RadarConf'24

2024 IEEE RADAR CONFERENCE

May 6-10, 2024 // Hilton Denver City Center // Denver, Colorado

IEEE RADAR CONFERENCE 2024

CONFERENCE PROGRAM

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2024.ieee-radarconf.org

Table of Contents

Cover Page 1
Table of Contents 2
Welcome from the Chairs 3
Organizing Committee 4
Reviewers 8
Venue Layout 11
RadarConf'24 Sponsors 12
Exhibit Hall 15
Exhibitor Bingo 16
Poster Layout 17
Program at a Glance 19
Plenary Speakers 25
Radar Boot Camp 28
Industry Panel 34
DEI Inclusion Workshop/Luncheon 37
Awards Ceremony 38
Tutorials 47
Technical Program – Tuesday, May 7 65
Technical Program – Wednesday, May 8 84
Technical Program – Thursday, May 9 120

Welcome from the Chairs

On behalf of the Organizing Committee, it is our pleasure to welcome you to the "Peak of Innovation" at the 2024 IEEE Radar Conference (RadarConf'24). The conference is held in Denver, in the heart of the walkable downtown. We gratefully acknowledge the financial and technical sponsorship of the IEEE Aerospace and Electronic Systems Society (AESS), and the Technical Co-Sponsorship of the Microwave Theory and Techniques Society (MTT-S). We also thank Conference Catalysts for managing the organization of this year's event.

This year's edition of the conference will kick off with the first-ever "Picard Talk", where last year's winner of the IEEE Denis J. Picard Medal for Radar Technologies and Applications, the IEEE's highest honor for contributions to radar, will give the keynote for the Radar Conference. We are honored that Dr. Alberto Moreira of the German Aerospace Center will provide the inaugural talk, and he will provide his perspective on the state-of-the-art and emerging paradigm shifts in spaceborne synthetic aperture radar (SAR). His talk will be followed by Plenary talks from Mr. Frank Sanders, Senior Technical Fellow of the Institute for Telecommunication Sciences at the U.S. National Telecommunications and Information Administration, and Dr. Tom Driscoll, the CTO of Echodyne.

Building on the successes of the past Radar Conference series, the exhibitor hall has sold out! We invite everyone to see the amazing products and services offered by our lineup of top-tier exhibitors and sponsors. As in past years, there will be a reception with exhibitor "Bingo" on Tuesday, May 7, 2024, a banquet on Wednesday, May 8, 20024, and an exciting, invited speaker for this year's Diversity, Equity, and Inclusion (DEI) Luncheon.

In addition to the high-quality technical program, we also have an excellent series of educational events. The Radar Boot Camp is featured on Saturday, May 4, 2024, and Sunday, May 5, 2024, with 10 talks from experts in the field of radar, and culminating with a hands-on lab featuring hardware from Analog Devices. There is also a terrific lineup of 17 tutorials from world-class experts, a student paper competition, and a Radar Challenge.

We hope that in between the exciting events, you take the time to explore the exciting city of Denver and the surrounding Rocky Mountains and look forward to seeing you in person at the 2024 Radar Conference!

Justin Metcalf
University of Oklahoma

Braham Himed
Air Force Research Laboratory

Organizing Committee

General Co-Chairs:

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Braham Himed, *Air Force Research Laboratory, USA*

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Diversity, Equity, and Inclusion (DEI) Chair

Jackie Fairley, *Georgia Tech Research Institute, USA*

Event Coordinator

Coral Miller, *Conference Catalysts, LLC., USA*

Reviewers

The conference thanks the following distinguished experts for their invaluable help with the review process.

Aboutanios, Elias
Abramovich, Yuri
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Addabbo, Pia
Adve, Ravi
Agate, Craig
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Alharbi, Hazza
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Charlish, Alexander
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Ivic, Igor
Jackson, Julie
Jahangir, Mohammed
Jansen, Feike
Jarvis, Rachel
Javadi, Hamed
Jeannin, Mayeul
Jedrzejewski, Konrad
Johnson, Ben
Jones, Aaron
Jones, Christian
Kadlimatti, Ravi
Kahlert, Moritz
Kang, Bosung
Karbasi, Seyed
Mohammad
Kemkemian, Stephane
Kenney, Russell
Kern, Nicolai
Khenchaf, Ali
Kim, Bongseok
Kim, Sangdong
Kim, Yoon-sl
Kirubarajan, Thia
Knott, Peter
Kohnert, Soren
Koivunen, Visa
Kollias, Pavlos
Kolodziej, Ken
Krasnov, Oleg
Kropfreiter, Thomas
Kruse, Nicolas
Kulpa, Krzysztof
Kumbul, Utku
Kurdzo, Jim
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Laroussi, Toufik
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Lee, Jonghun
Lee, William
Leifer, Mark
Li, Changzhi
Li, Guchong
Li, Haobo
Liu, Jun
Li, Wenchao
Lisi, Francesco
Liu, Shengheng
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Loffeld, Otmar
Lops, Marco
Lukowski, Tom
Luong, David
Lupidi, Alberto
Maffei, Marco
Malanowski, Mateusz
Mancuso, Francesco
Mani, Anil Varghese
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Massaro, Davide
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Qiao, Xingshuai
Quintero, Chuck
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Rahman, Mahbubur
Ram, Shobha
Ramasubramanian,
Karthik
Rangaswamy, Muralidhar
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Ricciardi, Gerald
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Robey, Frank
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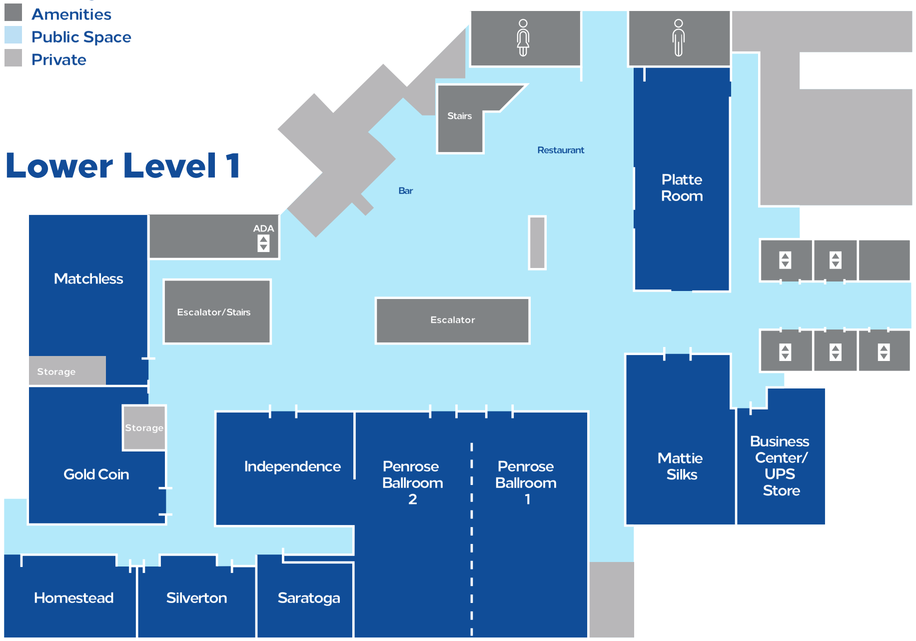
Romero, Ric

Rosamilia, Massimo
Rosenberg, Luke
Rothmeier, Thomas
Ruan, Hongning
Rucker, Robert
Ruggiano, Mayazzurra
Safa, Ali
Sahin, Cenk
Sahli, Hichem
Sakhnini, Adham
Salazar, Cesar
Samczynski, Piotr
Santi, Fabrizio
Santra, Avik
Schily, Hans
Schvartzman, David
Sharifi, Hasan
Shifrin, Michael
Showman, Greg
Sletten, Mark
Smith, Josiah
Solodky, Gaston
Soltanalian, Mojtaba
Steffes, Christian
Stevens, Daniel
Stevens, Malcolm
Stiles, Jim
Stone, Sam
Story, Mark
Stove, Andy
Summerfield, John
Sun, Guohao
Sun, Shunqiao
Sun, Yuliang
Talisa, Salvador
Techau, Paul
Teixeira, Chris
Tema, Hebert
Tharmarasa, Ratnasingham
Thoresen, Thomas
Tillman, Hank
Tomei, Sonia
Trezza, Anthony
Ullmann, Ingrid
Ummenhofer, Martin
Uysal, Faruk
Vaesen, Kristof
Valdes Crespi, Ferran
Vergara, Humberto
Verlangieri, Bianca
Vijay, Kumar
Vishwakarma, Shelly
Von Dem Bussche, Tetmar
Wachowiak, Marcin
Wachtel Granado, Diogo
Wagner, Simon
Waldschmidt, Christian
Walterscheid, Ingo
Wang, Fangzhou
Wang, Guoli
Wang, Tianqi
Wang, Xiangrong
Wang, Ziqi
Watts, Simon
Weiß, Matthias
Wen, Yixin
Willett, Peter
Williamson, Chane
Winter, Robert
Wolff, David
Wong, Ken
Wu, Jian
Wu, Min
Wu, Ryan
Xie, Zongxing
Xu, Lifan
Yan, Junkun
Yan, Linjie
Yan, Shihao
Yarovoy, Alexander
Yi, Wei
Young, Robert
Yu, Tian-you
Yuan, Sen
Zaybekian, Guy
Zhang, Xin
Zhang, Yimin
Zhang, Yin
Zhang, Yongchao
Zheng, Rong
Zheng, Ruxin
Zhu, Simin

