8202: Spectrogram Filtering and Ridge Graph Fitting Based Time Frequency Analysis
Bingcheng Li
Lockheed Martin, United States
Since a frequency modulation signal can be approximated by polynomial chirplet in a local time window, polynomial chirplet transform has been applied to acoustic signal processing, radar Doppler analysis and gravity wave analysis. However, the direct implementation of a polynomial chirplet transform has extremely high computational cost due to its high dimensional polynomial chirplet parameter space. In this paper, we propose a spectrogram time-frequency filtering and ridge graph polynomial fitting approach to estimate polynomial chirplet parameters for the time-frequency analysis. In the proposed method, a low dimensional spectrogram ridge graph fitting is developed to extract high dimensional polynomial chirplet parameters for the computational cost reduction. Furthermore, the spectrogram filtering in the time-frequency space is proposed to improve the reliability of spectrogram ridge extraction, and a ridge interpolation technique is recommended to improve the accuracy of ridge extraction. Test results show that the proposed method has a low computational cost, high reliability and accuracy for extracting polynomial chirplet parameters.

8258: Automated Impulse Response Detection and Analysis in Synthetic Aperture Radar Imagery
Aimee Shore{2}, John Summerfield{2}, Roger West{2}, Brandon Conder{2}, Frederick Koehler{1}, Wade Schwartzkopf{1}
{1}National Geospatial-Intelligence Agency, United States; {2}Sandia National Laboratories, United States
We present a framework for the automated detection and analysis of impulse responses (IPRs) in synthetic aperture radar (SAR) images. Many elements of the state-of-health of SAR images can be derived from the analysis of IPRs and help to determine if the sensor met its as-tasked requirements. The first step of our framework is an automated method to detect candidate IPRs. Metrics derived from the candidate IPRs are compared to the same metrics computed from ideal IPRs constructed from image metadata. A classification stage determines if the sensor met its tasking requirements and reports a confidence score.

7:30 – 9:10
SAR Automatic Target Recognition
Room: CONF RMS 1-4
Session Chairs: Matthew Ritchie and Willie Nell

8044: SAR-ATR Using EO-Based Deep Networks
Chris Kreucher
KBR Government Solutions, United States
In recent years there has been widespread adoption of Deep Convolutional Neural Networks to electo-optical (EO) image classification problems, most famously using the ImageNet database to form challenge problems. The Synthetic Aperture Radar (SAR) classification problem, typically referred to as Automatic Target Recognition (ATR), has received less attention. A natural question arises as to how well the state-of-the-art EO networks on SAR ATR problems. This paper evaluates a number of well-known EO architectures (including DenseNet, ResNet, Inception and Xception) on a standard SAR ATR problem and identifies the factors that drive performance.

8128: Deep Learning Based Synthetic Aperture Imaging in the Presence of Phase Errors via Decoding Priors
Samia Kazemi, Bariscan Yonel, Birsen Yazici
Rensselaer Polytechnic Institute, United States
We designed a deep learning (DL) based method for synthetic aperture imaging in the presence of phase errors. Random variations in transmission medium resulting from unforeseen environmental changes, fluctuations in sensor locations, and multiple scattering in the background medium often amount to uncertainties in the assumed data models. Our imaging network incorporates DL in three steps: first, we implement a deep network for pre-processing erroneous measurements; second, we implement DL-based decoding prior by recovering encoded version of the reflectivity vector to reduce sample complexity; finally, we consider a fixed step implementation of an iterative algorithm by using the unrolling technique.

8147: Adaptive Target Enhancer: Bridging the Gap Between Synthetic and Measured SAR Images for Automatic Target Recognition
Alexandre Campos{3}, Ricardo Molin Jr.{3}, Lucas Ramos{1}, Renato Machado{1}, Viet Thuy Vu{2}, Mats I. Pettersson{2}
{1}Aeronautics Institute of Technology, Brazil; {2}Blekinge Institute of Technology, Sweden; {3}German Aerospace Center, Germany

Automatic target recognition (ATR) algorithms have been successfully used for vehicle classification in synthetic aperture radar (SAR) images over the past few decades. For this application, however, the scarcity of labeled data is often a limiting factor for supervised approaches. While the advent of computer-simulated images may result in additional data for ATR, there is still a substantial gap between synthetic and measured images. In this paper, we propose the so-called adaptive target enhancer (ATE), a tool designed to automatically delimit and weight the region of an image that contains or is affected by the presence of a target. Results for the publicly released Synthetic and Measured Paired and Labeled Experiment (SAMPLE) dataset show that, by defining regions of interest and suppressing the background, we can increase the classification accuracy from 68% to 84% while only using artificially generated images for training.

8308: Deep-Layer Training of CNN for SAR with Two-Stage Data Augmentation

Alexander Denton, David Garren
Naval Postgraduate School, United States

A novel two-stage data augmentation technique expands the training capacity of the small synthetic SAMPLE dataset through the mechanism of deep-layer training. Kernel operations remove high-level information and effectively bypass initial convolution layers. Overfitting is reduced by changing the background texture using threshold segmentation and alpha blending. Combined, these two augmentations improve a CNN's effectiveness at classifying measured data. Transfer learning and data augmentation scenarios are tested against the measured SAMPLE dataset using the five-layer AConvNet CNN. Test accuracy and training activity provide qualitative evidence of deep-layer training and improved training capacity with synthetic SAR imagery.

8332: Self-Supervised Contrastive Learning on Cross-Augmented Samples for SAR Target Recognition

Xiaoyu Liu, Chenwei Wang, Jifang Pei, Weibo Huo, Yin Zhang, Yulin Huang, Zhichao Sun
University of Electronic Science and Technology of China, China

Self-supervised contrastive learning is prospective for advancing SAR target recognition because it relies only on the data inherently without label information. Therefore, in this paper, we propose a self-supervised contrastive learning method via learning feature representation of cross-augmented samples for SAR target recognition to achieve better clustering of features of the same target, benefitting the subsequent target recognition. Experiments are conducted on the moving and stationary target acquisition and recognition (MSTAR) benchmark dataset, and the experimental results indicate that the proposed method can effectively extract target features and achieve promising recognition performance.

7:30 – 9:10
Human Monitoring
Room: CONF RMS 20-21
Session Chairs: Francesco Fioranelli and Marina Gashinova

8235: Evaluation of Different Radar Placements for Food Intake Monitoring Using Deep Learning

Chunzhuo Wang{2}, T. Sunil Kumar{2}, Walter De Raedt{1}, Guido Camps{3}, Hans Hallez{2}, Bart Vanrumste{2}
{1}imec, Belgium; {2}Katholieke Universiteit Leuven, Belgium; {3}Wageningen University and Research, Netherlands

Automated food intake monitoring has drawn significant attention due to its potential applications in the healthcare domain. Plenty of research, including wrist-worn imu-based and camera-based approaches, have emerged to detect food intake activity passively and objectively. Recently, researchers explored radar for food intake monitoring because of its contactless and privacy-preserving characteristics. In this study, we deploy the Frequency Modulated Continuous Wave (FMCW) radar in three different positions to investigate the performance of each position in automated eating gesture detection. The three positions are front, side, and overhead. Fifteen participants are recruited to have three meals (45 meals, 641 min in total), while the radar is deployed in different positions in each meal. A 3D Temporal Convolutional Network (3D-TCN) is used to process the range-doppler cube (RD Cube) of each dataset. The Leave-One-Subject- Out (LOSO) validation method shows that putting radar in the front position obtains the best performance with a segmental F1-score of 0.786 and 0.825 for eating and drinking gestures, respectively.

8011: Human Activity Recognition Based on 4-Domain Radar Deep Transfer Learning

Ahmad Alkasimi{2}, Anh-Vu Pham{2}, Christopher Gardner{1}, Brad Funsten{1}
{1}Lawrence Livermore National Laboratory, United States; {2}University of California, Davis, United States

We demonstrate the improvement of the radar-based human activity recognition using the combination of four data domains: time-frequency, time-range, range-Doppler and, for the first time, time-angle domain. Six different activities are observed from nine subjects using frequency-modulated continuous-wave millimeter-wave radar. Each domain offers additional information to the classification process. The classification results of four deep convolutional neural networks are then combined using the Joint Probability Mass Function method to achieve a combined classification accuracy of 100%. The proposed system also demonstrates similar performance in recognizing activities from participants not involved in training the network.

8190: Light-Weight Learning Model with Patch Embeddings for Radar-Based Fall Event Classification: A Multi-Domain Decision Fusion Approach

Ankita Dey{1}, Sreeraman Rajan{1}, George Xiao{2}, Jianping Lu{2}
{1}Carleton University, Canada; {2}National Reseach Council of Canada, Canada

Deep learning algorithm like vision transformers for human fall event classification are computationally expensive and unsuitable when training datasets are small. Patch-based learning models such as Multi-Layer Perceptron-Mixer (MLP-Mixer) and Convolutional-Mixer (ConvMixer) have been developed as alternatives to ViT. In this work, the decision outputs of light-weight ConvMixer models with different domain representations of radar returns as inputs are fused for classifying the events in a publicly available dataset as fall or non-fall. The proposed approach utilizes supplementary information present in different domains for enhancing the classification accuracy. Decision fused ConvMixer model shows superior performance over ViT and MLP-Mixer.

8204: mm-Wave Wireless Radar Network for Early Detection of Parkinson’s Disease by Gait Analysis

Ignacio Esteban López-Delgado{1}, Elías Antolinos{1}, Ignacio Sardinero-Meirás{1}, Marcos Gómez-Bracamonte{1}, Julián David Arias-Londoño{1}, Elisa Luque-Buzo{2}, Francisco Grandas{2}, Juan Ignacio Godino-Llorente{1}, Jesús Grajal{1}
{1}Information Processing and Telecommunications Center, Universidad Politécnica de Madrid, Spain; {2}Movement Disorders Unit, Hospital General Universitario Gregorio Marañón, Spain

Anticipating the detection of Parkinson's Disease is critical to delay its effects. This paper presents the design of a radar network for the early-detection of Parkinson's Disease analyzing gait impairments. The preliminary results of the radar network show that gait biometrics, and gait asymmetries linked to Parkinson's Disease can be clearly identified in the micro-Doppler signature.

8403: Ablation Catheter Tracking with Ultrawideband Radar

Seyedmahmoud Mohammadi{2}, Raviraj S. Adve{2}, Ali Tavallaei{1}
{1}Toronto Metropolitan University, Canada; {2}University of Toronto, Canada

High positional accuracy is necessary for successful catheter ablation procedures. Electromagnetic based tracking solutions use magnetic resonance imaging to visualize, detect, track, and navigate the catheter through the procedure. The efficacy of ultrawideband radar for ablation catheter tracking is investigated, due to its low cost and non-contact methodology. Three experiments were designed to test the localization and position tracking of the catheter tip and the detection of catheter pose. Results show that a single sensor can localize and track the position of the catheter with 1cm of spatial accuracy, and an array of sensors can be implemented for pose detection.

9:10 – 9:40
Coffee Break

9:40 – 11:20
Advanced Signal Processing Approaches for Next Generation Automotive Radar
Room: SALON D (CD)
Session Chairs: Sandeep Rao and Shunqiao Sun

8062: Antenna Array Design for Coherent MIMO Radar Networks

Vinzenz Janoudi{2}, Pirmin Schoeder{2}, Timo Grebner{2}, Dominik Schwarz{2}, Christian Waldschmidt{2}, Juergen Dickmann{1}, Nils Appenrodt{1}
{1}Mercedes-Benz Group AG, Germany; {2}Universität Ulm, Germany

High angular resolution provides improved environmental perception and increases the detection quality of extended targets. It is therefore a key requirement towards future radar systems for autonomous driving. The angular resolution of a radar system fundamentally depends on its antenna array aperture size. It is technically difficult and economically challenging to realize a large aperture radar system as a single sensor. Radar networks, consisting of multiple individual radar sensors, mitigate the challenges caused by creating a large aperture radar system. This paper presents a radar network consisting of two individual MIMO radar sensors equipped with L-shaped physical antenna arrays. Furthermore, the paper discusses the performance of the resulting virtual aperture in the context of DoA estimation. Measurements of a bicycle, conducted with a coherently coupled radar network consisting of 768 virtual channels, demonstrate the performance of a high angular resolution radar system.

8080: 3D Radar and Camera Co-Calibration: A Flexible and Accurate Method for Target-Based Extrinsic Calibration

Lei Cheng, Arindam Sengupta, Siyang Cao
University of Arizona, United States

In this paper, we propose a method for extrinsic calibration of 3D radar and camera. This method uses only a single corner reflector as the calibration target, and there are no strict requirements or regulations for the operation. All operations are to place the CR freely in any open space and repeat it many times to obtain enough data for calibration. This makes the method flexible and easy to reproduce. A series of controlled environmental and real-world experiments, including different experimental scenarios and experimental objects, demonstrate the accuracy and robustness of the proposed method.

8214: Automotive Radar Interference Mitigation Using Two-Stage Signal Decomposition Approach

Ashwin Bhobani Baral, Bhaskar Upadhyay, Murat Torlak
University of Texas at Dallas, United States

The mutual interference between automotive radar sensors is inevitable due to their increasing demand in automotive applications. To reliably estimate the target parameters, this interference needs to be detected and mitigated. This paper proposes a two-stage approach for suppressing the mutual interference between frequency modulated continuous wave (FMCW) radars. In the first stage, the signals corresponding to the strong interference components or targets are separated using the singular value decomposition (SVD) technique across the spatial domain. Following this, each separated signal at each receive channel is further decomposed into different frequency components using various mode decomposition techniques such as empirical mode decomposition (EMD), ensemble empirical mode decomposition (EEMD), and variational mode decomposition (VMD) methods. The performance comparison of these different mode decomposition approaches with our proposed idea is presented through a simulation and a real experiment.

8370: Fast Forward-Backward Hankel Matrix Completion for Automotive Radar DOA Estimation Using Sparse Linear Arrays

Shunqiao Sun{2}, Yining Wen{2}, Ryan Wu{1}, Dongyin Ren{1}, Jun Li{1}
{1}NXP Semiconductors, United States; {2}University of Alabama, United States

Automotive multiple-input multiple-output (MIMO) radar with sparse linear arrays is a cost-effective solution to achieve large aperture size with low hardware cost and reduced mutual coupling. The challenges associated with automotive MIMO sparse linear arrays are the high sidelobes, which might result in angular detection errors. This paper presents a fast forward-backward Hankel matrix completion and matrix pencil method for joint array interpolation and super-resolution single-snapshot angle finding by exploiting the structure of Hankel matrix. The novelty of the proposed approach lies in two parts. It not only saves the computational cost of singular value decomposition (SVD) in each iteration of the matrix completion, but also increases the degrees of freedom to construct a low-rank matrix with larger dimensions using the same number antenna elements, as a result of which, more targets can be completed and estimated with better accuracy.

Numerical results demonstrate the effectiveness and efficiency of the proposed method.

8300: A Fast 2D Super-Resolution Imaging Method via Bayesian Compressive Sensing for mmWave Automotive Radar

Yanqin Xu{2}, Yuan Song{1}, Shunjun Wei{2}, Xiaoling Zhang{2}, Lanwei Guo{1}, Xiaowo Xu{2}
{1}Sichuan Province Engineering Research Center for Broadband Microwave Circuit High Density Integratio, China; {2}University of Electronic Science and Technology of China, China

To address poor imaging performance in single-snapshot and high computational complexity, we propose a fast 2D super-resolution imaging method for real-time and high-quality automotive radar imaging. First, a novel Bayesian compressive sensing (BCS) imaging method is proposed to achieve superior angular super-resolution in single-snapshot, in which the Kailath-Variant (K-V) is used to reduce the complexity of matrix inversion. Then, in the range dimension, a Multi-Channel Accumulate (MCA) is utilized to detect the effective range unit to further reduce the 2D imaging computational complexity.

9:40 – 11:20
Waveform Design
Room: SALON E
Session Chairs: Bill Melvin and Justin Metcalf

8249: Alternative "Bases" for Gradient-Based Optimization of Parameterized FM Radar Waveforms

Bahozhoni White, Matthew B. Heintzelman, Shannon D. Blunt
Radar Systems Lab, University of Kansas, United States

Even for a fixed time-bandwidth product there are infinite possible spectrally-shaped random FM (RFM) waveforms one could generate due to phase-continuity. Moreover, certain RFM classes rely on an imposed basis-like structure scaled by underlying parameters that can be optimized (gradient-descent was recently demonstrated). Because these structures must include oversampling with respect to 3-dB bandwidth to account for sufficient spectral roll-off, they are not true bases (not square) and therefore any individual structure cannot represent all possible waveforms. Consequently, it becomes useful to explore the attributes of RFM waveforms designed according to some particular cases.