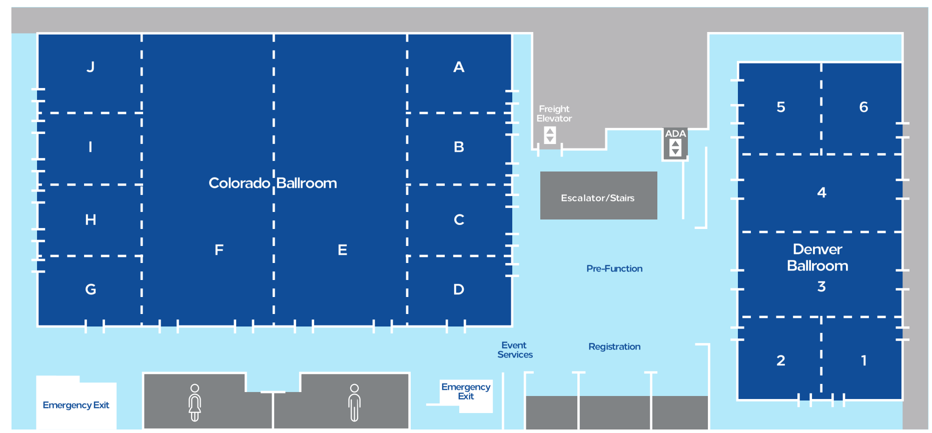
Conference & Events Rooms Floor Maps

FLOOR MAPS KEY
- Meeting/Conference Rooms
- Amenities
- Public Space
- Private

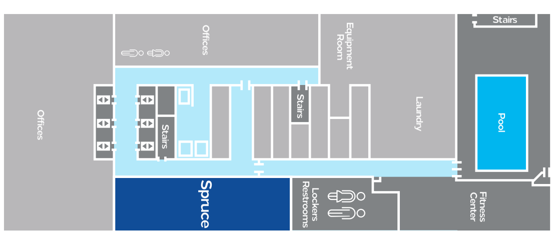
Lower Level 1



Lower Level 2



2nd Floor



3rd Floor

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EXHIBITOR HALL MAP

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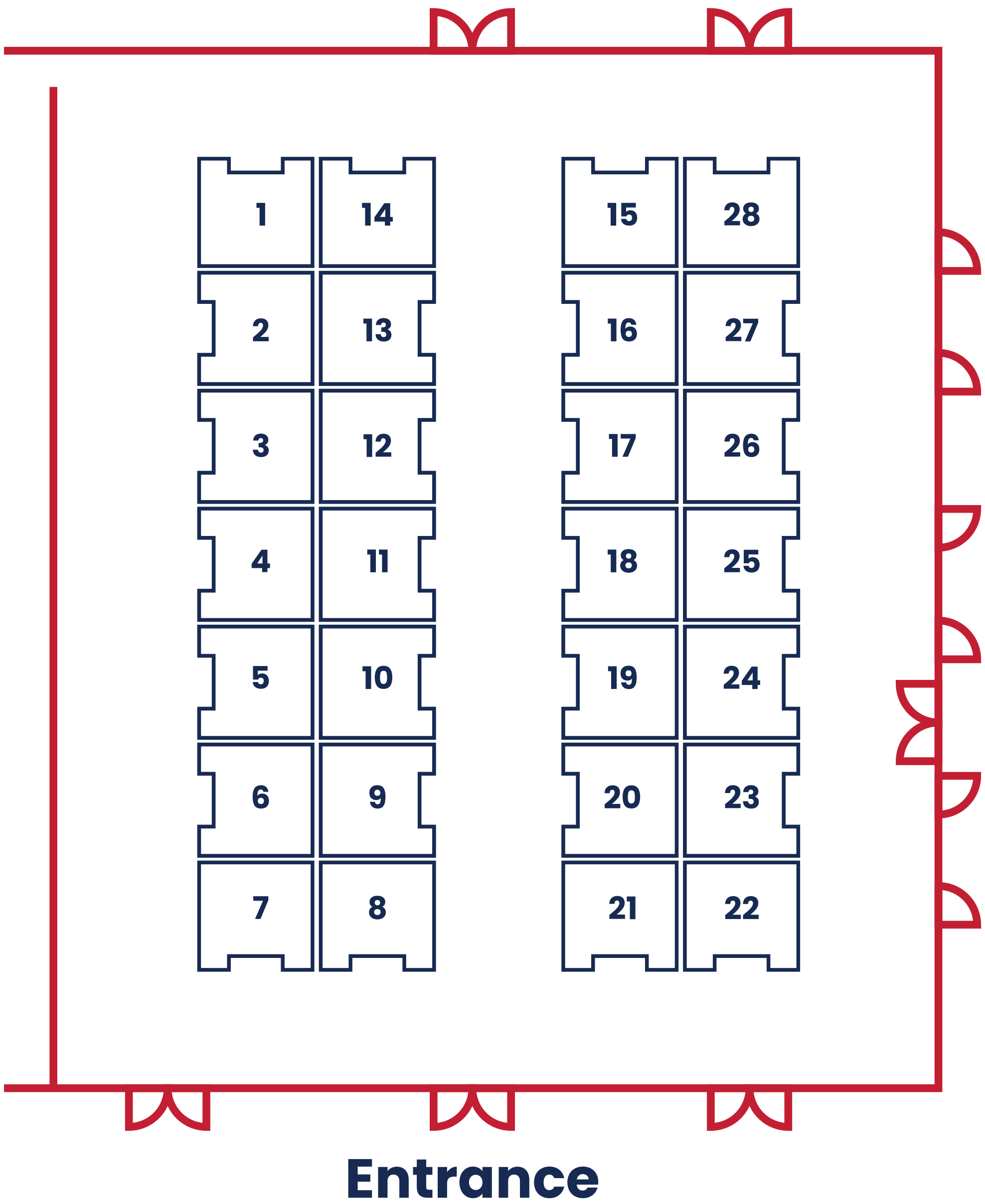

1. Vitesse Systems
2. Empower RF Systems, Inc.
3. AESS
4. Capella Space
5. Optical Zonu
6. Association of Old Crows
7. R&S
8. Rohde & Schwarz — Make ideas real
9. NSI MI — Ametek
10. BAE Systems
11. Samtec
12. Interface Concept
13. Trexon
14. Mitsubishi Electric — Changes for the Better
15. Stellant
16. MathWorks
17. Ophir RF — The Art of Wireless
18. str
19. Extreme Waves
20. Emerson. NI
21. Continental Electronics
22. Continental Electronics
23. Georgia Tech Research Institute
24. TTM Technologies — Time-To-Market Interconnect Solutions
25. Advanced Radar Research Center — The University of Oklahoma
26. Lockheed Martin
27. RFHIC
28. Information Systems Laboratories, Inc. ISL

Exhibitor Bingo

Exhibitor Bingo and Prize Drawing!

Bingo: Tuesday in the Exhibitor Hall

Drawing: Tuesday, 7:45 PM at the Exhibitor Reception

<u>STEP 1</u>

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.

<u>STEP 2</u>

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

<u>STEP 3</u>

Attend the Exhibitor Reception on Tuesday, May 7th in the Expo from 6pm to 8pm.

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

POSTER ROOMS

Wednesday, May 8, 2024

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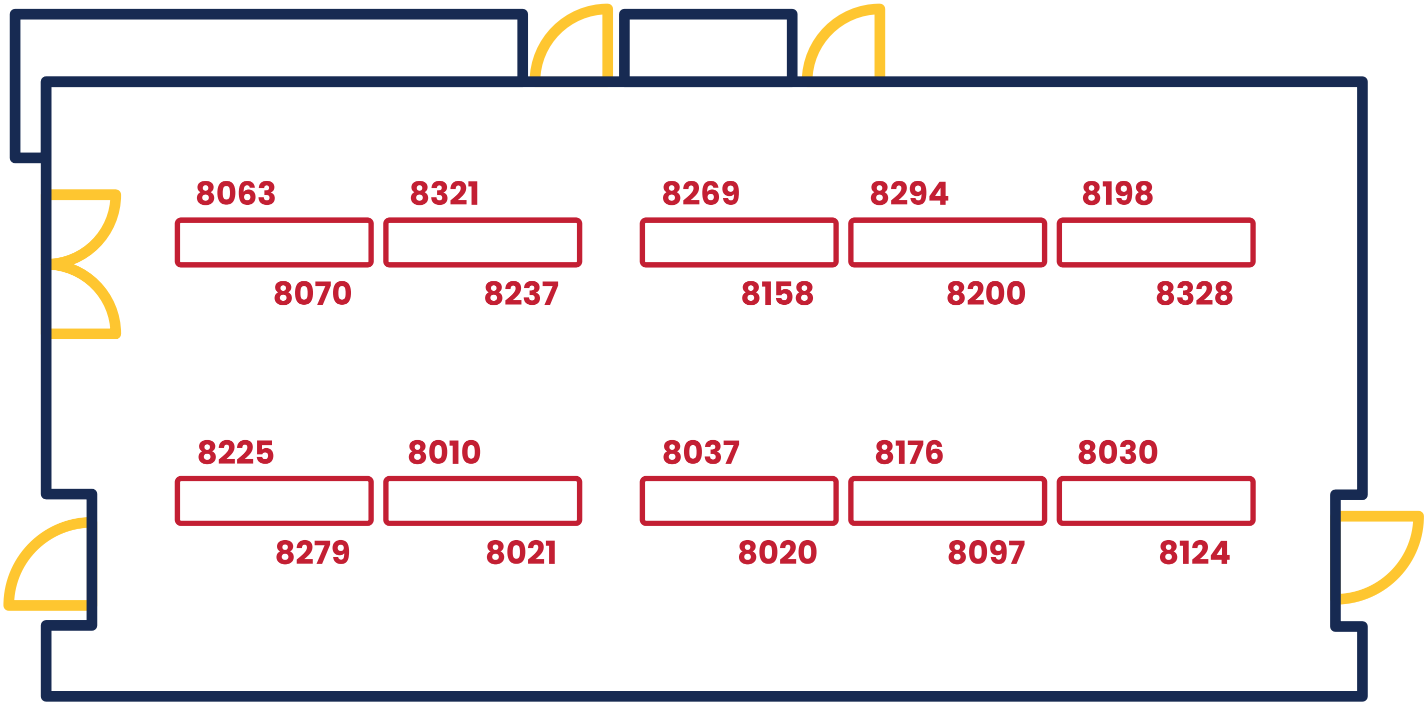
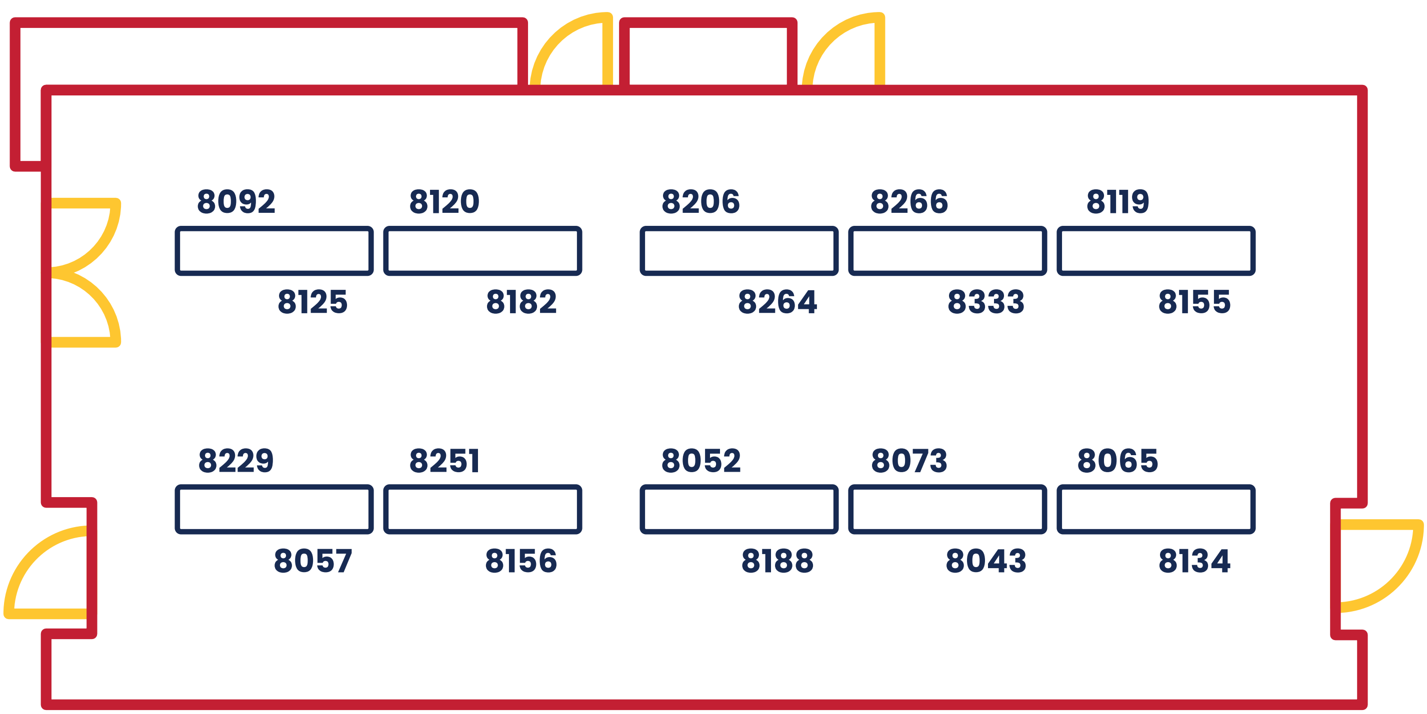
09:40 - 10:50



14:10 - 15:20



POSTER ROOMS
Thursday, May 9, 2024

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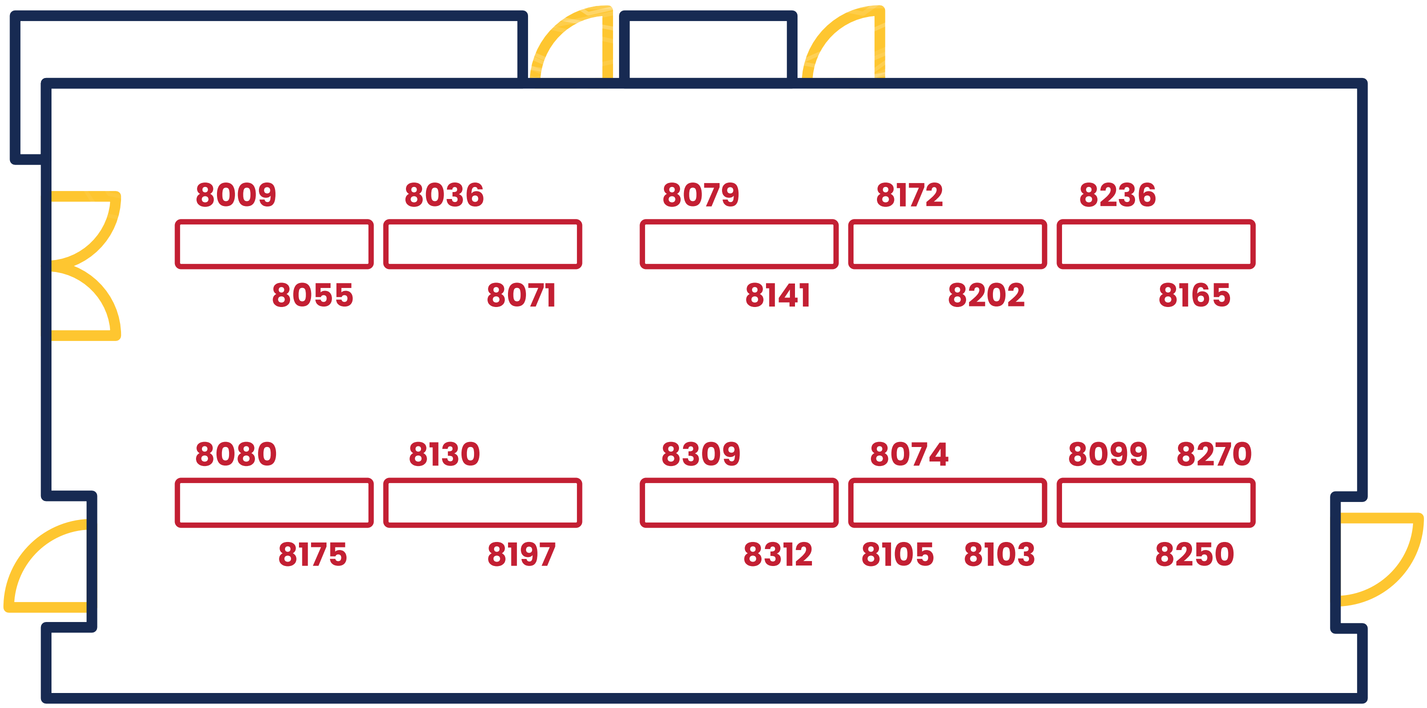
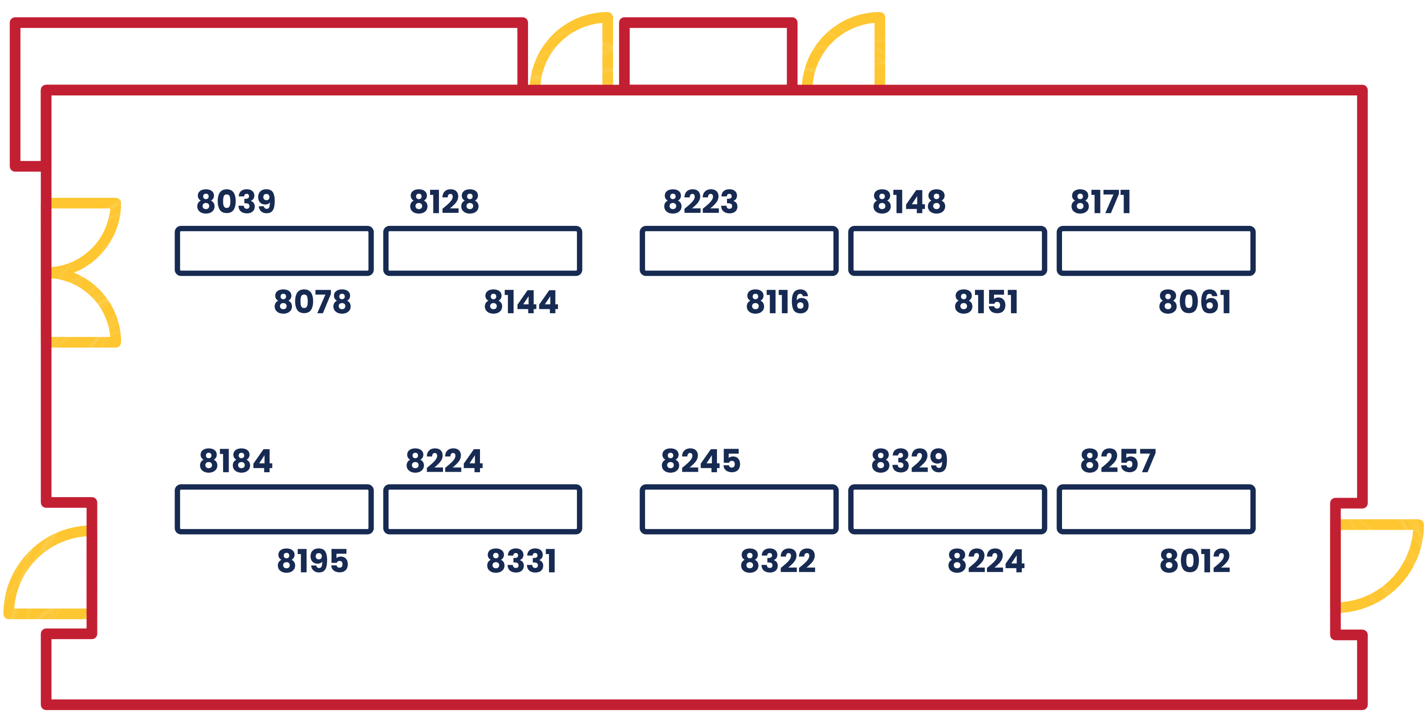
2024 IEEE RADAR CONFERENCE
May 6-10, 2024 // Hilton Denver City Center // Denver, Colorado