8402: Optimizing the Tradeoff Between Radar Waveform Resolution and Sidelobe Level Using a Dolph-Chebyshev Approach

Brian Carlton, Jay McDaniel, Justin Metcalf
University of Oklahoma, United States

The tradeoff between main lobe resolution and sidelobe level is formally linked via the Dolph-Chebyshev window formulation. It is shown that the frequency-domain Dolph-Chebyshev formulation can be leveraged to generalize this tradeoff for waveform design. Further, the two-tone waveform (known to be optimal from a resolution perspective) and the Gaussian power spectral density waveform (known to be optimal from a sidelobe perspective) are shown to be special cases of this more generic expression. Finally, this new waveform design technique is combined with the pseudo-random optimized frequency modulation (PRO-FM) framework to produce physically realizable, constant modulus waveforms.

8023: Spectrum-Controlled Waveforms Design with the Thumb-Tack Ambiguity Function for HF OTH Radars

Yuri Abramovich{2}, Dan Dickey{1}, Victor Abramovich{2}
{1}Continental Electronics Corp., United States; {2}WR Systems. Ltd., United States

The problem of a constant modulus (CM) continuous wave (CW) waveform design with the thumb-tack ambiguity function that meets the NTIA RSEC requirements is addressed. The ad-hoc and alternating projection techniques are proposed to modify the spectrum of a prototype waveform to meet the NTIA RSEC requirements, retaining the thumb-tack property of the original waveform ambiguity function. Periodic binary frequency shift keying (BFSK), Costas FSK, and noise-like waveforms are modified to meet CM and NTIA RSEC requirements. Introduced examples demonstrate the spectrum modification consequences and the proposed technique's efficiency for generating the CM spectrum-controlled waveforms with the thumb-tack ambiguity function.

8272: Gradient-Descent Based Optimization of Constant Envelope OFDM Waveforms

David G. Felton{2}, David A. Hague{1}
{1}Naval Undersea Warfare Center, United States; {2}Radar Systems Lab, University of Kansas, United States

This paper describes a Gradient-Descent based optimization algorithm for synthesizing Constant Envelope Orthogonal Frequency Division Multiplexed (CE-OFDM) waveforms with low Auto-Correlation Function (ACF) sidelobes in a specified region of time-delays. Simulations demonstrate the algorithm on CE-OFDM waveforms employing Phase-Shift Keying (PSK) symbols that take on a continuum of values that reside on the unit-circle. Results from these simulations show that the gradient-based optimization algorithm can indeed reduce ACF sidelobes in a desired region of time-delays. However, truncating the symbols to finite M-ary alphabets introduces perturbations to the waveform's instantaneous phase which increases the waveform's ACF sidelobe levels.

8166: Cooperative Waveforms Design for Distributed Radars in Multiple Blanket Jamming

Rui Tan, Maosen Liao, Yi Bu, Xianxiang Yu, Guolong Cui
University of Electronic Science and Technology of China, China

This paper deals with multiple mainlobe blanket jamming for a distributed radar system via a cooperative waveform strategy in frequency domain. We consider one transmitting/receiving site and two transmitting sites with short baseline arrangement. We design a detecting signal with good autocorrelation for the transmitting/receiving site, and desired deceiving and protecting signals for other two sites. So a complex spectrum can be formed when the three signals arrive at the enemy jammers via reasonably controlling the powers and launch timings of the three sites. Thus, the enemy jammers can't identify the detecting signal resulting in degradation of the jamming efficiency.

9:40 – 11:20
AI/ML in Radar
Room: CONF RMS 1-4
Session Chairs: Sevgi Gurbuz

8028: Drone Detection & Classification with Surveillance 'Radar On-the-Move' and YOLO

Hani Haifawi{3}, Francesco Fioranelli{1}, Alexander Yarovoy{1}, Rob van der Meer{2}
{1}Delft University of Technology, Netherlands; {2}Robin Radar Systems, Netherlands; {3}Robin Radar Systems & Microwave Sensing, Signals and Systems Group, Delft University of Technogy, Netherlands

A new method to jointly detect and classify drones using moving surveillance radars and computer vision is presented. While most conventional systems are limited in volumetric spatial coverage and focus on classification via time-frequency distributions, this work presents surveillance radars with full spatial coverage. However, establishing the best detection and classification approach remains an open challenge. The computer vision framework, the You Only Look Once network, is applied to radar data for joint detection and classification. The method is validated on experimental data, with initial results on a small dataset showing precision, recall, and area under curve of over 99%.

8192: Radar-Based Multiple Target Classification in Complex Environments Using 1D-CNN Models

Muhammet Yanik, Sandeep Rao
Texas Instruments, India; Texas Instruments, United States

In this paper, we propose a robust multiple target classification algorithm for real-world complex cluttered environments that can be mapped into low-cost millimeter-wave (mmWave) sensors considering limited memory and processing power budget. A novel approach is developed to create both μ-Doppler and μ-range spectogram of multiple objects concurrently using an extended Kalman filter (EKF) based tracking layer integration. One-dimensional (1D) time sequence features are extracted from both spectogram per target object, and a 1D convolutional neural networks (CNN) based classifier is built to classify multiple target objects (human or non-human) in the same scene accurately.

8410: Influence of Radar Signal Processing on Deep Learning-Based Classification

Sean Kearney, Sevgi Zubeyde Gurbuz
University of Alabama, United States

The short-time Fourier transform was implemented on FMCW radar data of human activities. The parameters of the short-time Fourier transform were then adjusted to find optimal combinations for the resulting micro-Doppler spectrogram. To determine these optimal combinations, the resulting spectrograms were used to train and test a Convolutional Autoencoder. Also, the t-Distributed Stochastic Neighbor Embedding and k-Nearest Neighbor Classification were utilized to find the nearest parameter combinations in a low-dimensional space of the spectrograms.

8102: CFAR-Guided Convolution Neural Network for Large Scale Scene SAR Ship Detection

Zikang Shao, Xiaoling Zhang, Xiaowo Xu, Tianwen Zhang, Tianjiao Zeng, Jun Shi
University of Electronic Science and Technology of China, China

Ship target detection in large scene synthetic aperture radar (SAR) image is a very challenging work. Compared with tradi-tional constant false alarm rate (CFAR) detector, detectors based on convolution neural networks (CNNs) perform better. However, there are still two defects -1) Small ship targets make it hard to extract ship features, and 2) Totally abandon tradi-tional methods leads to the increasement of positioning-risk. In order to solve these problems, we propose a SAR ship detection network which combines CFAR and CNN, called CFAR-guided Convolution Neural Network (CG-CNN). CG-CNN realizes the fusion of CFAR and CNN at the original image level and feature level, and enhances the guiding role of CFAR detection for CNN detection. Detection results on Large-Scale SAR Ship Detection Dataset-v1.0 show that CG-CNN has the best detection performance.

9:40 – 11:20
Tracking 1
Room: CONF RMS 20-21
Session Chairs: Paolo Braca and Dale Blair

8040: Efficient High Degree Cubature Kalman Filters with Reduced Dimension Update

Benjamin Davis
Hill Technical Solutions, United States

Cubature Kalman Filters (CKF) and other related techniques based on evaluation of non-linear functions at so-called sigma-points are a popular and effective modern non-linear state estimation technique. For problems with more severe non-linearity, it is possible to make use of higher degree rules that involve evaluation of the function at increasingly many points. The number of points required for higher degree rules may grow rapidly with the state dimension (sometimes exponentially). This paper introduces a technique by which a cubature rule in the dimension of the measurement may be used for the filter update step rather than a rule in the dimension of the state. This introduces a large potential savings in terms of functional evaluations when the state dimension is large.

8239: RKHS Based Dynamic State Estimator for Non-Gaussian Radar Measurements

Uday Kumar Singh, Mohammad Alaee-Kerahroodi, Mysore R. Bhavani Shankar
Université du Luxembourg, Luxembourg

In this work, firstly, we propose to use EKF-MCC for estimating the dynamic state of the target from non-Gaussian measurement. After that, utilizing MCC, we propose reproducing kernel Hilbert space (RKHS) based non-linear estimation of system non-linearity and using it with EKF-MCC. Amid non-linear estimation utilizing MCC, the proposed filter is named EKF-MCC-RKHS. The simulation performed to estimate the dynamic states of the complex constant acceleration (CA) target motion model validates the superiority of EKF-MCC-RKHS over recently introduced EKF-MCC and traditional EKF.

8252: Track-Before-Detect with Kullback-Leibler Divergence Sampling

Du Yong Kim{2}, Luke Rosenberg{1}, Branko Ristic{2}, Robin Guan{2}
{1}Defence Science and Technology Group, Australia; {2}RMIT University, Australia

Track-before-detect (TBD) is a joint detection and tracking approach that takes advantage of a targets motion over time. For most TBD algorithms, the computationally load is very demanding and efficient implementations need to be developed. An algorithm recently proposed for maritime radar is the Bernoulli TBD particle filter with the number of particles determined heuristically. However, this is not a good approach in the maritime domain due to time and range-varying characteristics of sea clutter. In this paper, an efficient TBD algorithm is developed using Kullback Leibler divergence (KLD) sampling to achieve computational efficiency and adaptive selection of the number of particles. Monte Carlo simulations demonstrate that the adaptive selection of particle number results in excellent detection and tracking results.

8303: Poisson Conjugate Prior for PHD Filtering Based Track-Before-Detect Strategies in Radar Systems

Haiyi Mao, Cong Peng, Yue Liu, Jinping Tang, Hua Peng, Wei Yi
University of Electronic Science and Technology of China, China

A variety of filters with track-before-detect (TBD) strategies have been developed and applied to low signal-to-noise ratio (SNR) scenarios, including the probability hypothesis density (PHD) filter. Assumptions of the standard point measurement model based on detect-before-track (DBT) strategies are not suitable for the amplitude echo model based

on TBD strategies. However, based on different models and unmatched assumptions, the measurement update formulas for DBT-PHD filter are just mechanically applied to existing TBD-PHD filters. In this paper, based on the Kullback-Leibler divergence minimization criterion, finite set statistics theory and rigorous Bayes rule, a principled closed-form solution of TBD-PHD filter is derived. Furthermore, we emphasize that PHD filter is conjugated to the Poisson prior based on TBD strategies. Next, a capping operation is devised to handle the divergence of target number estimation as SNR increases. Moreover, the sequential Monte Carlo implementations of dynamic and amplitude echo models are proposed for the radar system. Finally, Monte Carlo experiments exhibit good performance in Rayleigh noise and low SNR scenarios.

11:20 – 12:20
Lunch
Room: SALON I (&GH)

12:20 – 14:00
MicroDoppler & Cognitive Radar - In memory of Dr. Graeme E. Smith
Room: SALON D (CD)
Session Chairs: J. Landon Garry and Peter Jean-Baptiste

8283: On the Optimality of Spectrally Notched Radar Waveform & Filter Designs
Jonathan W. Owen, Patrick M. McCormick, Christian C. Jones, Shannon D. Blunt
Radar Systems Lab, University of Kansas, United States
Designing radar waveforms with notched spectral regions can mitigate mutual interference with other proximate RF users. To evaluate the limitations of correlation-based processing, the null-constrained power spectral density that minimizes correlation sidelobe levels is determined for comparison with waveform and pulse compression filter design methods. Here, waveforms designed according to the optimal null-constrained spectral template are demonstrated to have improved sidelobe performance after pulse compression and slow-time processing. Further, because these waveforms are designed according to the LS optimal spectral template, application of the LS mismatched filter provides additional sidelobe reduction (toward the global limit) with minimal mismatch loss.

8365: The Role of Target Signatures in Bird-Drone Classification
George Atkinson, Mohammed Jahangir, Daniel White, Joseph Wayman, Christopher John Baker, Jon Sadler, James Reynolds, Michail Antoniou
University of Birmingham, United Kingdom
Mapping and characterising low to medium airspace in an urban setting using radar presents significant challenges, especially for low observable targets such as drones and birds. This paper presents some examples of micro-Doppler signatures which make up part of a larger dataset of control drone, control bird, and opportune bird signatures measured with a pair of L-band staring radars installed at an urban location at the University of Birmingham. The results of multiple measurements over a two-year period are used to facilitate the classification of birds and drones, and the results of a machine learning classifier on the collected data is shown.

8384: When Is Cognitive Radar Beneficial? Insights from Dynamic Spectrum Access
Charles Thornton, Michael Buehrer
Virginia Polytechnic Institute and State University, United States
When should an online reinforcement learning-based frequency agile cognitive radar be expected to outperform a rule-based adaptive waveform selection strategy? We seek insight regarding this question by examining a dynamic spectrum access scenario, in which the radar wishes to transmit in the widest unoccupied bandwidth during each pulse repetition interval. Online learning is compared to a fixed rule-based sense-and-avoid strategy. We show that given a simple Markov channel model, the problem can be examined analytically for simple cases via stochastic dominance. Additionally, we show that for more realistic channel assumptions, learning-based approaches demonstrate greater ability to generalize.

8434: Interactive RF Game Design for Deciphering Real-World Human Motion: Activities, Gestures, and Sign Language
Sevgi Zubeyde Gurbuz, Chris Crawford, Darrin Griffin, Emre Kurtoglu, Oladipupo Adeoluwa, Josh Haeker
University of Alabama, United States
Current methods for acquiring datasets for human motion classification are limited to controlled settings where participants

are directed by a human experiment organizer. Datasets acquired in controlled settings often cannot capture natural human behaviors and are inadequate for obtaining large amounts of real-world data in a sustainable fashion. This paper proposes a new paradigm for automated acquisition of natural human movements based on Interactive RF Gaming. The training of AI/ML models is considered over an evolution of time: pre-deployment via physics-aware batch training and post-deployment via continual learning from interactions. Algorithms needed to address real-world considerations such as the parsing of continuous streams of data, computational constraints, real- time processing, and game design considerations based on cyber- physical human system requirements are also discussed.

8096: Optimization of Waveform Parameters for Multiple Target Tracking Systems in Cognitive Radars

Taylan Denizcan Çaha, Lütfiye Durak Ata

Istanbul Technical University, Turkey

In this study, cognitive radar (CR) applications including radar waveform parameters and track update interval selection are investigated in order to balance the time resource cost of multiple target tracking systems. The waveform parameters and track update interval are adaptively updated by using the outputs of the radar data processing block including target tracking and classification algorithms. Along with the proposed cost function, system performance is demonstrated depending on the target characteristics. In the simulations part, multiple target scenarios that include targets with different maneuvers and radar cross sections (RCS) have been examined.

12:20 – 14:00
Detection & Estimation 2
Room: SALON E
Session Chairs: Stephanie Bidon and Luke Rosenberg

8187: Multiple Change Point Detection-Based Target Detection in Clutter

Batu Chalise{1}, Jahi Douglas{1}, Kevin Wagner{2}

{1}New York Institute of Technology, United States; {2}United States Naval Research Laboratory, United States

We propose a complete data driven non-parametric multiple change point detection (CPD) for target detection, which, under certain conditions, performs well irrespective of the underlying clutter distribution. The key concept is to iteratively search for the slow time instance that maximizes the cumulative sum (CUMSUM) Kolmogorov-Smirnov (KS) statistics. If such statistics exceeds a pre-specified threshold value, then this slow time instance is added to the collection of the estimated change points. This process continues until all CUMSUM-KS statistics are below the threshold. Computer simulations are used to demonstrate the effectiveness of the proposed method for Weibull, Gamma, and K-distributed clutter.

8377: Phenomenology Based Decomposition of Sea Clutter with a Secondary Target Classifier

Masoud Farshchian{1}, Benjamin Cowen{2}, Ivan Selesnick{2}

{1}MITRE Corporation, Empyreal Waves, LLC, United States; {2}New York University, United States

Sea clutter consists of three components: a mean Doppler spectrum, persistent spikes, and discrete spikes, with a random degree of relative power for each component. We propose a non-linear optimization technique designed to de- compose noisy sea clutter into these three components plus a noise component using sparsity inducing norms and linear time-invariant (LTI) filtering in various domains. This novel approach is proposed for non-stationary clutter because it avoids any quasi- stationarity assumptions, unlike the currently proposed state-of- the-art detectors [1]. The decomposition is applied to real South African sea clutter data provided by the Council for Scientific and Industrial Research (CSIR) [2]. We additionally propose a secondary classifier stage for post-processing of potential target detections from the decomposition, and discuss some features that assist in classification between targets and persistent spikes beyond amplitude. Several such extensions are discussed in the conclusion.