09:40 - 10:50



14:10 - 15:20



SATURDAY, MAY 4, 2024

Radar Boot Camp

08:45-09:00	OPENING REMARKS Christ Richmond Penrose 1
09:00-10:00	HISTORY OF RADAR Alfonso Farina Penrose 1
10:00-10:30	COFFEE BREAK Penrose 1
10:30-11:30	RADAR RANGE EQUATION Justin Metcalf Penrose 1
11:30-13:00	BOXED LUNCH Penrose 1
13:00-14:00	INTRODUCTION TO RADAR SYSTEMS Justin Metcalf Penrose 1
14:00-15:00	ESTIMATION AND DETECTION Christ Richmond Penrose 1
15:00-15:30	COFFEE BREAK Penrose 1
15:30-16:30	ARRAY SIGNAL PROCESSING David Schvartzman Penrose 1
16:30-17:00	LOW COST GNU RADIO RADAR DEMO Shane Flandermeyer Penrose 1

SUNDAY, MAY 5, 2024

Radar Boot Camp

09:00-10:00	STAP Mike Picciolo and Scott Goldstein Penrose 1
10:00-11:00	RADAR IMAGING Elisa Giusti Penrose 1
11:00-11:30	COFFEE BREAK Penrose 1
11:30-12:30	TRACKING Kristine Bell Penrose 1
12:30-14:00	BOXED LUNCH Penrose 1
14:00-15:00	HANDS ON LAB EXERCISES I: PHASED ARRAY BEAMFORMING Matt Ritchie /Jon Kraft, AD Penrose 1
15:00-15:30	COFFEE BREAK Penrose 1
15:30-16:30	HANDS ON LAB EXERCISES II: RADAR SIGNAL PROCESSING Matt Ritchie /Jon Kraft, AD Penrose 1

MONDAY, MAY 6, 2024

	TUTORIALS					
08:00-12:00	Introduction to Synthetic Aperture Radar COLORADO F	Introduction to Passive Radar COLORADO G	Introduction to Electronic Warfare COLORADO H	Micro-Doppler Signatures: Principles, Analysis & Applications COLORADO I	Hands On Phased Array Beamforming Workshop MATTIE SILKS	An Overview of Practical Spectrum Sharing Techniques for Radar and Communica-tions COLORADO J
10:00-10:30	Coffee Break Hall outside Colorado F-J					
12:00- 13:00	Lunch Penrose 2					
	TUTORIALS					
13:00: 17:00	Space-based Synthetic Ap-erture Radar (SAR): Princi-ples, Imaging Techniques and Future Develop-ments COLORADO F	Advanced Techniques and Applications for Passive Radar COLORADO G	Advanced Radar Detection and Capabilities COLORADO H	Systematic Filter Design for Tracking Maneuvering Targets: Getting Guaranteed Performance Out of Your Sensors COLORADO I	Hands On Adaptive Digital Beamforming Workshop MATTIE SILKS	Bistatic and Multistatic Radar Imaging COLORADO J
15:00-15:30	Coffee Break Hall outside Colorado F-J					
14:30-17:00	Student Paper Competition HOMESTEAD					
17:15-19:00	Radar Challenge COLORADO F					
18:30-20:30	IEEE AESS Young Professionals (YP) Network Colorado/Denver Ballroom Pre-function					

TUESDAY, MAY 7, 2024

07:00-08:30	SPEAKER BREAKFAST COLORADO F-J			
08:00-17:00	EXHIBIT HALL COLORADO A-E			
08:00-08:30	GENERAL & TECHNICAL CHAIR'S OPENING REMARKS DENVER BALLROOM			
08:30-09:15	PLENARY 1 - DR. ALBERTO MOREIRA DENVER BALLROOM			
09:15-10:00	PLENARY 2 - MR. FRANK SANDERS DENVER BALLROOM			
10:00-10:30	COFFEE BREAK COLORADO A-E			
10:30-11:15	PLENARY 3 - DR. TOM DRISCOLL DENVER BALLROOM			
11:15-12:00	INDUSTRY PANEL DENVER BALLROOM			
12:00-13:10	LUNCH COLORADO F-J		TAES LUNCH (CLOSED) INDEPENDENCE	
13:10-14:50	CLASSIFICATION DENVER BALLROOM 4	SPECTRUM SHARING DENVER BALLROOM 3	TRACKING DENVER BALLROOM 5-6	ARRAY PROCESSING FOR AUTOMOTIVE RADAR DENVER BALLROOM 2-1
14:50-15:20	COFFEE BREAK COLORADO A-E			
15:20-17:00	HUMAN PRESENCE & ACTIVITIES MONITORING (INVITED) DENVER BALLROOM 4	SAR IMAGE FORMATION DENVER BALLROOM 3	WAVEFORM DESIGN DENVER BALLROOM 5-6	ECCM AND INTERFERENCE CANCELLATION DENVER BALLROOM 2-1
18:00-20:00	EXHIBITOR RECEPTION COLORADO A-E			
19:00	RSP PANEL DINNER (CLOSED) PENROSE 2			

WEDNESDAY, MAY 8, 2024

07:00-08:30	SPEAKER BREAKFAST COLORADO F-J		
08:00-17:00	EXHIBIT HALL COLORADO A-E		
08:00-09:40	INTEGRATED RF SENSING AND COMMUNICATIONS (INVITED) DENVER BALLROOM 4	SDR PLATFORMS DENVER BALLROOM 3	RADAR RESOURCE MANAGEMENT DENVER BALLROOM 2-1
09:40-10:50	COFFEE BREAK COLORADO A-E	POSTER 1 DENVER BALLROOM 5-6	
10:50-11:50	INTEGRATED RF SENSING AND COMMUNICATIONS 2 (INVITED) DENVER BALLROOM 4	DETECTION DENVER BALLROOM 3	COMPONENT & SUBSYSTEM TECHNOLOGIES DENVER BALLROOM 2-1
11:50-12:50	LUNCH COLORADO F-J	DEI LUNCH PENROSE	
12:50-14:10	BEYOND LINEAR PROCESSING (BLIP) (INVITED) DENVER BALLROOM 4	PASSIVE RADAR DENVER BALLROOM 3	ANTENNA ARRAYS DENVER BALLROOM 2-1
14:10-15:20	POSTER 2 DENVER BALLROOM 5-6	COFFEE BREAK COLORADO A-E	
15:20-17:00	HISTORY OF RADAR (INVITED) DENVER BALLROOM 4	DIGITAL BEAMFORMING DENVER BALLROOM 3	COGNITIVE RADAR DENVER BALLROOM 2-1
18:00-19:00	PRE-DINNER RECEPTION PREFUNCTION SPACE		
19:00-22:00	BANQUET DINNER COLORADO F-J	BANQUET DINNER (OVERFLOW) PENROSE	

THURSDAY, MAY 9, 2024

07:00-08:30	SPEAKER BREAKFAST COLORADO F-J		
08:00-17:00	EXHIBIT HALL COLORADO A-E		
08:00-09:40	ON AI/ML FOR RADAR (INVITED) DENVER BALLROOM 4	LOCALIZATION AND AOA ESTIMATION DENVER BALLROOM 3	ESTIMATION DENVER BALLROOM 2-1
09:40-10:50	COFFEE BREAK COLORADO A-E	POSTER 3 DENVER BALLROOM 5-6	
10:50-11:50	RF SENSING FOR SPACE DOMAIN AWARENESS (INVITED) DENVER BALLROOM 4	WEATHER RADAR DENVER BALLROOM 3	MACHINE LEARNING FOR ACTIVITY DETECTION DENVER BALLROOM 2-1
11:50-12:50	HANDOFF LUNCH (CLOSED) HOMESTEAD	LUNCH COLORADO F-J	
12:50-14:10	SPARSE ARRAYS DENVER BALLROOM 4	PHENOMENOLOGY AND MODELING DENVER BALLROOM 3	SAR/ISAR ATR DENVER BALLROOM 2-1
14:10-15:20	POSTER 4 DENVER BALLROOM 5-6	COFFEE BREAK COLORADO A-E	
15:20-17:00	MULTISTATIC & DISTRIBUTED DENVER BALLROOM 4	SAR/ISAR IMAGING & EXPLOITATION DENVER BALLROOM 3	MACHINE LEARNING FOR RADAR APPLICATIONS DENVER BALLROOM 2-1
17:00-17:30	CLOSING DENVER BALLROOM 4		

FRIDAY, MAY 10, 2024

	TUTORIALS				
08:00-12:00	THREE-DIMENSIONAL INVERSE SYNTHETIC APERTURE RADAR COLORADO F	ACTIVE ELECTRONICALLY SCANNED ARRAYS: FUNDAMENTALS AND APPLICATIONS COLORADO G	MULTI-FUNCTION RF SYSTEMS FOR RADAR AND COMMUNICATIONS: SIGNAL PROCESSING, PROTOTYPING, AND EXPERIMENTS COLORADO H	NOISE RADAR: PRINCIPLES, SIGNAL PROCESSING, AND WAVEFORM DESIGN COLORADO J	DISTRIBUTED DETECTION, ESTIMATION, AND RESOURCE MANAGEMENT IN A NETWORK RADAR COLORADO I
10:00-10:30	COFFEE BREAK OUTSIDE COLORADO BALLROOM				
08:00-17:00	AESS BOARD OF GOVERNORS (CLOSED) PENROSE 1				

SATURDAY, MAY 11, 2024

08:00-17:00	AESS BOARD OF GOVERNORS (CLOSED) PENROSE 1

Plenary Speakers

Alberto Moreira
"Space-based Synthetic Aperture Radar: Future Technologies and Mission Concepts"
German Aerospace Center

Abstract: In a changing and dynamic world, high-resolution and timely geospatial information with global coverage and access is becoming increasingly important. Among many different space-based sensor technologies, Synthetic Aperture Radar (SAR) plays an essential role in this task as it is the only sensor technology which provides high-resolution imagery on a global scale independent of the weather conditions and solar illumination.

This talk will first provide an overview on the state of the art in spaceborne SAR. A prominent example is the TanDEM-X mission, the first bistatic radar in space consisting of two satellites in close formation flight. With a typical separation between the satellites of 150 to 400 m a global Digital Elevation Model (DEM) has been generated and is available for scientific and commercial applications since September 2016. All specifications for the final DEM product of TanDEM-X were achieved and even surpassed, confirming the excellent quality of the bi-static radar instruments, the interferometric processing and the data calibration.

The second part of this talk describes the paradigm shift is taking place in spaceborne SAR systems. The rapidly growing user community poses demanding requirements for data with higher spatial resolution, wider coverage and higher timeliness, which push the development of new technologies to achieve a wide-swath high-resolution imaging. New antenna and SAR instrument concepts with multichannel and digital beamforming will boost the performance of future SAR systems by at least one order of magnitude. Examples include ALOS-4 (JAXA), NISAR (NASA/ISRO), ROSE-L and Sentinel-1NG (ESA/EC).

Augmenting complex SAR missions with global coverage, low-cost, lightweight SAR systems based on NewSpace concepts are being implemented with the aim of imaging small areas with a very short revisit time. The combination of full-fledged SAR systems with disruptive NewSpace SAR concepts leads to new system approaches for multistatic SAR missions with enhanced imaging capabilities. One example is the MirrorSAR concept, which consists of a main satellite and several small, receive-only satellites using a space transponder concept. Further opportunities arise for distributed SAR system concepts using a multistatic configuration. By this, the information content in the multi dimensional data space is increased, opening the door to a new class of information products like 3D differential SAR interferometry, polarimetric SAR interferometry and tomography.

The talk concludes with a vision for spaceborne SAR. The ultimate goal for spaceborne SAR remote sensing is the deployment of a space-based sensor network consisting of a radar observatory with a constellation of satellites capable of providing real-time geospatial information as an essential contribution to solving global societal challenges related to climate change, sustainable development, resource scarcity, land use, food security, environmental protection, disaster monitoring, and civil and military security.

Frank Sanders

“Adventures in Radar Spectrum, and Radar Coexistence in Today’s World”

NTIA/ITS, U.S. Department of Commerce

Abstract: Of all the radio system types that occupy the electromagnetic spectrum, perhaps none are so important while also being so generally misunderstood, even within technical communities, as radars. Radar technology, the revolutionary innovation that the Allies leveraged to win the Second World War, gained a notoriety and reputation for mystery and secrecy in those years that it has never entirely shaken. To this day, radar systems are frequently the subject of poorly informed debates and exchanges regarding their spectrum use, their spectrum needs, and their potential for coexistence (or not) with other radio systems. This talk’s introduction provides a historical perspective on radar spectrum use and engineering, beginning with some of the author’s world-spanning adventures in measuring radar spectra and resolving radar-related interference problems from the 1980s to the present. Recognizing the unique characteristics of radars that distinguish them from all other radio systems (including the highest effective radiated power levels combined with the most exquisitely sensitive receivers), the author lays out the direction in which spectrum management and coexistence requirements between radars and other radio systems are now moving. The challenges to designing, developing and operating radars are far greater now than they have ever been in the past. Simultaneously, the collective needs for radars, in remote sensing; air and maritime traffic surveillance and management; surveillance and defense; and other applications are also greater than at any time in the past. The author concludes with his own outlook, and conclusions, on how to meet these needs and challenges as we move into a new world.

Tom Driscoll

"Commercial Phased Array Radars: Opportunities, Challenges, & Progress"

Echodyne

Abstract: The rapid increase in capability and prevalence of autonomous systems is driving demand for new and better sensors. Radar has always held a prestigious position among sensor suites as one of the only all-weather long-range modalities. However, the missions and environments for autonomous systems are now demanding higher performance than most traditional radars architectures can provide. Phased array radars – including MIMO phased arrays – are capable of the high performance required, but historically have been out of reach for all but the most exclusive systems, due to their cost and complexity. This talk will outline the growing opportunity for next-generation radar sensors across multiple markets. We will look at major trends and progress advancing phased array technology, as well as examine key challenges and inevitable design tradeoffs. We'll end with an optimistic outlook for areas that seem poised for breakthrough and market success.

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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

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, as a Senior Associate Editor for IEEE Signal Processing Letters (SPL), and currently serves as Editor-in-Chief for IEEE SPL, and as a member of the IEEE Aerospace and Electronics Systems Society (AESS) Radar Systems Panel.

Alfonso Farina

Alfonso Farina joined Selenia (subsequently renamed as "Selex Sistemi Integrati" and then "Selex ES") in 1974 as part of the Leonardo Finmeccanica group. Throughout the following decades, he became a world-leading expert in radar and C2 system design, signal, data & image processing, data fusion, and large systems for civilian as well as defense applications. Nevertheless, from 1979 to 1985, he was also Professor of Radar Techniques at the University of Naples Federico II, Naples, Italy. Accordingly, his precious academic and industrial experience jointly with his creative talent were the keystone for the development of innovative algorithms and related digital-based signal processors applied to modern operative radar systems.

In relation to the Radar and Sensors Academy activities, he has organized and supervised - from October 2021 to February 2022 - Basic, Intermediate, and Advanced Courses on Radar and EO/IRST including 2800 hours of training for 140 attendees from 12 sites of the Company with 38 lecturers and 15 professors from academia.

Interestingly, as President of the Radar and Sensors Academy he has interviewed Princess Elettra Marconi, the daughter of Nobel Laureate Guglielmo Marconi, recollecting a number of legacy anectodes and profound reflections on modern radar systems. Remarkably, he was one of the few top managers to be interviewed at RAI Storia (National TV channel) on October 26, 2018 for the 70th anniversary of Leonardo Company.

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.

David Schvartzman

David Schvartzman was born in Piracicaba, SP, Brazil, on March 17, 1988. He received the B.S. degree in electrical and computer engineering from the National University of Asunción, San Lorenzo, Paraguay, in 2011, and the M.S. and Ph.D. degrees in electrical and computer engineering from the University of Oklahoma, Norman, OK, USA, in 2015 and 2020, respectively. From 2015 to 2020, he was a Research Scientist with the NOAA National Severe Storms Laboratory (NSSL) and the Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO). At NSSL, he gained key insights on observational needs to improve weather warnings and forecasts. He developed several signal processing algorithms to improve meteorological products that were transitioned to the operational US Weather Surveillance Radar (WSR-88D). From 2021 to mid-2022, he was a Research Scientist with the Advanced Radar Research Center (ARRC) at The University of Oklahoma. Currently, he is an Assistant Professor with the University of Oklahoma School of Meteorology, affiliated with the ARRC. He works on novel signal and array processing algorithms to improve understanding of atmospheric processes using phased array radar. He also works on calibration and integration of phased array radar systems.