8335: Kernel Design Meets Clutter Cancellation for Irregular Waveforms

Pepijn Cox, Mario Coutiño, Wim van Rossum

TNO Netherlands Organisation for Applied Scientific Research, Netherlands

Efficient clutter filtering for pulsed radar systems remains an open issue when employing pulse-to-pulse modulation and irregular pulse interval waveforms within the coherent processing interval. The range and Doppler domain should be jointly processed for effective filtering leading to a large computational overhead. In this paper, the joint domain filtering is performed by constructing a clutter projection matrix, also known as the projected non-identical multiple pulse compression (NIMPC) method. The paper extends the projected NIMPC filter to irregular pulse interval waveforms. Additionally, a kernel-based regularization will be introduced to tackle with the ill-conditioning of the matrix inverse of the NIMPC method. The regularization is based on modeled second-order statistics of the clutter. Moreover, a computationally efficient algorithm is formulated based on fast Fourier transforms and the projected conjugate gradient method. Through a Monte Carlo study it is demonstrated that the proposed kernelized clutter filtering approach outperforms the classical NIMPC in estimating the clutter signal.

8348: Efficient Processing of Irregular PRF Waveforms: Clutter Suppression and Approximate 2D Matched Filtering

Keith Klein, Mario Coutiño, Remko Struiksma, Pepijn Cox, Laura Anitori
TNO Netherlands Organisation for Applied Scientific Research, Netherlands

Focused on the application to irregular PRF waveforms, this work introduces computationally efficient methods to suppress low-velocity clutter and perform approximate two-dimensional matched filtering using sub-pulse processing. The performance is verified through numerical experiments and it is shown that the proposed methods can efficiently remove slow-moving clutter and process large Doppler spans, while incurring a limited loss (1 to 3 dB) to target energy.

8078: A Deep Learning Method for Rough Surface Clutter Reduction in GPR Image

Yan Zhang, Dryver Huston, Tian Xia
University of Vermont, United States

A deep auto-encoder based method is proposed for reducing the rough surface clutter in GPR images. The rough surface clutter reduction is formulated as an anomaly detection problem. The rough surface region in a B-scan image is divided into small patches and used as the training data set to train a deep auto-encoder. After training, the whole B-scan image is divided into small patches of the same size as the training patches and each of which is fed into the auto-encoder to compute an anomaly score to for clutter removal. For performance evaluation, simulation and laboratory tests are Conducted and characterized.

12:20 – 14:00
Inverse Methods & Applications
Room: CONF RMS 1-4
Session Chairs: Debora Pastina and Mark Davis

8242: Experimental Demonstration of Single Pulse Imaging (SPI)

David G. Felton, Christian C. Jones, Daniel B. Herr, Lumumba A. Harnett, Shannon D. Blunt, Christopher T. Allen
Radar Systems Lab, University of Kansas, United States

The Single Pulse Imaging (SPI) algorithm was developed as a means to generalize adaptive pulse compression (APC) by incorporating fast-time Doppler , thereby enhancing separability of scatterers in both range and Doppler. Here, we modify this model-based method by introducing dynamic beamspoiling to provide additional robustness. Open-air experimental results for this robust instantiation of SPI are then shown using a random FM waveform.

8254: An Adaptive Monostatic Inverse Scattering Approach Using Virtual Multistatic Geometries

Hatim Alqadah, Matthew Burfeindt
United States Naval Research Laboratory, United States

In this work we consider a qualitative inverse scattering approach suitable for synthetic aperture radar (SAR) based on a minimum variance distortionless response (MVDR) framework. As discussed in the paper, the derived MVDR approach closely resembles another well established qualitative imaging technique known as the Linear Sampling Method (LSM). Unfortunately, similar to the LSM, the proposed MVDR approach requires a significant amount of multistatic diversity for satisfactory imaging performance, which in general, makes it unsuitable for monostatic geometries. To address this major drawback, we propose a technique for constructing virtual multistatic data from wideband monostatic data based on exploiting spatial frequency redundancy. Examples of the proposed imaging algorithm using simulated monostatic data are presented.

8070: Suppression Performance of Reciprocal Filtering in DVB-T Based Passive Radar

Erlend Finden, Idar Norheim-Næss, Øyvind Thingsrud, Tor Holmboe, Stein Kristoffersen
Norwegian Defence Research Establishment, Norway

Passive radars exploit illuminators of opportunity to detect moving objects. The ambiguity function of the DVB-T broadcast contain ambiguities that will mask most targets. We analyze the reciprocal filtering method that improve the ambiguity surface of the DVB-T signal. However, simulations showed that when targets were present at long range, the range-Doppler floor increased, which subsequently masked weak targets. We conducted a measurement with a radar and a synthetic target generator of a worst case scenario. The experimental results show that the increase in the range-Doppler floor under such conditions are considerably lower than the case that was simulated.

8369: Experimental Evaluation of Supervised Reciprocal Filter Strategies for OFDM-Radar Signal Processing

Javier Trujillo Rodriguez, Fabiola Colone, Pierfrancesco Lombardo
Università degli Studi di Roma La Sapienza, Italy

The paper presents an experimental evaluation of recently proposed Supervised Reciprocal Filter approaches for the compression of OFDM-radar signals. It shows the limitations of using the OFDM fragmentation when evaluating the range-Doppler map and motivates a flexible batch length selection. Supervised Reciprocal Filters have been recently proposed to operate with batches longer than the OFDM symbol. In this paper, we extend the study by proving the effectiveness of the supervised techniques against a real scenario using batches equal to a fraction of the OFDM symbol, which provides higher flexibility to adapt the processor to the range-Doppler scenario of interest.

8385: Practical Considerations for Optimal Mismatched Filtering of Nonrepeating Waveforms

Matthew B. Heintzelman{1}, Jonathan W. Owen{1}, Shannon D. Blunt{1}, Brianna Maio{2}, Eric Steinbach{2}
{1}Radar Systems Lab, University of Kansas, United States; {2}Sandia National Laboratories, United States

We consider the intersection between nonrepeating random FM (RFM) waveforms and practical forms of optimal mismatched filtering (MMF). Specifically, the spectrally-shaped inverse filter (SIF) is a well-known approximation to the least-squares MMF that provides significant computational savings. Given that nonrepeating waveforms likewise require unique nonrepeating MMFs, this efficient form is quite attractive. Moreover, both RFM waveforms and the SIF rely on spectrum shaping, which turns out to highlight a relationship between the goodness of a particular waveform and the mismatch loss (MML) that the filter can achieve. Both simulated and open-air experimental results are shown.

12:20 – 14:00
Advances & Current Trends in Radar Sensing of Physiological Parameters for Human Wellness
Room: CONF RMS 20-21
Session Chairs: Fauzia Ahmad and Yu Rong

8056: Point Transformer-Based Human Activity Recognition Using High-Dimensional Radar Point Clouds

Zhongyuan Guo, Ronny Guendel, Alexander Yarovoy, Francesco Fioranelli
Delft University of Technology, Netherlands

Radar-based Human Activity Recognition (HAR) is considered by using snapshots of point clouds. Such point clouds interpret 2D images generated by an mm-wave FMCW MIMO radar enriched by including Doppler and temporal information. We use the similarity between such radar data representation and the core of the self-attention concept in artificial intelligence. Three self-attention models (Point Transformer) are investigated to classify Activities of Daily Living (ADL). An experimental dataset collected at TU Delft is used to explore the best combination of different input features, the effect of a proposed Adaptive Clutter Cancellation (ACC) method, and the robustness in a leave-one-subject-out scenario. Results with a macro F1 score in the order of 90% are demonstrated with the proposed method, including activities that are static postures with little associated Doppler.

8424: Self-Supervised Contrastive Learning for Radar-Based Human Activity Recognition

Mohammad Mahbubur Rahman, Sevgi Zubeyde Gurbuz
University of Alabama, United States

Short-range radars are widely used for microDoppler-based human activity recognition by using the supervised training paradigm. However, acquiring labeled trained RF data is not always possible. This paper presents a self-supervised contrastive learning (SSCL) framework that utilizes physicsaware augmented radar micro-Doppler signatures for human activity recognition. The SSCL requires two augmented views of the input data samples. For the first augmented view, the Short-time-Fourier-transform properties have been manipulated to generate Multi-Resolution micro-Doppler (MR-mD) signatures. The Second augmented view has been generated through synthesizing micro-Doppler signatures by a Physics-aware Generative adversarial Network (PhGAN). Experimental result shows that the proposed SSCL framework achieved 4% improvement over conventional unsupervised autoencoder pretraining while classifying 14 ambulatory human activities.

8186: Null/Optimum Point Optimization for Indoor Passive Radar Motion Sensing

Aaron Carman, Changzhi Li
Texas Tech University, United States

Much like Doppler radar motion detection, passive radar exhibits a null-point for Doppler sensing. An analysis of this null-point problem is presented, alongside various methods of null-point mitigation in the case of Wi-Fi illumination.

8397: Radar-Based Whitening-Aided Human Activity Recognition

Zahra Sadeghi-Adl, Fauzia Ahmad
Temple University, United States

A variety of deep learning architectures have been proposed for reliable recognition of human activities using micro-Doppler signatures. Convolutional Neural Network (CNN) forms the basis of a majority of these architectures. CNN-based models often utilize batch normalization for efficient network training and enhanced generalization. In this paper, we consider whitening-aided CNN models for human activity recognition, wherein the batch normalization layers are replaced with whitening layers. Whitening provides standardized activations similar to batch normalization, but at the same time, it also decorrelates the activations. Using radar measurements of six different activities, we demonstrate the superiority of whitening over batch normalization in terms of classification accuracy for a CNN-based classifier.

8183: Radarcardiograph Signal Modeling and Time-Frequency Analysis

Isabella Lenz, Yu Rong, Daniel W. Bliss
Arizona State University, United States

In this paper, we delve deeper into recent advancements in radar based biomedical measurements that capture fine movements associated with human heart sounds. We analyze the Radar measurements of several subjects to build a parametric signal model for the radar heart sound signal. From there, we collect and time synchronize the radar measurement with conventional contact based cardiac interval measurements and compare these signals using several time-frequency analysis techniques. We comment on the similarities and difference of the signals, using the model as reference. Our results improve current understanding of radar based heart sound measurements and provide further validation that radar can be used for non-contact technology heart sound monitoring.

14:00 – 14:30
Coffee Break

14:30 – 16:10
Integrated Sensing & Communication 2
Room: SALON D (CD)
Session Chairs: Taneli Riihonen and Christos Masouros

8063: Joint Antenna Selection and Transmit Beamforming for Dual-Function Radar-Communication Systems

Fangzhou Wang{2}, Lee Swindlehurst{2}, Hongbin Li{1}
{1}Stevens Institute of Technology, United States; {2}University of California, Irvine, United States

Dual-function radar-communication (DFRC) design is a promising approach for solving the challenging spectrum congestion problem. This paper considers joint antenna selection and digital beamforming design for a DFRC system that serves multiple multicast communication groups and, meanwhile, performs sensing. The dual-function transmit design is cast as maximizing the minimum target illumination power in multiple target directions by jointly selecting the antennas and designing the beamformers subject to a lower bound on the signal-to-interference-plus-noise ratio (SINR) for the communication users and an upper bound on the clutter power at each clutter scatterer. The resulting optimization formulation is a mixed integer programming problem that is solved with a penalized sequential convex relaxation scheme along with semidefinite relaxation (SDR). Numerical results verify the effectiveness of the proposed DFRC scheme and the associated algorithm.

8094: RIS-Assisted Integrated Sensing and Communications: A Subspace Rotation Approach

Xiao Meng{1}, Fan Liu{3}, Shihang Lu{3}, Sundeep Prabhakar Chepuri{2}, Christos Masouros{4}
{1}Beijing Institute of Technology, Southern University of Science and Technology, China; {2}Indian Institute of Science, India; {3}Southern University of Science and Technology, China; {4}University College London, United Kingdom

In this paper, we propose a novel joint active and passive beamforming approach for integrated sensing and communication (ISAC) transmission with assistance of reconfigurable intelligent surfaces (RISs) to simultaneously detect a target and communicate with a communication user. We first show that the sensing and communication (S&C) performance can be jointly improved due to the capability of the RISs to control the ISAC channel. In particular, we show that RISs can favourably enhance both the channel gain and the coupling degree of S&C channels by modifying the underlying subspaces. In light of this, we develop a heuristic algorithm that expands and rotates the S&C subspaces that is able to attain significantly improved ISAC performance. To verify the effectiveness of the subspace rotation scheme, we further provide a benchmark scheme which maximizes the signal-to-noise ratio (SNR) at the sensing receiver while guaranteeing the SNR at the communication user.

8307: A Secure Dual-Function Radar Communication System via Time-Modulated Arrays

Zhaoyi Xu, Athina Petropulu
Rutgers, the State University of New Jersey, United States

Dual-function radar-communication (DFRC) systems offer high spectral, hardware and power efficiency, as such are prime candidates for 6G wireless systems. DFRC systems use the same waveform for simultaneously probing the surroundings and communicating with other equipment. By exposing the communication information to potential targets, DFRC systems are vulnerable to eavesdropping. In this work, we propose to mitigate the problem by leveraging directional modulation (DM) enabled by a time-modulated array (TMA) that transmits OFDM waveforms. DM can scramble the signal in all directions except the directions of the legitimate user. However, the signal reflected by the targets is also scrambled, thus complicating the extraction of target parameters. We propose a novel, low-complexity target estimation method that estimates the target parameters based on the scrambled received symbols. We also propose a novel method to refine the obtained target estimates at the cost of increased complexity. With the proposed refinement algorithm, the proposed DFRC system can securely communicate with users while having high-precision sensing functionality.

8316: Reinforcement Learning Based Integrated Sensing and Communication for Automotive MIMO Radar

Weitong Zhai{1}, Xiangrong Wang{1}, Maria S. Greco{2}, Fulvio Gini{2}
{1}Beihang University, China; {2}Università di Pisa, Italy

In this paper, we propose a reinforcement learning (RL) based integrated sensing and communication (ISAC) system with a MIMO automotive radar. The target sensing and downlink communication are separately performed by dividing the transmit antennas into two non-overlapping subarrays. We first design a RL framework to adaptively allocate the proper number of transmit antennas for the two subarrays under any unknown environment. We proceed to propose a co-design method to jointly optimize the configurations of the two subarrays to further enhance the sensing accuracy with a constrained communication quality.

8364: Phased Array Architecture Enabling Scalable Integrated Sensing and Communication

Kenneth E. Kolodziej, Glenn A. Brigham, Matthew A. Harger, Brian A. Janice, Adrienne I. Sands, Richard Scott Teal, Louis Turek, Pierre-Francois W. Wolfe, Jonathan P. Doane, Bradley T. Perry
MIT Lincoln Laboratory, United States

Phased array systems can straightforwardly support integrated sensing and communication (ISAC) as well as other functions simultaneously by incorporating in-band full-duplex (IBFD) technology. Digitally-controlled self-interference cancellation techniques have been shown to create isolation between transmit and receive subarrays within a single aperture for limited numbers of elements. This paper discusses the key components of a scalable panel-based IBFD array system, including the aperture and backplane assemblies as well as a cold plate structure for thermal management. The array is designed to operate from 2.7 to 3.5 GHz, and will provide the opportunity to demonstrate ISAC capability in a fashion that is scalable for many different deployment locations and/or platforms.

14:30 – 16:10
MIMO & Frequency-Diverse Arrays
Room: SALON E
Session Chairs: Nathan Goodman and Alan Fenn

8052: Quantized, Power Law Frequency Diverse Arrays

Bill Correll Jr{1}, Brian Rigling{2}
{1}Maxar Technologies, United States; {2}University of Dayton, United States

We generalize research on symmetric carrier frequency offsets for linear frequency diverse arrays by using a power law for parametric control of the resultant field. Use of a power law can destroy periodicity in range that facilitates measurement of range but we show that quantization of power law frequency offsets to a design frequency grid restores it and can simplify radar design and operation. We conduct element location and frequency offset sensitivity analyses using Gaussian and quadratic best-fit models for a notional linear array that suggest important uncertainty tolerances.