Dr. Schvartzman is also an Adjunct Assistant Professor with the University of Oklahoma School of Electrical and Computer Engineering. He is the recipient of the 2019 American Meteorological Society's *Spiros G. Geotis* Prize and the 2022 IEEE R5 *Outstanding Young Professional* Award. He is a Senior Member of the Institute for Electrical and Electronic Engineers (IEEE) and a member of the American Meteorological Society (AMS).

Shane Flandermeyer

Shane Flandermeyer is a PhD 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.

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 is a Senior Vice President at Parsons Corporation and has served at executive levels in government, industry and academia. He achieved the rank of Major General in the United States Air Force and has led organizations in industry as well as served as a Chief Technology Officer, Chief Strategy Officer and Chief Scientist. He has performed fundamental research and development in radar detection and estimation theory, Space Time Adaptive Processing and advanced systems concepts. He is a Fellow of the IEEE and a member of the IEEE Radar Systems Panel. He received the 2002 IEEE Fred Nathanson Radar Engineer of the Year Award and the 2019 IEEE Warren D. White Award for Excellence in Radar Engineering.

Elisa Giusti

Elisa Giusti obtained the specialist degree in Telecommunication Engineering from the University of Pisa in 2006 (cum Laude) and obtained the title of PhD in Remote Sensing at the Department of Information Engineering of the University of Pisa in 2010. She was a Research Fellow at the Department of Information Engineering of the University of Pisa until 2014 and subsequently she worked as a researcher at the National Interuniversity Consortium for Telecommunications (CNIT), and in particular at the National Radar Laboratory and Surveillance Systems (RaSS), where she still works today and where she holds the role of research manager (Head of Research).

She participated in numerous international research projects, funded by Italian ministries (Ministry of Defence, Ministry of Economic Development, Ministry of University and Research) and European organizations (EDA, ESA, EC), as researcher and as technical and scientific manager. Many of the projects carried out have seen the validation of many technological demonstrators through field trials and demonstrations.

She is Senior Member of the IEEE and Associate Editor of the IEEE TCI journal. She is author of 107 papers published in international journals and conference proceedings, 1 book and 7 book chapters. She received international awards including the Fall 2021 NATO Sensors and Electronics Technology (SET) Panel Early Career Award (SPECA) and the 2016 Outstanding Information Research Foundation Book publication award for the book Radar Imaging for Maritime Observation. In 2015, she co-founded ECHOES, a radar systems-related spin-off company. Her research interests are mainly in the field of radar systems and radar data processing algorithms.

Kristine Bell

Kristine Bell is a Distinguished 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.

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 joined Analog Devices in 2007, after spending 9 years at Motorola/ON Semiconductor. He is now a principal field applications engineer with a focus in software-defined radio and phased array radar. He posts examples of these concepts, using simple hardware and software, at www.youtube.com/@jonkraft. He is also the architect, and perpetual explorer, of the CN0566 Software Defined Phased Array Radar project, commonly called the "Phaser." He received a B.S.E.E. from Rose-Hulman, a M.S.E.E. from Arizona State University, and has 10 patents issued.

Industry Panel

Please join us for the IEEE Radar Conference Industry Panel! This 45-minute 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 from the following RadarConf24 platinum sponsors: National Instruments, Rohde & Schwarz, ARRC, GTRI, Continental Electronics, and ISL.

Moderator: Bill Correll, Jr. (Maxar Intelligence)

Hayden Nelson

Haydn Nelson a US Navy Veteran, he has a great passion for working in the Aerospace and Defense industry. With a Masters in ECE, Haydn has worked in Aerospace and Defense for 19 years across the industry from EW research to deployable embedded systems for Radars. Haydn currently manages Radar and EW Test applications business development at NI.

Bill Kardine

Bill Kardine has been a Radar and EW Business Development Manager in North America for 4.5 years at Rohde and Schwarz. Prior to that he was an Application Engineer focusing on Radar test and measurement solutions. In his current role he works closely with industry partners to provide the Aerospace and Defense market with test and measurement solutions closely aligned with end-user's key measurement objectives. This role spans customer conversations in the Test & Evaluation community, Science & Technology community, and defense contractors of all different tiers. Bill has a BE in Electrical Engineering & BS in Physics from the University of Delaware, and also has an MSEE in Electromagnetics from UCLA.

David Schvartzman

David Schvartzman (Senior Member, IEEE) received the M.S. and Ph.D. degrees from The University of Oklahoma, Norman, OK, USA, in 2015 and 2020, respectively, in electrical and computer engineering. From 2015 to 2020, he was a Research Scientist with the NOAA National Severe Storms Laboratory (NSSL). At NSSL, he gained key insights on observational needs to improve weather warnings and forecasts. He developed several signal processing algorithms to improve meteorological products that were transitioned to the operational US Weather Surveillance Radar (WSR-88D). From 2021 to mid-2022, he was a Research Scientist with the Advanced Radar Research Center (ARRC), The University of Oklahoma. He is currently an Assistant Professor with the School of Meteorology, affiliated with the ARRC and also an Adjunct Assistant Professor with the School of Electrical and Computer Engineering. David has worked with several ground-based radar systems, including those with reflector-antenna technology, and those with phased array antennas. His research interests are in exploring novel signal and array processing algorithms to improve the understanding of atmospheric processes using phased array radar. He also works on the calibration and integration of phased array radar systems. He was a recipient of the 2022 IEEE R5 Outstanding Young Professional Award and the 2019 American Meteorological Society's Spiros G. Geotis Prize.

Kristin F. Bing

Dr. Kristin F. Bing is a principal research engineer at GTRI with experience in signal and image processing applied to radar, sonar, and medical ultrasound. Her current research efforts include space-time adaptive processing, ground moving target identification, and synthetic aperture radar. She regularly teaches in Georgia Tech professional education courses on various radar topics and is an active volunteer in IEEE, serving on the Radar Systems Panel and the Region 3 executive committee.

Mike Rosso

Mike Rosso joined Continental Electronics in 2012 as Vice President of Sales and Marketing. He has over 25 years of high-power RF experience. Since joining CEC, Mike has worked on several radar programs including OTHR and Deep Space Applications.

Mike Rosso holds a Bachelor of Science Degree in Electrical Engineering from Pennsylvania State University.

Radu Visina

Radu Visina (PhD EE University of Connecticut) is Vice President of Product Development at ISL and has been leading research and development in state of the art radar and far-field RF simulation technology for commercial and defense applications. He has contributed to the theory and practical methods of real-time radar clutter simulation and maneuvering target tracking and has extensive experience bridging the gaps between the industrial and academic worlds through years of experience in cutting-edge hardware and software product design and development.

DEI Inclusion Workshop/Luncheon

Trish Ahjel Roberts
"Unveiling Unconscious Bias: Overcoming Barriers to Inclusion"

Abstract: Innovation thrives on diverse perspectives. Unconscious bias can be an invisible barrier that hinders diversity and slows growth. This captivating presentation sheds light on the concept of unconscious bias and its impact on businesses and people. Led by Transformational Coach and DEI Expert, Trish Ahjel Roberts (https://trishahjelroberts.com/about/), this session incorporates journaling, breathwork, and meditation to allow participants to not only intellectualize ideas but experience personal growth.

Awards Ceremony

RadarConf'24 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 8th at dinner time (7:00 - 10:00 PM).

IEEE Dennis J. Picard Medal

Frederick E. Daum

For research, design, development, analysis, and testing of complex phased array radar systems, making them work in the real world.

2023 IEEE AESS Pioneer Award

Dr. Joachim Ender

For seminal pioneering contributions to multichannel Synthetic Aperture.

2024 Warren D. White Award

Antonio De Maio

For contributions to radar signal processing techniques for target detection, waveform design and electronic protection.

2023 IEEE AESS Judith A. Resnik Space Award

Puneet Singla

For extensive contributions to the field of accurate uncertainty propagation for space situational awareness.

IEEE 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 2024 AESS Class of IEEE Fellows.




Nathan Goodman
For contributions to cognitive and distributed radar signal processing.

Neil Gordon
For contributions to sequential Monte Carlo methods and applications.

Zaher (Zak) Kassas
For contributions to navigation with signals of opportunity.

Luke Rosenberg
For contributions to maritime radars.

2024 Fred Nathanson Memorial Radar Award

Francesco Fioranelli

For contributions to radar-based target classification.

2024 IEEE AESS Industrial Innovation Award

Igal Bilik

For innovations in automotive imaging and electronically steerable radars implemented in autonomous vehicles and used for active safety capabilities.

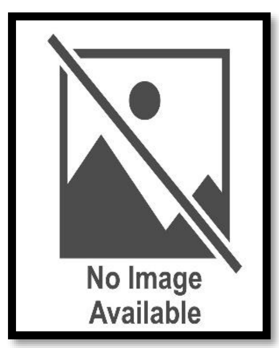
2023 IEEE AESS Robert T. Hill Best Dissertation

Award David Luong

In recognition of the Ph.D. dissertation “Quantum Radar Signal Processing".