8271: Experimental Demonstration of a Low-Complexity Multiple-Input Single-Output Frequency Diverse Array Framework

Patrick M. McCormick{2}, Nicholas Kellerman{2}, Andrew Mertz{2}, Aaron Jones{1}, Brandon Mathieu{1} {1}Air Force Research Laboratory Sensors Directorate, United States; {2}Radar Systems Lab, University of Kansas, United States

We experimentally demonstrate a Multiple-input Single-output (MISO) concept with a linear frequency modulated continuous-wave frequency diverse array (LFMCW-FDA) framework. The experimental results show that, as predicted, the MISO virtual aperture for the LFMCW-FDA transmission appears in the delay dimension after matched filtering and contains the spatial information of the scatterer.

8121: Near-Field/Far-Field Transformation for Estimating Direction of Arrival with Bistatic MIMO Radar

Kazuhiro Tsujimura, Hiroki Mori
Toshiba Corporation, Japan

Object detection with millimeter-wave radar is required for many applications. The major challenges for these applications are reduction of miss detection and high-resolution detection in the near field. The signals received at array antennas in bistatic multi-input/multi-output radar lack a far-field condition at short ranges. Therefore, conventional receive beamforming cannot be applied to determine the direction of arrival. In this paper, we propose a receive beamforming method with near-field/far-field transformation. The measurement results using radar modules show that our proposal method formed a sharp main beam for a target at short range and separated nine adjacent targets.

8189: A Novel Antenna Placement Algorithm for Compressive Sensing MIMO Radar

Bastian Eisele, Ali Bereyhi, Ingrid Ullmann, Ralf Müller
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

In colocated compressive sensing MIMO radar, the measurement matrix is specified by antenna placement. To guarantee an acceptable recovery performance, this measurement matrix should satisfy certain properties, e.g., a small coherence. Prior work in the literature often employs randomized placement algorithms which optimize the prior distribution of antenna locations. We suggest an iterative antenna placement algorithm which determines the antenna locations deterministically. The proposed algorithm locates jointly the antenna elements on the transmit and receive arrays, such that the coherence of the resulting measurement matrix is minimized. Numerical simulations demonstrate that the proposed algorithm outperforms significantly the benchmark.

8327: Bistatic MIMO Radar with Unsynchronized Arrays

Adham Sakhnini{2}, André Bourdoux{1}, Sofie Pollin{2}
{1}imec, Belgium; {2}imec, Katholieke Universiteit Leuven, Belgium

This paper presents a method for enabling bistatic radar under time synchronization offsets. Multiple transmitters and receivers are used to provide direction of arrival and departure measurements. These provide the receivers sufficient diversity to estimate the target locations and timing offsets from the target lists. The signal processing is presented and the parameter estimation is formulated as a non-linear least squares problem. The performance is validated numerically where we show nanosecond accurate synchronization.

14:30 – 16:10
AI Radar Applications 1
Room: CONF RMS 1-4
Session Chairs: Daniel Rabideau and Simon Watts

8137: Snow Radar Echogram Layer Tracker: Deep Neural Networks for Radar Data from NASA Operation IceBridge

Oluwanisola Ibikunle{1}, Hara Madhav Talasila{1}, Debvrat Varshney{3}, John Paden{1}, Jilu Li{1}, Maryam Rahnemoonfar{2}

{1}CReSIS, University of Kansas, United States; {2}Lehigh University, United States; {3}University of Maryland, Baltimore County, United States
This paper documents the performance of two deep learning models developed to automatically track internal layers in Snow Radar echograms. A novel iterative RowBlock approach is developed to circumvent the small training-data problem peculiar to radar data by recasting pixel-wise dense prediction problem as a multi-class classification task with millions of training data. The proposed models, Skip_MLP and LSTM_PE, achieved tracking accuracies of 81.2% and 87.9%, respectively, on echograms from the dry snow zone in Greenland. Moreover, 96.7% and 97.3% of the errors are less than or equal to two pixels for both models respectively. The tracked layers were used to estimate annual accumulation over two decades and compared with Regional Atmosphere Model (MAR) estimates to yield a coefficient of determination of 0.943, thus validating this approach.

8414: Recurrent Graph Convolutional Networks for Spatiotemporal Prediction of Snow Accumulation Using Airborne Radar

Benjamin Zalatan, Maryam Rahnemoonfar
Lehigh University, United States
In this work, we propose a temporal, geometric, multi-target machine learning model based on GCN-LSTM that predicts the thickness of shallow ice layers in the Greenland ice sheet given the thickness of deeper ice layers. Our proposed model was shown to perform better and with more consistency than equivalent non-geometric and non-temporal models.

8259: DeepASTC:Antenna Scan Type Classification Using Deep Learning

Emirhan Ozmen{1}, Yakup Ozkazanc{2}
{1}ASELSAN A.Ş., Turkey; {2}Hacettepe University, Turkey
In this work, we propose a new method which we call DeepASTC, for antenna scanning type classification in Electronic Warfare Systems. DeepASTC is a deep neural network composed of LSTMs. Amplitude patterns of the deinterleaved radar pulses are fed into our network, and the corresponding scanning type is automatically obtained. DeepASTC and the Multiclass Support Vector Machine (SVM) based classifier methods are compared. It is observed that the proposed DeepASTC is able to achieve 93.8% correct classification rate on average, whereas the corresponding rate for the Multiclass SVM method is 86.3%. Conducted experiments show that, the proposed DeepASTC performs successfully on the real and synthetic data sets.

8381: Spiking Neural Networks for LPI Radar Waveform Recognition with Neuromorphic Computing

Alex Henderson{1}, Steven Harbour{1}, Chris Yakopcic{2}, Tarek Taha{2}, David Brown{1}, Justin Tieman{1}, Garrett Hall{1}
{1}Southwest Research Institute, United States; {2}University of Dayton, United States
This paper presents a novel spiking neural network based low probability of intercept (LPI) radar waveform recognition system for extreme low size, weight and power efficient LPI signal classification to enable intelligent electronic support systems that demand high throughput efficiency and ultra-low power. To the best of our knowledge, this work presents the first spike-based implementation of an LPI radar waveform recognition system. The proposed system can be ported onto neuromorphic hardware to push processing towards the edge and enable real-time decision making with ultra-low power and noise robustness.

8416: Estimation of Electrical Characteristics of Complex Walls Using Deep Neural Networks

Kainat Yasmeen, Shobha Sundar Ram
Indraprastha Institute of Information Technology Delhi, India
Electromagnetic wave propagation through complex inhomogeneous walls introduces significant distortions to through-wall radar signatures. Estimation of wall thickness, dielectric, and conductivity profiles may enable wall effects to be deconvolved from target scattering. We propose to use deep neural networks (DNNs) to estimate wall characteristics from broadband scattered electric fields on the same side of the wall as the transmitter. We demonstrate that both single deep artificial and convolutional neural networks and dual networks involving generative adversarial networks are capable of performing the highly nonlinear regression operation of electromagnetic inverse scattering for wall characterization. These networks are trained with simulation data generated from full wave solvers and validated on both simulated and real wall data with approximately 95\% accuracy.

14:30 – 16:10
Radar Technology & Subsystems
Room: CONF RMS 20-21
Session Chairs: Alfonso Farina and Jeffrey Herd

8142: Metasurface-Based, Pattern-Reconfigurable, Wide-Angle Scanning Antenna Array for UAV-Borne Radar
Christos Milias{4}, Rasmus Andersen{3}, Thomas Jørgensen{3}, Pavlos Lazaridis{5}, Zaharias Zaharis{2}, Bilal Muhammad{1}, Jes Kristensen{3}, Albena Mihovska{1}, Dan Hermansen{3}
{1}Aarhus University, Denmark; {2}Aristotle University of Thessaloniki, Greece; {3}MyDefence A/S, Denmark; {4}MyDefence A/S, Aarhus University, Denmark; {5}University of Huddersfield, United Kingdom
This paper presents the design of an antenna array suitable for UAV-borne radars. The array is synthesized by thirteen reflector-backed, pattern-reconfigurable dipoles arranged in an E-plane configuration. The dipole elements provide three different radiation patterns in the elevation plane (H-plane), where the main beam can be steered towards -40, 0 and 40 degrees for the three states. This is achieved through the incorporation of two tunable metasurfaces in the antenna structure. The final array design operates between 9.5 and 10.5 GHz, exhibits a maximum gain of almost 19 dBi and has a scanning range of 130 degrees in the azimuth plane for all three states of the dipoles. The proposed antenna array provides a wide coverage that enables the detection of targets flying at different altitudes and can also be exploited to correct a potential beam misalignment in airborne radar systems. As a result, it is an excellent candidate for low-cost, UAV-borne radar platforms for drone detection, sense-and-avoid, and surveillance applications.

8438: Microwave Quantum Radar Using a Josephson Traveling Wave Parametric Amplifier and a Phase-Conjugate Receiver for a Long-Distance Detection
Patrizia Livreri{3}, Emanuele Enrico{1}, David Vitali{2}, Alfonso Farina{3}
{1}INRiM Istituto Nazionale di Ricerca Metrologica, Italy; {2}Università degli Studi di Camerino, Italy; {3}Università degli Studi di Palermo, Italy
A Microwave Quantum Radar based on the Quantum Illumination protocol and using a Josephson Traveling Wave Parametric Amplifier (JTWPA) and a Phase-Conjugate receiver is described for the first time. The JTWPA, operating as a two-mode squeezed vacuum state quantum source, emitting a microwave signal-idler entangled state is designed and characterized in terms of scattering parameters. A phase-conjugate receiver is used a joint detecting unit for the entangled signal-idler pair measurements and the corresponding receiver operating characteristic (ROC) curves are reported. The proposed MQR paves the way to the long-distance detection of the stealth objects.

8290: Modular Multi-Channel RFSoC System Expansion and Array Design
Nial Peters, Colin Horne, Amin Amiri, Piers Beasley, Matthew Ritchie
University College London, United Kingdom
This paper presents recent developments with UCL's RFSoC-based ARESTOR system. Specifically, the creation of a modular, phased-array based sensor which is comprised of several nodes. These can be deployed either in a distributed multi-static configuration, or combined into a single and more capable mono-static sensor. We detail the hardware developed to enable this along with details of our timing and synchronisation solution.

8031: VehMIR: Vehicle-Borne Mobile Imaging Radar for Scattering Imaging Measurement in the Near-Field Region
Xu Zhan, Xiaoling Zhang, Jun Shi, Shunjun Wei, Tianjiao Zeng, Ling Pu
University of Electronic Science and Technology of China, China
A new vehicle-borne mobile imaging radar (VehMIR) is designed for scattering imaging measurements in the near-field region. VehMIR features its mobile ability, enabling on-the-scene measurements for aircraft-like targets. It's designed for flexible, efficient, and sensitive measurements. To this end, a retractable and adjustable planner scanner is designed for flexibly multidimensional measurements. A high-speed and multi-band with ultra-wide bandwidth transceiver is designed for efficient multi-band high-resolution measurements. An integrated power amplifier is designed for ultra-low scattering measurements. A streaming parallel processing chain is designed to enable real-time measurements. Details of them are presented with the preliminary experiment's results.

16:10 – 18:00
Government Panel
Room: SALON E

Hugh Griffiths
UK Ministry of Defence

Vasu D. Chakravarthy
Air Force Research Laboratory

Frank Robey
MIT Lincoln Laboratory

Joshua Weaver
Office of the Under Secretary of Defense for Research and Engineering

18:00 – 19:00
Exhibitor Reception
Room: SALONS A&B (ABF)

19:00 – 22:00
Banquet Dinner
Room: SALON I (&GH)

7:30 – 9:10
Synthetic Aperture Radar for Automotive Applications
Room: SALON D (CD)
Session Chairs: Marco Manzoni and Stefano Tebaldini

8068: On the Minimum Set of Navigation Sensors to Enable High-Resolution Automotive SAR Imaging
Giovanni Ciaramitaro{2}, Pietro Morri{2}, Dario Tagliaferri{2}, Monica Nicoli{2}, Umberto Spagnolini{2}, Ivan Russo{1}, Damiano Badini{1}
{1}Huawei Technologies Italia s.r.l., Italy; {2}Politecnico di Milano, Italy
The possibility of exploiting the natural motion of the vehicle for synthesizing antenna arrays makes the automotive scenario an interesting application for Synthetic Aperture Radar (SAR) technology. The latter enhances the imaging resolution without increasing the hardware cost. A fundamental requirement of SAR imaging is the knowledge of position and velocity of the the radar platform along the synthetic aperture, with an accuracy that shall be in the order of the wavelength. Navigation techniques fusing data from heterogeneous onboard sensors provide a good positioning solution, to be possibly refined with radar data. This paper addresses the question of whether there exist a minimum set of navigation sensors that guarantees sufficiently accurate SAR imaging in realistic urban scenarios, to minimize the hardware cost. We develop a multi-sensor navigation algorithm, considering different sets of sensors, and we discuss the impact of each one on navigation accuracy. The latter is validated against experimental data using Real Time Kinematics (RTK) positioning measurements as ground truth and SAR imaging results.

8132: Analysis of Multipath Effects in Automotive MIMO-SAR
Marco Manzoni, Stefano Tebaldini, Andrea Virgilio Monti-Guarnieri, Claudio Maria Prati
Politecnico di Milano, Italy
This paper analyzes the concept of multipath in automotive radar imaging, particularly in MIMO-SAR imaging. We show how the position and brightness of the ghost targets are inherently related to the radar's physical layout, including the number of transmitting and receiving elements and their positions. We also show how MIMO-SAR, if implemented with the MIMO aperture orthogonal to the SAR aperture, is intrinsically robust to double bounces resulting in the suppression of ghost targets due to this effect. A set of simulations representing typical automotive scenarios support the theoretical analysis.

8405: Multi-Pass Automotive Synthetic Aperture Radar Image Fusion
Jason Merlo, Jeffrey Nanzer
Michigan State University, United States
In this work we demonstrate an efficient technique for the registration and compositing of multiple automotive SAR images as a step towards distributed SAR imaging. Through the use of an efficient sub-pixel Fourier-based iterative correlation and refinement technique, sub-sections of the overall SAR image are aligned. Because only small sub-regions of the full SAR image are aligned at a time, this technique inherently compensates for accelerations experienced when sampling the synthetic aperture, by assuming a quasi-constant velocity over small sub-regions of the image. Because the image fusion is performed after image formation, this technique lends itself well to a distributed architecture where the image formation is performed on-vehicle and transferred to other vehicles or a centralized cloud processor where images from other vehicles can be aggregated. Finally, because the registration of sub-regions of the SAR image are performed, the registration alignment vector can be used as a odometry provider to improve vehicle odometry estimates; if a metrology grade SAR map is used as reference, a globally reference position estimate could be performed.

8358: Doppler Resiliency with Golay Sequences and Mocs in PMCW MIMO Radars
André Bourdoux, Marc Bauduin
imec, Belgium
Golay complementary sequences and mutually orthogonal complementary sets (MOCS) are attractive for binary PMCW MIMO radars thanks to exactly zero range sidelobes and perfect orthogonality between simultaneously transmitting antennas for MIMO schemes. However, their performance degrades quickly with moving targets. We introduce a radar frame and a low-complexity method to mitigate the degradations due to Doppler. Our method does not require any

knowledge about the targets and achieves excellent sidelobes and orthogonality over the full unambiguous Doppler interval. We show by simulation that our scheme achieves sidelobe levels and orthogonality leakages below -80dB with respect to the target level.

8423: Explainable Artificial Intelligence Based Classification of Automotive Radar Targets

Neeraj Pandey, Shobha Sundar Ram
Indraprastha Institute of Information Technology Delhi, India

Explainable decision making is a key component for compliance with regulatory frameworks and winning trust among end users. In this work, we propose to understand the mis-classification of automotive radar images through counterfactual explanations generated from generative adversarial networks. The proposed method enables perturbations of original radar images belonging to a query class to result in counterfactual images that are classified as the distractor class. The key requirement is that the perturbations must result in realistic images that belong to the original distribution of the query class and also provide physics-based insights into the causes of the misclassification. We test the methods on simulated automotive inverse synthetic aperture radar data images for a query class of a four-wheel mid-size car and a distractor class of a three-wheel auto-rickshaw. Our results show that the shadowing of one or more wheels of the query class is most likely to result in misclassification.

7:30 – 9:10
Detection & Estimation 3
Room: SALON E
Session Chairs: Elisa Giusti and Scott Goldstein

8007: Detection of Fractional Fourier Transform Rotated Chype Pulse with a Discrete Chype Transform

Seema Sud
Aerospace Corporation, United States

Radar systems use linear chirp signals to locate targets. Detection is done by a matched filter (MF), which looks for a correlation peak between the received and transmitted signals. If targets move, Doppler in the reflected signal requires a cross-ambiguity function (CAF), which correlates across both frequency and time. But fast moving targets result in degradation of the CAF peak due to Doppler distortion in the received pulse. A hyperbolic chirp (chype) does not suffer from this performance loss. To detect the chype, a Discrete Chype Transform (DChyT) should be used instead of the CAF. But the DChyT is computationally complex, so we further propose to rotate the transmitted chype using a Fractional Fourier Transform (FrFT) to a domain where it may be transmitted and processed by the DChyT with far fewer samples. We show both mathematically and by simulation that use of the FrFT rotated chype transmit signal and DChyT to detect it can be done efficiently with just 5-6% of the samples required by the chype, with up to 10 dB lower MSE than existing detection methods, at very low SNR (-20<SNR<-10 dB), coming within a few dB of the Cramer-Rao Lower Bound (CRLB).

8231: Variational Bayes Estimation of Off-Grid Migrating Targets with a Delta Method

Gabriel Meuter, Stephanie Bidon
Institut Supérieur de l'Aéronautique et de l'Espace ISAE-SUPAERO, France

This paper describes a variational Bayes sparse recovery to estimate off-grid range-migrating targets unambiguously. Off-grid parameters depend non-linearly on the observation and are thus challenging to estimate. Though, if not estimated, targets may be erroneously recovered in the velocity-ambiguity sidelobes of the true ones. A so-called Delta method is used and results in a fast and efficient algorithm able to leverage velocity ambiguity on synthetic and experimental data. The proposed approach is less complex than state-of-the-art algorithms, a desirable property for real-time applications.

8241: An Application of Artificial Intelligence to Adaptive Radar Detection Using Raw Data

Pia Addabbo{2}, Dario Benvenuti{1}, Goffredo Foglia{1}, Gaetano Giunta{4}, Danilo Orlando{3}
{1}Elettronica SpA, Italy; {2}Università degli Studi Giustino Fortunato, Italy; {3}Università degli Studi Niccolò Cusano, Italy; {4}Università degli Studi Roma Tre, Italy

In this paper, we address the detection of targets in clutter-dominated environments. We apply a new approach to solve the Interference Covariance Matrix estimation problem based upon the neural networks. Assuming a specific structure for the ICM, we train a Neural Network to estimate the parameters of ICM. Then, we use the results provided by the NN to build up an estimate of the entire ICM and plug it into the adaptive matched filter and the adaptive coherence estimator. The performance assessment is conducted by resorting to synthetic as well as real-recorded data and shows the effectiveness of the proposed approach also in comparison with conventional competitors relying on the sample estimates of the ICM parameters

8253: Efficient Iterative MMSE Range Profile Estimation

Pranav Raju, Daniel B. Herr, James M. Stiles
Radar Systems Lab, University of Kansas, United States

For adaptable pulse-agile radar systems, an optimal method to combine the responses from dissimilar transmit signals is sought. As the traditional method of matched filtering fails to provide sufficient performance in a pulse-agile regime, an iterative form of the MMSE estimator is presented to be the solution. By using the linear radar model and opting to process data within the temporal frequency domain, the implementation of the iterative MMSE estimator becomes computationally efficient. This method is compared with matched filtering, in both simulation and experimental data, and shown to produce a more accurate estimate of the scattering profile with finer range resolution and decreased correlation error.

8108: MGRFT-Based Coherent Integration Method for High-Speed Maneuvering Target with Range Ambiguity

Kaiyao Wang, Xiaolong Li, Haixu Chen, Mingxing Wang
University of Electronic Science and Technology of China, China

we propose a coherent integration method based on modular generalized Radon Fourier transform with range ambiguity.

7:30 – 9:10
Passive Radar
Room: CONF RMS 1-4
Session Chairs: Pierfrancesco Lombardo and Diego Cristallini

8135: Detecting and Tracking Multiple Small UAV Using Passive Radar

Benjamin Knoedler, Martina Broetje, Christian Steffes, Wolfgang Koch
Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE, Germany

Based on past research results, passive radars are generally considered a class of sensor systems well suited for the detection and tracking of small UAVs. When applying conventional detection and tracking methods (Detect-then-Track), however, several challenges arise. Target reflections may not be detected due to low signal-to-noise ratio. Further, multiple target-dependent measurements, due to non radar optimized waveforms and target movement, make data association more demanding. Track-before-Detect methods represent an alternative to such processing schemes, where a classical threshold detector is avoided and the whole target reflection is modeled in the measurement space. This work gives an overview of the fundamentals and differences of both target tracking concepts, before evaluating experimental data using two cooperative drones in a GSM passive radar scenario.

8299: LEO/MEO-Based Multi-Static Passive Radar Detection Performance Analysis Using Stochastic Geometry

Shubhi Singhal, Sanat K. Biswas, Shobha Sundar Ram
Indraprastha Institute of Information Technology Delhi, India

In this work, we perform a system-level study of space-based multi-static passive radar for target detection. We model the distribution of satellite transmitters as a homogeneous Poisson point process. Subsequently, we use stochastic geometry tools to derive the probability of target detection. The proposed theoretical framework enables us to draw performance insights into low earth orbit (LEO) and medium earth orbit (MEO)-based passive radar at a fraction of the computational costs of Monte Carlo simulations. Our study shows that LEO-based passive radar systems are likely to outperform MEO-based passive radar systems with comparable receiver characteristics.

8413: Experimental Comparison of Starlink and OneWeb Signals for Passive Radar

Rodrigo Blázquez-García, Diego Cristallini, Martin Ummenhofer, Viktor Seidel, Jörg Heckenbach, Daniel O'Hagan
Fraunhofer Fraunhofer Institute for High Frequency Physics and Radar FHR, Germany

Given the limited available information about Starlink and OneWeb signals but the relevant capabilities that they may provide, this work is focused on the experimental acquisition and comparison for passive radar applications of the user downlink signals transmitted by these emerging satellite constellations. In order to received these signal, an updated version of the SABBIA system here described has been developed with satellite tracking capabilities and enhanced instantaneous bandwidth to enable a complete transmission channel to be digitized. Based on the analysis of the received Starlink and OneWeb signals in terms of the ambiguity function, both constellations are considered suitable as complementary potential illuminations of opportunity for high-resolution passive radar applications.

8329: Multi-Angle DVB-S Based Passive ISAR Sensitivity to Target Motion Estimation Errors

Fabrizio Santi{2}, Iole Pisciottano{1}, Debora Pastina{2}, Diego Cristallini{1}
{1}Fraunhofer Fraunhofer Institute for High Frequency Physics and Radar FHR, Germany; {2}Università degli Studi di Roma □La Sapienza, Italy

This work considers a multistatic passive radar configuration comprising a DVB-S illuminator of opportunity and multiple receivers for multi-angle passive ISAR imaging. Back-Projection Algorithm (BPA) allows producing the individual images on a common reference plane regardless the different bistatic angles. However, as the exploitation of satellite signals of opportunity entails a poor capability to estimate accurately the target kinematics, a significant geometry-dependent image distortion is likely experienced. Theoretical and numerical analyses are provided to measure the impact of target motion estimation errors on the resulting multi-angle image. A few experimental results, comprising a turning ferry and an Astra satellite, are also provided.

8197: Analysis of Starlink Users' Downlink for Passive Radar Applications: Signal Characteristics and Ambiguity Function Performance

Pedro Gomez-Del-Hoyo{2}, Piotr Samczyński{1}, Filip Michalak{1}
{1}Warsaw University of Technology, Poland; {2}Warsaw Universiy of Technology, Poland

In this work, an acquisition system based on RFSoC with an instantaneous bandwidth of 256MHz was employed to record Starlink signals on the users´ downlink. A detailed analysis in time and frequency domains is carried out to identify Starlink's capabilities for passive radars. Results show similar behavior of Starlink signals at different channels, with an under-demand pulse-kind transmission for users' data as well as the continuous transmission for synchronization purposes. The pulsed data signal was employed to compute the first ambiguity function of a Starlink signal to determine the performance of Starlink-based passive radar.

7:30 – 9:10
Distributed Sensing & Communications in Cognitive Radar Network
Room: CONF RMS 20-21
Session Chairs: Batu Chalise and Ben Kirk

8168: Bayesian Detection for Distributed MIMO Radar with Non-Orthogonal Waveforms in Non-Homogeneous Clutter

Cengcang Zeng{1}, Fangzhou Wang{1}, Hongbin Li{1}, Mark Govoni{2}
{1}Stevens Institute of Technology, United States; {2}United States DEVCOM Army Research Laboratory, United States

This paper considers target detection in distributed multi-input multi-output (MIMO) radar with non-orthogonal waveforms in non-homogenous clutter. We first present a general signal model for distributed MIMO radar in cluttered environments. To cope with the non-homogenous clutter and possible clutter bandwidth mismatch, the covariance matrix of the disturbance (clutter and noise) signal is modeled as a random matrix following an inverse complex Wishart distribution. Then, we propose three Bayesian detectors, including a non-coherent detector, a coherent detector, and a hybrid detector. The latter is a compromise of the former two, as it forsakes phase estimation needed by the coherent detector, but requires the samples within a coherent processing interval (CPI) to maintain phase coherence that is unnecessary for the non-coherent detector. Simulation results are presented to illustrate the performance of these Bayesian detectors and their non-Bayesian counterparts in non-homogeneous clutter when the clutter bandwidth is known exactly and, respectively, with uncertainty.

8176: A Pattern Shaping Approach for Distributed Collaborative Beamforming

Michael Lipski{3}, Sastry Kompella{1}, Ram Narayanan{2}
{1}Nexcepta, Inc., United States; {2}Pennsylvania State University, United States; {3}United States Naval Research Laboratory, United States

This paper presents an approach to adding additional beams or nulls at specified angles to the pattern of a coherent distributed transmit array by using global optimization techniques. The system model is a simplified planar model, and side beams or nulls can be created in any arbitrary azimuth angle using node positions as optimization variables. Simulations are used to show that the global optimization techniques are effective at creating strong side beams and deep nulls.

8184: Harmonic Mean SINR Maximization-Based Bandwidth and Carrier Frequency Allocation for Distributed Radar Networks

Batu Chalise{1}, Anthony Martone{2}, Benjamin Kirk{2}
{1}New York Institute of Technology, United States; {2}U.S. Army Combat Capabilities Development Command Army Research Laboratory, United States

We propose joint bandwidth and carrier frequency allocation for distributed radar network with a central coordinator. We maximize harmonic mean of the node signal-to-noise-interference ratios (SINRs) under total bandwidth and individual node's range resolution constraints. This non-convex optimization is solved efficiently utilizing an implicit relationship between bandwidth and carrier frequencies, and the monotonically decreasing property of SINR with respect to bandwidth and carrier frequency. We propose an iterative method that approximates the optimization with geometric programming problem. Simulations show that the proposed method significantly outperforms equal bandwidth allocation method and enables poor performing nodes to enhance their individual SINRs significantly.

8353: Timely Target Tracking in Cognitive Radar Networks

William Howard, Charles Thornton, Michael Buehrer
Virginia Polytechnic Institute and State University, United States

We consider a scenario where a fusion center must decide which updates to receive during each update period in a communication-limited cognitive radar network. When each radar node in the network only is able to obtain noisy state measurements for a subset of the targets, the fusion center may not receive updates on every target during each update period. The solution for the selection problem at the fusion center is not well suited for sequential learning frameworks. We derive an Age of Information-inspired track sensitive metric to inform node selection in such a network and compare it against less-informed techniques.

8380: Directional Modulation for Multi-Node Interaction from an Artificially Intelligent Power Amplifier Array: Simultaneous Radar and Communication While Optimizing Circuit Performance

Samuel Haug{1}, Adam Goad{1}, Austin Egbert{1}, Charles Baylis{1}, Anthony Martone{2}, Benjamin Kirk{2}, Robert J. Marks II{1}
{1}Baylor University, United States; {2}U.S. Army Combat Capabilities Development Command Army Research Laboratory, United States

This paper was funded by the army research office and requires security approval for public release. This approval process has taken an abnormally long time and as of 11/21/2022 has not been completed. Unfortunately, we are unable to submit the full paper. When the approval process is complete, we will be able to submit the full paper. We apologize for any inconvenience.

9:10 – 9:40
Coffee Break

9:40 – 11:20
Advanced Systems and Algorithms for mmWave Radars
Room: SALON D (CD)
Session Chairs: Shengheng Liu and Tai Fei

8015: Velocities in Human Hand Gestures for Radar-Based Gesture Recognition Applications

Theresa Antes, Lucas Giroto de Oliveira, Axel Diewald, Elizabeth Bekker, Akanksha Bhutani, Thomas Zwick
Karlsruher Institut für Technologie, Germany

To tailor a radar sensor parametrization to the use in gesture recognition, the expectable velocities, amongst other parameters, have to be known. An investigation with a set of 15 defined gestures plus one individually chosen movement and 25 participants was carried out to find the main dependencies for these velocities and give an outline on how to approach radar parametrization concerning velocities for gesture recognition applications. The gesture set and setup of a certain application were identified to be the most relevant design choices, from which the expectable velocities can be determined with just a few test participants.

8226: Millimeter-Wave Radar Beamforming with Spatial Path Index Modulation Communications

Ahmet M. Elbir{3}, Kumar Vijay Mishra{2}, Abdulkadir Çelik{1}, Ahmed M. Eltawil{1}

{1}King Abdullah University of Science and Technology, Saudi Arabia; {2}United States DEVCOM Army Research Laboratory, United States; {3}Université du Luxembourg, Luxembourg

To efficiently utilize the wireless spectrum and save hardware costs, the fifth generation and beyond (B5G) wireless networks envisage integrated sensing and communications (ISAC) paradigms to jointly access the spectrum. In B5G systems, the expensive hardware is usually avoided by employing hybrid beamformers that employ fewer radio-frequency chains but at the cost of the multiplexing gain. Recently, it has been proposed to overcome this shortcoming of millimeter wave (mmWave) hybrid beamformers through spatial path index modulation (SPIM), which modulates the spatial paths between the base station and users and improves spectral efficiency. In this paper, we propose an SPIM-ISAC approach for hybrid beamforming to simultaneously generate beams toward both radar targets and communications users. We introduce a low complexity approach for the design of hybrid beamformers, which include radar-only and communications-only beamformers. Numerical experiments demonstrate that our SPIM-ISAC approach exhibits a significant performance improvement over the conventional mmWave-ISAC design in terms of spectral efficiency and the generated beampattern.

8349: Improved Implementation of the Frequency Hopped Code Selection DFRC Scheme

Elias Aboutanios{2}, William Baxter{2}, Yimin Zhang{1}
{1}Temple University, United States; {2}University of New South Wales, Australia

Dual Function Radar Communications strategies aim to embed communication symbols into the radar waveforms, which serves to alleviate the spectrum congestion problem. In this context, frequency hopping code selection (FHCS) has been proposed as a effective DFRC approach in frequency hopped (FH) Multiple-Input Multiple-Output (MIMO) radar. FHCS encodes the communication symbols through the selection from the available hops of the subset of hops to be assigned to the waveforms in each chip. In this manner, FHCS applies information embedding in the fast time, which greatly increases the achievable bit rate at the expense of increased impact on the radar performance. In this work we propose an enhanced version of the FHCS scheme that ameliorates the resulting ambiguity function, thus improving the radar performance. Furthermore, we present a practical implementation that employs a greedy divide and conquer approach. The performance of the new strategy is then evaluated using simulations and the benefits to the radar ambiguity function are demonstrated

8291: Channel Covariance Matrix Construction for DOA Estimation with Limited Communication Symbols

Luning Lin, Hang Zheng, Chengwei Zhou, Zhiguo Shi
Zhejiang University, China

The covariance matrix serves an important role in direction-of-arrival (DOA) estimation methods for joint sensing and communication systems. However, under the condition of limited communication symbols, the conventional sample data covariance matrix derived from received symbols can deviate from its ideal version, leading to a considerable DOA estimation error. To address this issue, we derive a sample channel covariance matrix from the estimated sensing channels in the frequency domain. It is proved that, by imposing sufficient subcarriers, the approximation error between the sample channel covariance matrix and the ideal one can be minimized. As such, the constructed sample channel covariance matrix facilitates an enhanced DOA estimation performance even with a small number of communication symbols. The effectiveness of the proposed method is validated via simulations in terms of both DOA estimation accuracy and angular resolution.