2022 Harry Rowe Mimno Award

Zak Kassas, Joe Khalife, Ali A. Abdallah, Chiawei Lee



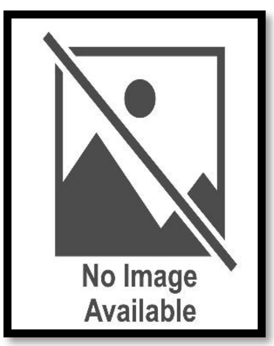
For the work "I Am Not Afraid of the GPS Jammer: Resilient Navigation Via Signals of Opportunity in GPS-Denied Environments"

2024 IEEE AESS Engineering Scholarship

Kayoum Djedidi
Graduate Student

Higher Institute of Informatics and Mathematics of Monastir, Tunisia

Oluleti Victor and Opeyemi Sodiq Owolabi
Undergraduates



Obafemi Awolowo University, Nigeria

2024 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 2024 Michael C. Wicks Award Recipients




Saraansh Agarwal
For the paper entitled "Design of Convolutional Neural Networks for Classification of Ships from ISAR Images"

Ilaria Nasso
For the paper entitled "Target Shape Reconstruction from multi-Perspective Shadows in drone-Borne SAR Systems"

Andrea Quirini
For the paper entitled "Enabling DPCA via Supervised Reciprocal Filter in CW-OFDM Radar Onboard Moving Platforms"

Peizhuo Yang
For the paper entitled "A Conformal L-Band Array with Multi-Polarization Digital Beamforming and Sidelobe Suppression"

2023 IEEE AESS Chapter of the Year Award

Chaired by Puneet Kumar Mishra

Chaired by Puneet Kumar Mishra

2023 IEEE AESS Technical Panel of the Year Award

Chaired by Jason Bingham

Gyro and Accelerometer Panel

2020 M. Barry Carlton Award

"Satellite Pose Estimation Challenge: Dataset, Competition Design, and Results" by Mate Kisantal, Sumant Sharma, Tae Ha Park, Dario Izzo, Marcus Märtens, Simone D'Amico

Student Paper Finalists

Curated by Luke Rosenberg and Laura Anitori

IEEE RadarConf 2024 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 8, 2024.

8053 Passive Radar Imaging Based on Multistatic Combination of Starlink and OneWeb Illumination
Rodrigo Blazquez-Garcia, Universidad Politecnica Madrid

8248 Target Shape Reconstruction from multi-Perspective Shadows in drone-Borne SAR Systems
Ilaria Nasso, University of Rome "La Sapienza"

8281 See Further Than CFAR: a Data-Driven Radar Detector Trained by Lidar
Ignacio Roldan, TU Delft

8293 Gamification of RF Data Acquisition for Classification of Natural Human Gestures
Emre Kurtoglu, The University of Alabama

8313 Delay-Doppler Parameter Estimation for DFRC-OTFS Using 2D Root-Music
Akshay Bondre, Arizona State University

Backup

8235 Flexible and Seamless Factorised Processor for Long-Range mono- and Bistatic UAV-Borne SAR
Mattia Giovanni Polisano, Politecnico di Milano

8052 A Data Efficient Deep Learning Method for Rough Surface Clutter Reduction in GPR Image
Yan Zhang, University of Vermont

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 6th and Friday, May 10th.

Monday Morning (8:00 AM – 12:00 PM)

T1: Introduction to Synthetic Aperture Radar
Where: Colorado F
Presenter: Armin Doerry

Description

Synthetic Aperture Radar (SAR) is a radar imaging mode that maps radar reflectivity of the ground. This is an important earth resource monitoring and analysis tool in the civilian and government communities, and an important intelligence, surveillance, and reconnaissance (ISR) tool for the military and intelligence communities. This tutorial intends to provide an introduction to the physical concepts, processing, performance, features, and exploitation modes that make SAR work, and make it useful. 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. Basic data models will be developed, and several image processing algorithms will be illustrated and compared. The radar equation for SAR will be explored in some detail to illustrate how SAR operating parameters can be traded for performance as measured by the Signal-to-Noise Ratio (SNR) for a target, and equivalently the Noise-Equivalent Reflectivity (NER). The unique nature of range-Doppler images will be discussed, including geometric distortions due to range-Doppler imaging such as wavefront curvature effects and layover. In addition, examples of SAR image dependence on wavelength, polarization, and atmospheric effects will be illustrated. Post-image-formation processing of SAR images will be exemplified, including autofocus, speckle reduction, and dynamic range compression for image display. Basic SAR image-quality metrics will be presented. Finally, a number of SAR image exploitation techniques and modes will be illustrated. Liberal use of example SAR images and other data products will be used to illustrate the concepts discussed.

Synthetic Aperture Radar (SAR) is a radar imaging mode that maps radar reflectivity of the ground. This is an important earth resource monitoring and analysis tool in the civilian and government communities, and an important intelligence, surveillance, and reconnaissance (ISR) tool for the military and intelligence communities. This tutorial intends to provide an introduction to the physical concepts, processing, performance, features, and exploitation modes that make SAR work, and make it useful. 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. Basic data models will be developed, and several image processing algorithms will be illustrated and compared. The radar equation for SAR will be explored in some detail to illustrate how SAR operating parameters can be traded for performance as measured by the Signal-to-Noise Ratio (SNR) for a target, and equivalently the Noise-Equivalent Reflectivity (NER). The unique nature of range-Doppler images will be discussed, including geometric distortions due to range-Doppler imaging such as wavefront curvature effects and layover. In addition, examples of SAR image dependence on wavelength, polarization, and atmospheric effects will be illustrated. Post-image-formation processing of SAR images will be exemplified, including autofocus, speckle reduction, and dynamic range compression for image display. Basic SAR image-quality

metrics will be presented. Finally, a number of SAR image exploitation techniques and modes will be illustrated. Liberal use of example SAR images and other data products will be used to illustrate the concepts discussed.

T2: Introduction to Passive Radar
Where: Colorado G
Presenters: Mateusz Malanowski & Fabiola Colone

Description

This tutorial is focused on passive radar and illustrates the amazing solutions that can be adopted in order to increase their reliability and hence widen the range of applications.

The tutorial starts from the basic concepts by discussing the possible illuminators of opportunity, the impact of the geometry, as well as the passive radar equation. A typical signal processing scheme is introduced and effective solutions are illustrated for the signal processing techniques to be implemented at each stage.

Ground based passive radar systems are first investigated, including the demonstrator and operational system design and mission planning. Therefore, advanced methods are illustrated to enhance the performance of the passive radar sensor by exploiting long integration times or polarization/frequency/spatial diversity. Then the discussion moves to passive radar onboard moving platforms, which enables SAR and GMTI modes. The principle of operation, the signal models, and the signal processing techniques are illustrated with reference to both approaches. Target imaging with passive ISAR is also considered along with the required techniques and main challenges.

In addition to the theoretical aspects, the tutorial provides the attendees with an insight into the real-world applications of passive radar. A wide range of applications is covered moving from air traffic control up to indoor surveillance and several experimental results are reported exploiting different illuminators. Walking through these results gives the chance to describe in more detail technical aspects and signal processing techniques as well as to understand the current limitations and future perspectives of passive radar sensing.

This tutorial is focused on passive radar and illustrates the amazing solutions that can be adopted in order to increase their reliability and hence widen the range of applications.

The tutorial starts from the basic concepts by discussing the possible illuminators of opportunity, the impact of the geometry, as well as the passive radar equation. A typical signal processing scheme is introduced and effective solutions are illustrated for the signal processing techniques to be implemented at each stage.

Ground based passive radar systems are first investigated, including the demonstrator and operational system design and mission planning. Therefore, advanced methods are illustrated to enhance the performance of the passive radar sensor by exploiting long integration times or polarization/frequency/spatial diversity. Then the discussion moves to passive radar onboard moving platforms, which enables SAR and GMTI modes. The principle of operation, the signal models, and the signal processing techniques are illustrated with reference to both

approaches. Target imaging with passive ISAR is also considered along with the required techniques and main challenges.

In addition to the theoretical aspects, the tutorial provides the attendees with an insight into the real-world applications of passive radar. A wide range of applications is covered moving from air traffic control up to indoor surveillance and several experimental results are reported exploiting different illuminators. Walking through these results gives the chance to describe in more detail technical aspects and signal processing techniques as well as to understand the current limitations and future perspectives of passive radar sensing.

T3: Introduction to Electronic Warfare
Where: Colorado H
Presenter: David Brown

Description

An introduction to electronic warfare (EW) concepts and principles necessary for modern combat systems. The intent is to familiarize the audience with EW concepts and achieve an understanding of how EW is used to interrupt radar processing chains. This talk covers a general discussion on the EW field, including terminology widely used within the field. A historical development of the EW field will be presented to motivate importance and historical use. Basic EW techniques (noise, range/velocity techniques, etc.) with associated effects on nominal radars will be presented/discussed to ensure an understanding of the technical underpinnings of EW. Building on the basic techniques, a brief discussion on concepts in advanced EW systems and current research will be presented, including Digital RF Memory (DRFM) technology and testing of advanced of EW systems. Open EW architectures will be discussed to present how open architecture enables advanced capability and rapid technology updates. The discussion will conclude by briefly presenting advanced EW research, including the revolutionary impact of cognitive and AI/ML processes on EW.

The intended audience is engineers (students through experts) who are interested in gaining an understanding of Electronic Warfare systems that are used to counter radars. This is introductory material, so it is accessible to all with a basic understanding of RF and radar concepts. An additional outcome is the fostering of a collaborative environment between radar and EW professionals, which have traditionally been separated. An implicit outcome is the exposure of the typically secretive EW field to a wider talent pool.
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T4: Micro-Doppler Signatures: Principles, Analysis & Applications
Where: Colorado I
Presenters: Francesco Fioranelli & Carmine Clemente

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 showcased in different areas of radar signal processing, such as improved target detection, characterization and tracking, in a variety 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 great 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-Doppler signatures 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 discussed 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.