8373: Detecting Vulnerable Road Users Utilizing the Harmonic RCS of Active Tags at 79/158 GHz

Tobias T. Braun, Jan Schöpfel, Nils Pohl
Ruhr-Universität Bochum, Germany

In this work, we present harmonic and fundamental RCS measurements of a bicycle equipped with a harmonic tag surrounded by clutter. We show the harmonic RCS of the tag increasing with range, as long as it is saturated. This highlights the importance of the amplifier chain at the tag's input. Additionally, even a small harmonic RCS is easily detectable in the harmonic channel, because it is nearly clutter-free. In the fundamental channel however, the RCS of a bicycle is easily exceeded by larger metal objects, making a detection surrounded by the cars of city traffic very challenging.

9:40 – 11:20
Radar Waveform Analysis
Room: SALON E
Session Chairs: Ravi Adve and Ram Raghavan

8178: Characterizing the Ambiguity Function of Constant-Envelope OFDM Waveforms

David G. Felton{2}, David A. Hague{1}
{1}Naval Undersea Warfare Center, United States; {2}Radar Systems Lab, University of Kansas, United States

This paper investigates the radar Ambiguity Function (AF) properties of CE-OFDM waveforms employing Phase-Shift Keying (PSK). We derive novel closed form expressions for the CE-OFDM waveform's spectrum, AF, and Auto-Correlation Function (ACF). We additionally derive exact closed form expressions that characterize the waveform's AF mainlobe shape that appear to be novel to the literature. We show that the CE-OFDM waveform almost always attains a "Thumbtack-Like" AF shape and that careful choice of the PSK symbols can produce waveforms with desirably lower ACF sidelobes.

8215: Correlation Coefficient vs. Transmit Power for an Experimental Noise Radar

David Luong{1}, Ian Lam{1}, Bhashyam Balaji{2}, Sreeraman Rajan{1}
{1}Carleton University, Canada; {2}Defence Research and Development Canada, Canada

In previous work, it was shown that a noise radars have two signal-to-noise ratios (SNRs) associated with them: one for the receive signal and another for the signal retained within for matched filtering. However, these two SNRs can be combined into a single correlation coefficient which can be easily be used for performance prediction. Unlike SNR, this correlation coefficient can be estimated directly from radar detection data. This work presents experimental verification of the theoretical relationship between the SNRs of a noise radar and the correlation coefficient, showing that it holds for a wide range of transmit powers.

8275: Compact Parameterization of Nonrepeating FMCW Radar Waveforms

Thomas J. Kramer{1}, Erik R. Biehl{1}, Matthew B. Heintzelman{1}, Shannon D. Blunt{1}, Eric Steinbach{2}
{1}Radar Systems Lab, University of Kansas, United States; {2}Sandia National Laboratories, United States

Spectrally shaped forms of random FM radar waveforms have been experimentally demonstrated for a variety of approaches and applications. Of these, the CW perspective is interesting because it enables the prospect of high signal dimensionality and arbitrary receive processing from a range/Doppler perspective, while also mitigating range ambiguities by avoiding repetition. Here we leverage a modification to the CE-OFDM framework, originally proposed for power-efficient communications, to realize a non-repeating FMCW radar signal that can be represented with a compact parameterization, thereby circumventing memory constraints that could arise for some applications. Simulation and open-air measurements are used to demonstrate this waveform type.

8306: Cramér-Rao Lower Bound and Estimation Algorithms for Scene-Based Bistatic Radar Waveform Estimation

Mario Coutiño, Ahmad Millad Mouri Sardarabadi, Pepijn Cox, Wim van Rossum, Laura Anitori
TNO Netherlands Organisation for Applied Scientific Research, Netherlands

Cooperative radar operations typically rely on the exchange of a limited amount of information to improve the quality of the estimated targets parameters. Unfortunately, in many instances, not all necessary information can be accessed or communicated, e.g., no line of sight (LOS) or limited resources. This problem would be exacerbated with the inset of novel (irregular) waveforms, exhibiting large number of degrees of freedom, on transmit. An instance of this situation, for example, is where monostatic and bistatic measurements are to be exploited for enhanced parameter estimation and only synchronization and geographical information is shared between two platforms. In this paper, we focus on this scenario and derive the Cramer-Rao lower bound for the estimation of the unknown bistatic waveform under no-LOS mild assumptions on the second-order statistic of the bistatic and monostatic returns. Also, we devise a set of algorithms exploiting the monostatic estimated scene, based on spectral methods, factor analysis and calibration techniques. Through numerical experiments, we compare the performance and discuss the limits of the introduced techniques.

8317: Impact of Phase Noise on FMCW and PMCW Radars

Marc Bauduin, André Bourdoux
imec, Belgium

Phase noise can severely degrade the radar performances by producing strong sidelobes which may mask small targets. Reducing those sidelobes by improving the radar analog front-end severely increases the system complexity. Another approach consists in developing waveforms more robust to phase noise. In this paper, we will provide a detailed analysis of the impact of phase noise on Frequency Modulated Continuous Wave (FMCW) radars and on different code sequences for Phase Modulated Continuous Wave (PMCW)radars. We will show that radar waveforms can be designed to provide low sidelobes in presence of phase noise.

9:40 – 11:20
AI Radar Applications 2
Room: CONF RMS 1-4
Session Chairs: Lam Nguyen and Alessio Balleri

8238: Point Cloud Transformer (PCT) for 3D-InISAR Automatic Target Recognition

Giulio Meucci{2}, Francesco Mancuso{2}, Elisa Giusti{1}, Ajeet Kumar{1}, Selenia Ghio{1}, Marco Martorella{2}
{1}CNIT, RaSS National Laboratory, Italy; {2}Università di Pisa, CNIT, RaSS National Laboratory, Italy

3D point clouds as a result of 3D-ISAR imaging were proposed as a more complete and reliable representation of the target. Since the acquisition system will output an unknown number of points in a random order, the chosen classifier must be able to process a variable number of input elements to correctly classify the target. After a brief presentation of the state of the art about the 3D classification problem, the architecture of Point Cloud Transformer (PCT) is introduced, trained and tested on an ad-hoc generated 3D dataset, which contains three different target types: cars, tanks and military trucks.

8262: Robust 3D ISAR Ship Classification

Chow Yii Pui{4}, Selenia Ghio{1}, Brian Ng{4}, Elisa Giusti{1}, Luke Rosenberg{2}, Marco Martorella{3}
{1}CNIT, RaSS National Laboratory, Italy; {2}Defence Science and Technology Group, Australia; {3}Università di Pisa, CNIT, RaSS National Laboratory, Italy; {4}University of Adelaide, Australia

Classification of inverse synthetic aperture radar (ISAR) ship imagery is difficult due to the motion of the sea causing a wide variation of the observed images. The three dimensional (3D)-ISAR technique was developed as an alternative representation with the target represented by a 3D point cloud. In this paper, we compare two different approaches to classification using 3D-ISAR point clouds of maritime targets. The first approach makes use of features extracted from the 3D-ISAR generated point cloud of the target from different perspectives (i.e. side, top and front views) to form three point density images (PDI). These are then fed into a convolutional neural network (CNN) to classify the targets. The second approach uses an offline target database comprising size and a coarse target silhouette and classifies using a few simple rules. Both algorithms do not require knowledge of the aspect angle making them robust when applied in an operational scenario.

8432: MrSARP: A Hierarchical Deep Generative Prior for SAR Image Super-Resolution

Tushar Agarwal, Nithin Sugavanam, Emre Ertin
Ohio State University, United States

Generative models learned from training using deep learning methods can be used as priors in under-determined inverse problems, including imaging from sparse set of measurements. In this paper, we present a novel hierarchical deep-generative model MrSARP for SAR imagery that can synthesize SAR images of a target at different resolutions jointly. MrSARP is trained in conjunction with a critic that scores multi resolution images jointly to decide if they are realistic images of a target at different resolutions. We show how this deep generative model can be used to retrieve the high spatial resolution image from low resolution images of the same target. The cost function of the generator is modified to improve its capability to retrieve the input parameters for a given set of resolution images. We evaluate the model's performance using three standard error metrics used for evaluating super-resolution performance on simulated data and compare it to upsampling and sparsity based image super-resolution approaches.

8387: Subspace Perturbation Analysis for Data-Driven Radar Target Localization

Shyam Venkatasubramanian{3}, Sandeep Gogineni{4}, Bosung Kang{5}, Ali Pezeshki{2}, Muralidhar Rangaswamy{1}, Vahid Tarokh{3}

{1}Air Force Research Laboratory, United States; {2}Colorado State University, United States; {3}Duke University, United States; {4}Information Systems Laboratories Inc., United States; {5}University of Dayton, United States
Recent works exploring data-driven approaches to classical problems in adaptive radar have demonstrated promising results pertaining to the task of radar target localization. Via the use of space-time adaptive processing (STAP) techniques and convolutional neural networks, these data-driven approaches to target localization have helped benchmark the performance of neural networks for matched scenarios. However, the thorough bridging of these topics across mismatched scenarios still remains an open problem. As such, in this work, we augment our data-driven approach to radar target localization by performing a subspace perturbation analysis, which allows us to benchmark the localization accuracy of our proposed deep learning framework across mismatched scenarios. Using a convolutional neural network (CNN) architecture and enabled by this analysis, we demonstrate that the performance of our framework in the presence of perturbations can be predetermined.

8355: CV-SAGAN: Complex-Valued Self-Attention GAN on Radar Clutter Suppression and Target Detection
Yuanhang Wu, Chenyu Zhang, Yiru Lin, Xiaoxi Ma, Wei Yi
University of Electronic Science and Technology of China, China
Traditional clutter suppression and target detection methods have limitations in that they must satisfy specific statistical models. This paper presents a unified deep learning model for complex-valued self-attentive generative adversarial networks (CV-SAGAN) for clutter suppression and target detection. In the complex-valued framework, we first use a generator module to learn the clutter distribution and perform clutter suppression. Then, a self-attentive module is used for the first time to perform corrective detection of sparse targets. Finally, a discriminator is used to judge between the real data and the network output results, improving the robustness of the model. We verified that the CV-SAGAN model has a better detection rate and robustness than the conventional CA-CFAR, real-valued GAN, and real-valued SAGAN on three clutter distributions and achieved better detection results on the publicly available IPIX real-world dataset.

9:40 – 11:20
Intelligent Reflecting Surfaces for Next-Generation Radar
Room: CONF RMS 20-21
Session Chairs: Kumar V. Mishra and Mojtaba Soltanalian

8095: Holographic Radar: Optimal Beamformer Design for Detection Accuracy Maximization
Haobo Zhang{1}, Hongliang Zhang{1}, Boya Di{1}, Zhu Han{2}, Lingyang Song{1}
{1}Peking University, China; {2}University of Houston, United States
As an emerging antenna technique, reconfigurable holographic surfaces (RHSs) have drawn much attention recently as a promising solution to enable future radar systems with stringent power and cost requirements. In this paper, we propose RHS-empowered holographic radar, where two RHSs serve as transmit and receive antennas to detect a far-field target. Due to the simple and low-cost structure of metamaterial elements in the RHS, the holographic radar is able to achieve satisfactory detection performance at a smaller cost and power consumption compared with a traditional phased array radar. To maximize the detection accuracy of a holographic radar, a closed-form beamformer expression with the highest signal-to-noise ratio~(SNR) is derived in order to fully exploit the benefit of incorporating RHSs. To the best of our knowledge, this is the first study on the global optimal beamformer design for RHSs. Simulation results also verify the superiority of the proposed scheme for holographic radar.

8114: Clutter Suppression for Target Detection Using Hybrid Reconfigurable Intelligent Surfaces
Fangzhou Wang{2}, Hongbin Li{1}, Lee Swindlehurst{2}
{1}Stevens Institute of Technology, United States; {2}University of California, Irvine, United States
This paper explores Reconfigurable intelligent surface (RIS) for clutter mitigation and target detection in radar systems. A new type of hybrid RIS is exploited to assist with clutter suppression. We consider two clutter suppression scenarios: without and with THE target range cell knowledge. The RIS design is formulated by minimizing the received clutter echo energy when there is no information regarding the potential target range cell information. This turns out to be a convex problem and can be efficiently solved. On the other hand, when target range cell information is available, we maximize the received signal-to-noise-plus-interference ratio (SINR). The resulting non-convex optimization problem is solved through fractional programming algorithms. Numerical results are presented to demonstrate the performance of the proposed hybrid RIS in comparison with conventional passive RIS in clutter suppression for target detection.

8284: Minorization-Based Low-Complexity Design for IRS-Aided ISAC Systems

Yi-Kai Li{2}, Athina Petropulu{1 }
{1}Rutgers, the State University of New Jersey, United States; {2}Southern Illinois University, United States

A low-complexity design is proposed for an integrated sensing and communication (ISAC) system aided by an intelligent reflecting surface (IRS). The radar precoder and IRS parameter are computed alternatingly to maximize the weighted sum SNR at the radar and communication receivers. The IRS design problem has an objective function of fourth order in the IRS parameter matrix, and is subject to highly non-convex unit modulus constraints. To address this challenging problem and obtain a low-complexity solution, we employ a minorization technique twice; the original fourth order objective is first surrogated with a quadratic one via minorization, and is then minorized again to a linear one. This leads to a closed form solution for the IRS parameter in each iteration, thus reducing the IRS design complexity. Numerical results are presented to show the effectiveness of the proposed method.

8285: Time-Code-Spatial Modulated IRS-Aided Radar Localization in NLoS Scenario

Yuan Liu, Moein Ahmadi, Johann Fuchs, Mysore R. Bhavani Shankar
Université du Luxembourg, Luxembourg

Following the developments in wireless communications, the usage of passive Intelligent Reflecting Surfaces (IRS) to extend radar illumination to non-line-of-sight (NLoS) scenarios has spurred the research interest. Initial works have assumed ideal propagation conditions based on the radar equation, to assess the signal noise ratio (SNR) enhancement. In this paper, we consider a realistic target position estimation of an IRS-aided radar system framework. Firstly, a time-coding-spatial (TCS) IRS array model was proposed, where each sub-unit array can work independently as a TX IRS unit or Rx IRS unit. Then, the signal model of the time division multiplexing (TDM) IRS array based on the frequency-modulated continuous waveform is derived. Thereafter, the developed signal model is used to emulate the radar performance utilizing a Blender-based simulator in NLoS scenarios, where the various assumptions commonplace in literature and their suitability in realistic scenarios are considered. The simulation result shows the validation of the proposed IRS-aided framework in target localization, besides, the trade-off between angle resolution and energy/time consumption is also discussed.

8389: Moving Target Detection via Multi-IRS-Aided OFDM Radar

Zahra Esmaeilbeig{2}, Arian Eamaz{2}, Kumar Vijay Mishra{1}, Mojtaba Soltanalian{2}
{1}United States DEVCOM Army Research Laboratory, United States; {2}University of Illinois Chicago, United States

An intelligent reflecting surface (IRS) consists of passive reflective elements capable of altering impinging waveforms, thus paving the way for improving the performance and reliability of wireless systems such as communications and radar remote sensing. We study the theoretically achievable accuracy of target detection in a multi-IRS-aided OFDM radar system designed to sense the moving targets. In addition, we jointly design the OFDM signal and IRS phase shifts to enhance the target detection performance. To do so, we formulate the IRS phase shift design problem as a unimodular bi-quadratic program and devise an alternating optimization of the phase shifts and the OFDM transmit signal. Through numerical investigations, we illustrate that by designing the phase shifts of the IRS platforms and the OFDM signal, the detection performance of the radar will be improved.

11:20 – 12:20
Lunch
Room: Salons GHI

12:20 – 14:00
Automotive Radar
Room: SALON D (CD)
Session Chairs: Igal Bilik and Daniel Bliss

8006: Angle Accuracy in Radar Target Simulation

Axel Diewald, Benjamin Nuss, Thomas Zwick
Karlsruher Institut für Technologie, Germany

Radar target simulators (RTSs) have recently drawn much attention in research and commercial development, as they are capable of performing over-the-air validation tests under laboratory conditions by generating virtual radar echoes that are perceived as targets by a radar under test (RuT). The estimated angle of arrival (AoA) of such a virtual target is controlled, among others, by the physical position of the respective RTS channel that generates it. In this contribution the authors investigate the achievable angle accuracy of RTS systems in dependence of their channel spacing and calibration.

8076: Automotive Radar Interference Avoidance Strategies for Complex Traffic Scenarios

Lizette Lorraine Tovar Torres, Timo Grebner, Christian Waldschmidt
Universität Ulm, Germany

The issue of interference between automotive radars is an emerging topic. Although different interference suppression techniques and mitigation approaches have been previously studied, none of them have been evaluated considering complex traffic scenarios where multiple vehicles are equipped with several radar sensors. This paper presents two different interference avoidance strategies: Random Frequency Hopping with Sub-Channels and the Compass Method. The effectiveness of the strategies is evaluated by simulating two complex scenarios: A highway with 105 vehicles and an intersection of two streets with 34 vehicles, each vehicle containing five radar sensors. Subsequently, the strategies are validated by taking measurements considering the intersection of two streets.

8198: Real-Time Interference Mitigation for Automotive Radar

Yubo Wu, Thomas Hou, Alexander Li, Wenjing Lou
Virginia Polytechnic Institute and State University, United States

In this paper, we present Soteria---a real-time compressed sensing based interference mitigation algorithm for the automotive radar system. Soteria identifies the interference signal by exploiting the sparsity of the signal in frequency-time domain. It then separates the intended signal and interference signal based on the Compressive Sampling Matching Pursuit (CoSaMP) algorithm. Soteria narrows down the search space for CoSaMP to reduce the complexity. To further accelerate computation time, Soteria pursues a parallel implementation based on GPU computing architecture. Simulation experiments show that Soteria can achieve 10ms processing time and outperforms the state-of-the-art algorithms in terms of target detection.

8200: Deep-Learning Based Spectrum Prediction for Cognitive Automotive Radar Interference Mitigation

Marius Schwarz, Axel Acosta Aponte, Gor Hakobyan
Robert Bosch GmbH, Germany

Interference affects the robustness of driver assistance systems that rely on automotive radars. Today's radar sensors use algorithms for suppression of interference in the received radar signal. In contrast, interference-aware cognitive radar (IACR) avoids interference based on spectral awareness, as opposed to suppressing it in post-processing. In this paper, we propose a machine learning (ML) based spectrum prediction model for IACR that infers the spectral occupation in the upcoming measurement cycle. Subsequently, interference is avoided by adapting the waveform to use the spectral resources with the least interference potential. By closing the cognitive loop, we show that IACR is capable of achieving an order of magnitude less average interference power compared to radars without a cognitive interference avoidance strategy.

8407: Darting-Out Target Detection with NLOS Signals for Vehicle MIMO mmWave Radar

Yuanjie Shen, Minglong Zhang, Yulin Wu, Guolong Cui, Shisheng Guo
University of Electronic Science and Technology of China, China

In this paper, a method is proposed to effectively detect the darting-out target occluded by parked vehicle during the entire movement for millimeter wave radar. Two typical situations of electromagnetic (EM) propagation are studied when the target darting out from NLOS area to LOS area. The ground reflection EM signal is used to detection and tracking when darting-out target is located at NLOS area. The reflecting plane of parked vehicle is estimated to assist in eliminating interference caused by NLOS signals when darting-out target is located at LOS area.

12:20 – 14:00
Multichannel Signal Processing
Room: SALON E
Session Chairs: Antonio De Maio and Braham Himed

8003: Optimal Subspace Estimation in Radar Signal Processing
Kaushallya Adhikari, Richard Vaccaro, Ridhab Al Kinani
University of Rhode Island, United States
Many space-time adaptive signal processing algorithms rely on the estimates of the bases of signal and noise subspaces. Traditionally, these bases' estimates are formed using singular vectors of the data matrix or eigenvectors of the sample covariance matrix. These estimates are not very accurate and their use in subspace-based algorithms yield high errors. We present bases' estimates that are optimal to first order term in the noise matrix. The use of the first order optimal bases leads to significant improvement in the outcomes of subspace-based signal processing algorithms.

8146: Low Complexity Single-Snapshot DoA Estimation via Bayesian Compressive Sensing
Ignacio Roldan, Lucas Lamberti, Francesco Fioranelli, Alexander Yarovoy
Delft University of Technology, Netherlands
The problem of single-snapshot direction of arrival (DoA) estimation with antenna arrays has been considered. A sectorized approach based on Bayesian Compressive Sensing (BCS) has been proposed. In this method, the angular space is discretized, defining many non-overlapping small grids which cover the desired large angular space. First, a BCS estimation is run in each of the sectors to estimate the DoA of the signals. Then, a second stage is performed to correct the inconsistencies at the edges due to signal leaking between sectors. The performance of the method has been analyzed via extensive Monte-Carlo simulations in which the number of targets, their Radar Cross Section (RCS), and their location have been varied in a large extent, and the targets were observed by a Frequency Modulated Continuous Wave (FMCW) radar with an 86-element Uniform Linear Array (ULA). The results are compared with state-of-the-art methods in terms of estimation accuracy and resolution. Moreover, an analysis of the computational time, critical for many real-time applications, is presented, which shows a reduction of 20 times in the computational time compared with the standard BCS.

8066: Simultaneous Radar Detection and DOA Estimation in the Presence of Unknown Mutual Coupling
Massimo Rosamilia{1}, Augusto Aubry{1}, Antonio De Maio{1}, Lan Lan{2}
{1}Università degli Studi di Napoli Federico II, Italy; {2}Xidian University, China
This paper focuses on the joint adaptive radar detection and target Direction-of-Arrival estimation in the presence of mutual coupling among the array elements. A suitable model of the signal received by the multichannel radar is developed via a linearization procedure of the actual Uniform Linear Array manifold around the nominal array looking direction. The detection problem is tackled by means of the Generalized Likelihood Ratio Test (GLRT) and Multifamily Likelihood Ratio Test (MFLRT), leveraging a specific Minorization-Maximization (MM) framework. The performance of the devised architectures is compared with benchmarks as well as with counterparts neglecting the coupling phenomenon.

8064: Hybrid AOI/AOA Target Localization for Distributed MIMO Radar
Kui Xiong, Guolong Cui, Maosen Liao, Xianxiang Yu, Lingjiang Kong
University of Electronic Science and Technology of China, China
The distributed MIMO radar system with directional transmitters and directional receivers generating the angle of incidence (AOI) and angle of arrival (AOA) measurements is first considered for target localization. A constrained total least squares (CTLS) problem is formulated considering noises in both the data matrix and the observation vector, and the weighted CTLS (WCTLS) algorithm is proposed to solve this problem to obtain the estimate of the target position in a closed form. Numerical simulation results demonstrate that the proposed algorithm is superior to other popular localization methods.

8248: Robust Adaptive Beamforming for Flexible Conformal Array with Parameter Errors and Mutual Coupling
Yizhen Jia, Kexin Huang, Minghui Ni, Wenqin Wang
University of Electronic Science and Technology of China, China
Since the performance of flexible conformal array (FCA) is sensitive to the errors of controlling parameters, an adaptive beamforming (ABF) method which is called multiple domain interference-plus-noise covariance matrix reconstruction and steering vector estimation (MD-SV) is proposed to compensate them associated with other types of errors. The FCA is

modeled as a structure which is composed of two splice rings whose radius that are named controlling parameters (CPs) can be changed by users. The ABF procedure is mainly consisted of multi-dimensional integral and CPs estimation stages, that to estimate the perturbational steering vector and approximate it using alternative optimization. Simply, the first stage is implemented by a discrete sum in multi-domain including CP and angle domain, and the second stage of SV estimation is fulfillment by an alternative optimization procedure. Simulation results demonstrate that the proposed method achieves better performance under multiple mismatches over a wide range of input signal-to-noise ratios.

12:20 – 14:00
Radar Imaging
Room: CONF RMS 1-4
Session Chairs: Marco Martorella and Brian Rigling

8026: Range Migration Algorithm Using Doppler-Division Multiplexed Multiple-Input Multiple-Output Imaging

Takayuki Kitamura, Satoshi Kageme, Kei Suwa
Mitsubishi Electric Corporation, Japan

This paper proposes a range migration algorithm (RMA) applied to Doppler-division multiplexed multiple-input multiple-output (DDM-MIMO) synthetic aperture radar imaging for security checkpoints attached to a moving walkway. It is possible to achieve faster image reconstruction of dangerous objects in combination with DDM-MIMO. The mathematical derivation of the algorithm and its computational complexity compared to the back-projection algorithm are detailed in this study. The details of the numerical simulation of a point target and an experiment with two objects are also presented to verify the performance of the algorithm.

8077: Curvilinear Aperture Monopulse

Mark Story
Oak Ridge National Laboratory, United States

By a symmetry argument, a synethic aperture radar collection along a linear path does not collect three-dimensional information about the scene. However, it is known that vertical curvature can be used to derive some vertical position information. This paper approaches the problem from a monopulse perspective, resulting in a non-iterative computation that commutes with efficient image formation algorithms.

8111: Change Detection for High-Resolution Drone-Borne SAR at High Frequencies – First Results

Ali Bekar, Michail Antoniou, Christopher John Baker
University of Birmingham, United Kingdom

This paper presents initial results of SAR imaging and change detection for a high-resolution (6x30cm), short-range drone-borne radar system. A novel hybrid approach to change detection is developed using the main SAR system parameters of altitude, look angle, and range to the scene center. These are used to determine the derived change detection sensitivity and to identify and quantify image decorrelation, a basic measure of change detection performance. An overview of the algorithm developed to generate incoherent/coherent change maps is also presented. In order to examine this approach to change detection on a practical basis, a high-resolution 24 GHz drone-borne SAR system is used, for the first time, to demonstrate and quantify performance based on real-world experiments.

8256: Low-Complexity Forward-Looking Volumetric SAR for High Resolution 3-D Radar Imaging

Adnan Albaba, Marc Bauduin, Hichem Sahli, André Bourdoux
imec, Belgium

In this paper, the three-dimensional (3-D) imaging problem of monostatic forward-looking synthetic aperture radar (FL-SAR) is analyzed. A 3-D guided-and-decimated backprojection (3-D GDBP) algorithm is proposed for reducing the computational complexity of 3-D FL-SAR image reconstruction. This is done by combining range and Doppler processing together with decimation along the slow-time samples and backprojection along the fast-time samples. In addition, the geometry and frequency-modulated continuous wave (FMCW) signal model for the 3-D FL-SAR problem are presented. Finally, the performance of the proposed method is tested and compared against the 3-D decimated backprojection algorithm.

8282: Drone-Based 3DInISAR: Experimental Results

Elisa Giusti{1}, Selenia Ghio{1}, Marco Martorella{2}
{1}CNIT, RaSS National Laboratory, Italy; {2}University of Birmingham, United Kingdom

Three-dimensional (3D) radar imaging of non-cooperative targets has become very attractive as it significantly improves the traditional two-dimensional radar imaging technology. Drone-based radar systems offer a very flexible, easily deployable and low-cost solution for airborne radar imaging applications. This paper presents the results of the first experiment in which 3D InISAR technique has been implemented using a swarm of drones. The systems is composed of four radars, one transmitting and three receiving, installed on drones. Drones were flying in a suitable formation to form a dual orthogonal baselines antenna configuration.

12:20 – 14:00
Tracking 2
Room: CONF RMS 20-21
Session Chairs: Stefano Coraluppi and Alex Charlish

8071: On the NCA Versus NCV Models in Tracking Maneuvering Targets
Dale Blair{1}, Yaakov Bar-Shalom{2}
{1}Georgia Institute of Technology, United States; {2}Univesity of Connecticut, United States
When tracking maneuvering targets with a nearly constant velocity (NCV) Kalman filter with discrete white noise acceleration (DWNA) or a nearly constant acceleration (NCA) Kalman filter with discrete Wiener process acceleration (DWPA), the selection of the process noise variance is complicated by the fact that the process noise errors are modeled as zero-mean white Gaussian, while target maneuvers are deterministic or highly correlated in time. In recent years, for the NCV Kalman filters with DWNA, the deterministic tracking index was introduced and used to develop a relationship between the maximum acceleration of the target and the process noise variance that minimizes the maximum mean squared error (MaxMSE) in position. Recently, the design methods for NCV Kalman filters with DWNA were extended to develop design methods for NCA Kalman filters with DWPA for tracking maneuvering targets, and the effectiveness of the design methods were illustrated via Monte Carlo simulations. However, the question of when to use an NCA filter instead of an NCV filter for tracking maneuvering targets remained unanswered. In this paper, this question is addressed.

8039: Adaptation of Multi-Target Tracker Using Neural Networks in Drone Surveillance Radar
Finn Goodall{1}, Bashar I. Ahmad{2}
{1}University of Cambridge, United Kingdom; {2}University of Cambridge, Thales Group, United Kingdom
In this paper, we present a study on adapting a radar multi-target tracker using neural networks to enhance its performance against agile, maneuvering, targets such as drones. In particular, a network dynamically adjusts the process noise of the target motion model based on the normalised filtering innovations. Different neural networks are evaluated for this task, namely fully connected, recurrent and convolutional networks. They are trained on representative simulated data, including from waypoint-driven trajectories which are common with (semi-)autonomous systems, e.g. small unmanned air systems. Results from synthetic radar data demonstrate the potential benefits of adapting a multi-target tracker with a low-complexity recurrent neural network, albeit the modest improvements it achieves.

8177: Drone Tracking Based on the Fusion of Staring Radar and Camera Data: An Experimental Study
Maxence de Rochechouart{4}, Bashar Ahmad{1}, Amal El Fallah Seghrouchni{3}, Frederic Barbaresco{5}, Stephen Harman{2}, Raed Abu Zitar{4}
{1}Aveillant Ltd, Thales Land and Air Systems, United Kingdom; {2}Aveillant, Land and Air Systems, Thales, United Kingdom; {3}Mohammed VI Polytechnic University, AI Movement, Morocco; {4}Sorbonne University Abu Dhabi, U.A.E.; {5}Thales Group, France
It is widely recognized by the security and defense community that the surge in the use of the widely available off-the-shelf (e.g. Class I, sub-50 kg) drone platforms represents a developing threat to the manned aviation and sensitive infrastructure or assets in the civil as well as the military sector. They are cheap with increasingly more capabilities (e.g. capitalizing on recent advances in artificial intelligence and sensing systems), and can be easily acquired and operated. Consequently, miscellaneous news items on drone-related incidents worldwide are regularly reported. This triggered a growing demand for non-cooperative drone surveillance technology, e.g. to monitor no-fly zones around airports

8287: Fusion of Asynchronous Radar and Infrared Sensors Data on a Moving Platform Using the PHD Filter
Jiaye Yang{2}, Wenxin Li{2}, Mahendra Mallick{1}, Wei Yi{2}
{1}Independent Consultant, United States; {2}University of Electronic Science and Technology of China, China
We consider heterogeneous asynchronous sensor fusion of radar and infrared (IR) data on a moving platform. Existing work

seldom considers heterogeneous and asynchronous problems simultaneously. First, we build models for radar and IR sensors. Since they have different coordinates, dimensions and data rates, some valid solutions are raised in the paper. The unscented transformation (UT) is used to unify their coordinates. Then, a cropping algorithm is proposed to align their dimensions. We use a batch processing method to handle the asynchronous arrival time. For efficient multitarget tracking (MTT), we extend the heterogeneous trackers into the Probability Hypothesis Density (PHD) filter even though their models are distinct. In view of the unknown dependence between sensors on the same platform, the posteriors are fused on the Generalized Covariance Intersection (GCI) rule. Further more, combined with the distinct models, a concrete form of heterogeneous asynchronous GCI rule is derived. Finally, numerical results confirm the excellent performance of the proposed fusion scheme.

8341: The GMCPHD Filter for Irregular Group Target Spawning Based on Star-Convex RHMs

Yue Liu, Wenxin Li, Haiyi Mao, Cong Peng, Wei Yi
University of Electronic Science and Technology of China, China

In this paper, a GMCPHD filter for group target spawning based on star-convex RHM is proposed. We aim to better estimating the irregular group shape in the scene of group target spawning. Star-convex RHM is used to describe the extended shape, besides, the distance division method is used to realize the division of measurement sets and the judgment of group spawning. On this basis, we develop a SRHM-CPHD filter and obtain the GM implementation. Simulation of group targets with spawning and star-convex shapes confirm that the proposed SRHM-CPHD filter significantly improves the accuracy of shape estimate. In addition, the proposed SRHM-CPHD filter also improve the accuracy of group target state estimate.

14:00 – 14:30
Coffee Break

14:30 – 16:10
Discrete Optimization for Radar Waveforms
Room: SALON D (CD)
Session Chairs: Bill Correll and Ram Narayanan

8053: Enumeration and Generation of Peak Sidelobe Level Equivalence Classes for m-ary Phase Codes

Bill Correll Jr{3}, Christopher Swanson{1}, Jon Russo{2}, Greg Coxson{4}
{1}Ashland University, United States; {2}Lockheed Martin Advanced Technology Laboratories, United States; {3}Maxar Technologies, United States; {4}United States Naval Academy , United States

The peak sidelobe level of the autocorrelation of a code for m-ary phase shift keying is invariant under a particular group of mappings. Thus, it suffices to search for codes having minimal peak sidelobe by testing a single representative of each equivalence class. We present a new, more efficient algorithm to find a single representative of each equivalence class for the sake of exhaustive searches. In order to validate the algorithm, we use Burnside's Lemma from group theory to enumerate the PSL equivalence classes as orbits of a group action. The closed form expression we derive determines the minimal fraction of the search space that must be examined in an exhaustive search.

8118: A Computational Electromagnetics Framework for a Matched Illumination Approach to Waveform Optimization

Zacharie Idriss{2}, Raghu Raj{2}, Ram Narayanan{1}
{1}Pennsylvania State University, United States; {2}U.S. Naval Research Laboratory, United States

A waveform is tailored to increase target information at the receiver by removing the effects of clutter such as signal dependant ground bounce in downward looking ground penetrating radar (GPR). The scene is modelled from an electromagnetic perspective where the scattering equations are discretized and solved using the Method of Moments (MoM). Monte Carlo runs are carried out to get an average surface roughness to be used in the waveform optimization. We see that the waveform optimized to match a target energy distribution is able to remove the ground bounce to better image a buried scatterer.

8169: A Nonlinear Sum of Squares Search for CAZAC Sequences

Mark Magsino{2}, Yixin Xu{1}
{1}Ohio State University, United States; {2}United States Naval Academy, United States

We report on a search for CAZAC sequences by using nonlinear sum of squares optimization. Up to equivalence, we found all length 7 CAZAC sequences. We obtained evidence suggesting there are finitely many length 10 CAZAC sequences with a total of 3040 sequences. Last, we compute longer sequences and compare their aperiodic autocorrelation properties to known sequences. The code and results of this search are publicly available through GitHub.

8390: Design of Binary Sequences with Low Periodic Autocorrelation Sidelobes

André Bourdoux, Marc Bauduin
imec, Belgium

Binary sequences with good periodic autocorrelation properties are essential for phase-modulated continuous-wave radars. Except for a few well-known sequence families with optimal sidelobes, the search for long binary sequences with low sidelobes is difficult because of the very large search space. We propose a search algorithm, valid for any length, that leads to near-optimal sequences in reasonable search time. The sequences that we generate have lower peak sidelobes than state-of-the-art sequences. This enables to create large sequence sets supporting waveform diversity. We provide search results for all lengths smaller than 200 and for some lengths up to 10000.

8002: Adaptive Radar Subarray Scheduling

Kevin Wagner, Taylor George
United States Naval Research Laboratory, United States

This document presents an adaptive subarray scheduling algorithm, capable of dynamically managing pre-defined subarray configurations for radar search and track functions.

14:30 – 16:10
Dual-Function Radar/Communications
Room: SALON E
Session Chairs: Cenk Sahin and Sabrina Greco

8379: Design and Demonstration of an OFDM Based RadCom System

Grant Norrie, Stephen Paine
University of Cape Town, South Africa

The paper presents the design, implementation and demonstration of a software defined radar that utilises OFDM based signals built on the digital audio broadcast (DAB) standard to perform radar detections and transfer communication data simultaneously. The approach differs from existing approaches in that it takes a radar first approach with the communication aspect secondary. This allows for the design of a radar to meet system requirements before injecting a communication signal into the radar signal. The system can be used as both an active monostatic or active/passive multistatic system depending on the target system design.

8205: Radar-Centric ISAC Through Index Modulation: Over-the-Air Experimentation and Trade-Offs

Murat Temiz, Nial Peters, Colin Horne, Matthew Ritchie, Christos Masouros
University College London, United Kingdom

This study experimentally demonstrates a radar-centric integrated sensing and communication (ISAC) system that exploits the radar transmission parameters as modulation indexes to communicate with the user devices while performing short-range radar sensing. The center frequency, bandwidth, and polarization of the transmitted radar chirps are used as modulation indexes. The simulation results have been verified by real-time over-the-air experimental measurements that have also revealed the trade-off between the radar sensing performance and communication data rate, depending on the radar waveform parameters selected in the ISAC system. The proposed dual-function radar and communication system was shown to reach up to 10 Megabits/s throughput depending on the bandwidth and centre frequency separations and chirp duration.

8221: High-Throughput Communications Using Constant-Modulus Waveforms with Mitigation of Range-Sidelobe Modulation

Ian Weiner, Houssam Abouzahra, Mitchell Leroy
MIT Lincoln Laboratory, United States

In a previous paper, we introduced a flexible methodology for the design of dual-use waveform alphabets which are suitable for simultaneous use in radar and wireless communications. Here we extend this work to accommodate waveforms of constant modulus, and explain how pulse compression constraints may be leveraged to significantly mitigate the significant issue of range-sidelobe modulation. We report results of a field test which validated performance expectations.

8274: Physically Realizable Multi-User Radar/Communications (MURC)

Brandon Ravenscroft{2}, Alfred Fontes{2}, Patrick M. McCormick{2}, Shannon D. Blunt{2}, Cameron Musgrove{1}
{1}IERUS Technologies, Inc., United States; {2}Radar Systems Lab, University of Kansas, United States

Leveraging a recent method for spectrally-shaped random FM (RFM) waveform generation, in conjunction with a particular implementation of spread-spectrum signaling, a multi-user form of dual-function radar/communication (DFRC) is proposed that seeks to balance the disparate requirements of each function. Using a radar-amenable spread-spectrum multiple-access signaling scheme, receive dynamic range for sensing is preserved by exploiting high-dimensional (and thus separable) waveforms, which are specifically structured to convey encoded information in a manner that can be readily decoded at a communication receiver.

8251: Experimental Testing of an OTFS-Modulated Waveform in a Joint Radar-Comm System

Pavel Karpovich{2}, Tomasz Zielinski{1}, Radoslaw Maksymiuk{3}, Piotr Samczyński{3}, Karol Abratkiewicz{3}, Piotr Tomikowski{3}
{1}AGH University of Science and Technology, Poland; {2}AGH University of Science and Technology, Nokia, Poland; {3}Warsaw University of Technology, Poland

This work presents novel results from experimental testing of a recently proposed Orthogonal Time Frequency Space Modulated (OTFSM) waveform in a joint radar-communication system (RadComm). A typical OTFSM signal is used with the standard pilot built from an impulse surrounded by a zero-value square zone in the delay-Doppler domain. The transmitter and receiver use software-defined radio (SDR) technology and have different static locations. The receiver, equipped with reference and surveillance antennas, works as a 4-QAM digital data communication decoder and a passive radar workstation. It is shown in the paper that both goals of the system are reached: 1) after channel estimation and correction, the transmitted data are recovered, and 2) cars moving nearby are properly detected.

14:30 – 16:10
Space Based Sensors
Room: CONF RMS 1-4
Session Chairs: Alberto Moreira and Richard Tillman

8203: The Tomorrow.io Pathfinder Mission: Software-Defined Ka-Band Precipitation Radar in Space

Richard Roy, James Carswell, Mauricio Sanchez-Barbetty, Timothy Maese, John Springmann
Tomorrow.io, United States

As the first stage in the development of a precipitation mapping constellation of microwave radars and sounders, Tomorrow.io is launching two Pathfinder spacecraft, Tomorrow-R1 and Tomorrow-R2, each outfitted with a novel Ka-band precipitation radar payload based on a software-defined radar (SDR) intermediate frequency (IF) transceiver. The radar transmitter is tunable throughout the allocated 35.5-36 GHz active transmission band, and features an all-solid-state transmitter capable of 42 dBm saturated power output at 30% duty cycle, which is coupled to a solid 1.2 m Cassegrain reflector antenna system. Capable of 500 MHz of instantaneous bandwidth, the SDR allows for pulse-to-pulse reconfigurability of the transmit waveform and digital receiver parameters, offering unique sampling capabilities for precipitation sensing as well as the ability to operate in a wideband altimetry mode. Here we provide an overview of the Pathfinder mission and development approach, placing it in the context of the broader spaceborne cloud and precipitation radar program of record, as well as relevant details around the instrument design, capabilities, sampling approach, and estimated sensitivity.

8273: Robustness of PolSAR Cs to Calibration Errors

Jacob Morrison, John Becker, Julie Jackson
Air Force Institute of Technology, United States; Air Force Institute of Technology, Australia

Dropped-channel polarimetric synthetic aperture radar (PolSAR) compressive sensing (CS) reduces data storage/transmission and receiver hardware requirements by utilising antenna crosstalk and CS techniques to recover dropped channel(s). This paper examines the robustness of dropped-channel PolSAR CS (DCPCS) to calibration errors on the antenna crosstalk matrix. Although the antenna design problem is relaxed to a large region of acceptable crosstalk values, very accurate calibration may be required.

8437: The P-Band Space Exploration Synthetic Aperture Radar (SESAR)

Rafael Rincon{1}, Lynn Carter{5}, David Hollibaugh-Baker{1}, Cornelis Du Toit{3}, Kenneth Segal{1}, Martin Perrine{4}, Peter Steigner{1}, Iban Ibanez{2}

{1}NASA, United States; {2}NASA, Catholic University, United States; {3}NASA, Science Systems and Applications Inc, United States; {4}NASA, University of Maryland, United States; {5}University of Arizona, United States

The Space Exploration Synthetic Aperture Radar (SESAR) is a P-band (435 MHz) radar instrument for planetary applications developed at the NASA Goddard Space Flight Center. The radar is capable of measuring the surface and subsurface of planetary terrains at full polarimetry and at meter-scale resolution. The radar architecture is based on a low power, lightweight, beamforming design, specifically developed to meet stringent requirements of planetary instruments. The SESAR developmental effort designed and built a prototype SAR instrument, and environmentally tested it, thus maturing the SESAR technology readiness level for upcoming planetary mission opportunities.

8032: A Parallel Dual-Task Learning Network for InSAR Phase Retrieval

Xu Zhan, Xiaoling Zhang, Xiangdong Ma, Jun Shi, Shunxin Zheng, Jiaping Chen, Shunjun Wei, Tianjiao Zeng

University of Electronic Science and Technology of China, China

This work focuses on the problem of InSAR phase retrieval. Current methods cascade filtering and phase unwrapping, causing precision loss from accumulated errors and efficiency loss. To address these issues, we propose a parallel dual-task learning work. The phase is retrieved in a parallel manner. Three core phases are considered: feature attraction, learning, and task balancing. A hybrid Trans-Encoder module is proposed to attract InSAR features locally and nonlocally. A dual-decoder is proposed to denoise and unwrap parallelly. An uncertainty-weighted loss is proposed to balance two tasks. Experiments verify its higher precision and efficiency compared to other methods.

14:30 – 16:10
Radar Modeling & Simulation
Room: CONF RMS 20-21
Session Chairs: Jamie Bergin and Sandeep Gogineni

8030: Single-Bounce, Physical-Optics Radar Target Modeling

Brian Rigling

University of Dayton, United States

Many applications of radar signal processing research call for the utilization of measurements or simulations of radar target responses. As measurements are difficult to obtain, simulations are often the approach of choice, but even there, it can be difficult to access high-fidelity scattering simulations, despire a wide variety of faceted models being openly available. This tutorial paper seeks to illustrate what can be accomplished through lower fidelity single-bounce, physical optics RF scattering simulation. We seek to demonstrate the relative ease with which researchers might implement their own scattering models to support the specific needs of their projects. We demonstrate the effectiveness and limitations of this approach through comparisons of single-bounce physical optics results with high-fidelity simulations.

8276: Stochastic Transfer Function Approach for Modeling Wideband Radar Signals with High-Fidelity Motion Effects

Sandeep Gogineni{2}, Jameson Bergin{2}, Joseph Guerci{2}, Muralidhar Rangaswamy{1}

{1}Air Force Research Laboratory, United States; {2}Information Systems Laboratories Inc., United States

In this paper, we present a time-frequency sub-banding method to represent wideband radar signals with high-fidelity motion effects using stochastic transfer functions for each sub-band. This approach can be used to represent effects such as waveform dilation using a bank of impulse responses since a single impulse response cannot capture this effect. Similarly, effects such as intrapulse Doppler phase progression are captured by this approach. The impulse responses for all the sub-bands are computed separately and appropriately combined to provide the desired effect on the waveforms. Realistic simulations are used to demonstrate these results.

8388: Linear Time Varying Channel Matrix Approach for Modeling MIMO Radar Returns

Touseef Ali{1}, Christ Richmond{2}

{1}Arizona State University, United States; {2}Duke University, United States

Conventional approaches to modeling radar returns typically treat clutter stochastically, characterizing clutter returns with a covariance matrix. Such models fail to leverage the waveform dependence of the returns induced by clutter. An alternative model, based on the emerging use of channel matrix, is set forth and analyzed in this paper. In this formulation, returns from target and clutter are both modeled as responses of linear time-varying systems. Linear time-invariant systems are intrinsically inadequate to capture the behavior of doubly and triply spread channels. In contrast, the linear time-varying model described here is well suited for modeling clutter and target returns in MIMO radar. We discuss the statistical properties of this model and also present numerical simulations that reveal the effects of spreading.

8393: CoFAR Clutter Channel Estimation via Sparse Bayesian Learning

Kunwar Pritiraj Rajput{3}, Mysore R. Bhavani Shankar{3}, Kumar Vijay Mishra{2}, Muralidhar Rangaswamy{1}, Bjorn Ottersten{3}

{1}Air Force Research Laboratory, United States; {2}United States DEVCOM Army Research Laboratory, United States; {3}Université du Luxembourg, Luxembourg

We consider the problem of clutter channel impulse response (CIR) estimation in cognitive fully adaptive radar (CoFAR). Using high fidelity modelling and simulation tool RFView, we explicitly show that the clutter CIR is sparse in nature as only few range bins have non-zero CIR. Subsequently, we develop a sparse Bayesian learning (SBL)-framework to estimate the underlying sparse channel. Further, we derive the Bayesian Cram´er-Rao bound (BCRB) for the proposed scheme and show the effectiveness of the proposed SBL-based clutter channel estimation scheme through comparing its performance with the derived BCRB.

8435: Modeling Frequency Dependent Scattering Models for SAR Image Spectrum Extrapolation

Nithin Sugavanam, Emre Ertin

Ohio State University, United States

Synthetic Aperture Radar Image of a target can be modeled as superposition of returns from the different scattering mechanisms that makes the target. Each scattering mechanism can have a reflectivity exhibiting a strong azimuthal pattern, which in turn can depend on the center frequency. In this work we present a method to jointly model the scattering response of targets over a wide aperture of measurements and a wide swath of frequencies spanning C to X Band. Specifically, we consider disjoint frequency bands and estimate the scattering centers and azimuth dependent responses that also consider the wavelength of the illuminating waveform. We verify the validity of the proposed model using simulated data from a backhoe over 7 to 12 GHz divided into non-overlapping frequency bands.

16:20 – 17:30
EW Panel and Closing
Room: SALON E

Garrett Hall
Southwest Research Institute (SwRI)

Karen Haigh
Haskill Consulting

Col. William Young, Jr
Eglin Air Force Base

Steven D. Harbour
Southwest Research Institute (SwRI)

Sevgi Gurbuz
University of Alabama

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