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T5: An Overview of Practical Spectrum Sharing Techniques for Radar and Communications
Where: Colorado J
Presenters: Cenk Sahin, Patrick McCormick, and Justin Metcalf

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. 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.
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.
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T6: Hands On Phased Array Beamforming Workshop
Where: Mattie Silks
Presenters: Jon Kraft, Mike Picciolo, Marc Lichtman, and Tarun Cousik

Description

Phased array communications and radar systems are finding increased use in a variety of applications. This places a greater importance on training engineers on these concepts and in rapidly prototyping new phased array designs. However, both those imperatives have historically been difficult and expensive. But in this hands-on workshop, we will use the CN0566 8 Channel Software Defined Phased Array (the "Phaser", from Analog Devices) to understand and experience these concepts. Fifteen identical lab stations will be setup to for the participants to build, program, and interact with their own phased array system. We will start at the beginning – with phased array fundamentals. Then we will methodically work through these concepts, step by step, until we have a complete operational beamformer. Each new concept will have a short lecture describing the theory and math, followed by the participants using the Phaser hardware to directly explore the lecture topic. The key topics we will cover are:

- Steering angle and beam formation: You will directly experiment with the impact of phase shifting, steering angle, and number of elements on the beam pattern.
- Antenna sidelobes: Where do they come from and how do we mitigate them? You will dynamically apply different tapering profiles and observe the impact to sidelobe suppression, beamwidth, and gain.
- Grating Lobes: Where does the half lambda spacing rule come from, and what happens if we violate it?
- Virtual Arrays: Reduce the antenna beamwidth by using switched transmitters.
- Monopulse Tracking: Use digitized subarrays to model and track the position of a target.
- Null Steering: Apply beamforming techniques to place a null at a jammer's location, while preserving the beamwidth and gain in the desired direction.

Relevant links for the workshop:
https://www.analog.com/cn0566
https://wiki.analog.com/phaser
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Monday Afternoon (1:00 PM – 5:00 PM)

T7: Space-based Synthetic Aperture Radar (SAR): Principles, Imaging Techniques and Future Developments
Where: Colorado F
Presenter: Alberto Moreira

Description

Today, more than 50 spaceborne SAR systems are systematically monitoring the Earth's surface. SAR is unique in its imaging capability: It provides high-resolution imaging independent from daylight, cloud cover and weather conditions for a multitude of applications ranging from geoscience and climate change research, environmental and Earth system monitoring, 2D and 3D mapping, change detection, 4D mapping (space and time), disaster monitoring, security-related applications up to planetary exploration. Therefore, it is predestined to monitor dynamic processes on the Earth's surface in a reliable, continuous and global way. In the past few years a new era has started for spaceborne SAR systems with the number of satellites fast increasing due to NewSpace SAR initiatives. These small satellites complement the large full-fledged SAR systems with global coverage, building a network of satellites which is able to provide sub-daily coverage in a reliable way. Looking ahead, future spaceborne SAR systems with advanced imaging modes and digital beamforming will have an imaging performance one order of magnitude superior than that of current systems. Innovative multistatic SAR concepts will allow for new information products opening the door for a wealth of novel applications.

This four-hour tutorial provides a wide overview on spaceborne Synthetic Aperture Radar (SAR) systems and is suitable for engineers, graduate and PhD students as well as practitioners which have already a basic knowledge on radar systems. The course's contents will be as follows: SAR basics, SAR theory, SAR signal processing, image properties, SAR imaging modes, SAR system concept and design, spaceborne SAR missions, interferometry, polarimetry, tomography, applications, advanced SAR technologies (e.g., digital beamforming), innovative SAR concepts and techniques (e.g., multistatic SAR) and future developments.

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T8: Advanced Techniques and Applications for Passive Radar
Where: Colorado G
Presenters: Diego Cristallini & Piotr Samczynski

Description

The purpose of this tutorial is to provide a serious exposition of the state-of-the-art of passive radar and its development in the context of target detection and imaging. The tutorial will focus on developing the grounding of advanced principles and concepts that are, and will be, of high relevance to the field. After an introduction the tutorial will move on to develop advanced topics, where new frontiers in passive radar for metropolitan area applications based on modern mobile communication standards and for short area applications will be discussed including different standards comparison regarding the sensing applications. 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 5G/6G, WiFi, DVB-S and Fixed Satellite Services (FSS, such as STARLINK and OneWeb), and the required signal processing techniques. The tutorial will include different standards comparison, challenges, opportunities and limitations analyzes with focus on modern applications for using wideband IoOs in passive radars, e.g., target detection, classification, SAR/ISAR imaging that participants would not have accrued through self-study of recently published literature. The challenges, opportunities and limitations analyses will be presented to the audience supporting by numerous examples of experimental results. Worked examples with interactive participation will ensure a lively tutorial for the full duration.

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T9: Advanced Radar Detection and Capabilities
Where: Colorado H
Presenters: Scott Goldstein & Michael Picciolo

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 the 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.

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T10: Systematic Filter Design for Tracking Maneuvering Targets: Getting Guaranteed Performance Out of Your Sensors
Where: Colorado I
Presenter: Dale Blair

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.

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T11: Bistatic and Multistatic Radar Imaging
Where: Colorado J
Presenters: Marco Martorella & Brian Rigling

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, monostatic SAR/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 multistatic SAR/ISAR may push forward the system limits both in terms of resolution and image interpretation and add to the system resilience.

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T12: Hands On Adaptive Digital Beamforming Workshop
Where: Mattie Silks
Presenters: Jon Kraft, Mike Picciolo, Marc Lichtman, and Tarun Cousik

Description

The surge in the ability to design and manufacture large arrays at higher frequencies (10 GHz-60 GHz), coupled with increased reconfigurability in array parameters, is fueling a renewed interest in adaptive array techniques. Concurrently, advancements in high-speed converters and signal processors are sparking a growing fascination with realizing digital beamforming techniques. These techniques aim to enhance Signal-to-Interference-plus-Noise Ratio (SINR), throughput, Error Vector Magnitude (EVM), Bit Error Rate (BER), and more. Comprehending the foundational concepts behind these advancements necessitates a profound grasp of linear algebra, optimization theory, array processing, RF design, and signal processing. As a consequence, entering this field presents a steep learning curve, posing substantial yet rewarding challenges even for seasoned experts.

In this workshop, we aim to demystify the intricacies surrounding adaptive beamforming techniques and offer participants a hands-on experience with bleeding-edge beamforming systems. The workshop will guide participants through the underlying mathematics, fostering an intuitive understanding of how the math translates into practical applications. Moreover, it will showcase what the implemented math looks like on a real array. Participants can anticipate leaving the workshop with a heightened understanding of key adaptive beamforming techniques, along with the confidence to implement these techniques on real antenna array systems. While the workshop does not have any prerequisites, familiarity with linear algebra and antenna theory would give the participants a competitive edge.

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Friday Morning (8:00 AM – 12:00 PM)

T13: Three-Dimensional Inverse Synthetic Aperture Radar
Where: Colorado F
Presenters: Marco Martorella & Elisa Giusti

Description

Inverse Synthetic Aperture Radar (ISAR) is a well-known technique to obtain high-resolution radar images of non-cooperative targets. ISAR images have been largely used to classify and recognise targets and ISAR technology is nowadays employed and integrated in modern radar systems. Nevertheless, despite decades of research and development work in ISAR imaging, two-dimensional (2D) ISAR images present some intrinsic drawbacks that limit the effectiveness of their use for target classification and recognition. Some of these limitations come from the unpredictability and uncontrollability of the image projection, which transforms three-dimensional (3D) targets in 2D images. One very effective way of overcoming this problem is to form 3D ISAR images instead of 2D ones.

This tutorial will present a unique walkthrough 3D ISAR imaging, including concepts, algorithms, systems and real data examples, which will provide the attendants the necessary tools for a full understanding of this new technology.
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T14: Active Electronically Scanned Arrays: Fundamentals and Applications
Where: Colorado G
Presenter: Arik Brown

Description

Active Electronically Scanned Arrays (AESAs): Fundamentals and Applications 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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T15: Multi-Function RF Systems for Radar and Communications: Signal Processing, Prototyping, and Experiments
Where: Colorado H
Presenters: Christos Masouros & Matt Ritchie

Description

This tutorial has been motivated by a) the rising demand for multi-functional RF systems to provide adaptivity and serve multiple tasks in an energy-, hardware-, space-, spectrum- efficient way, b) the recent interest in Dual-Functional Radar-Communication (DFRC) systems featuring in numerous IEEE workshops and special issues across the IEEE AESS and ComSoc societies, and an IEEE Emerging Technology Initiative on Integrated Sensing and Communications. In line with this research agenda, there has been increasing innovation in agile multi-function RF systems that have the capability the meet the requirements for a system that needs to perform both sensing and communications. At the same time, DFRC has drawn significant attention in the wireless cellular domain, not just from academic researchers, but also from major industrial companies. Recently, Ericsson, Nokia, NTT DOCOMO, Intel, and Huawei have all suggested that sensing will play an important role in their 6G white papers and Wi-Fi 7 visions. In particular, in July 2023 wireless sensing was endorsed as one of six key 6G usage scenarios by the United Nations' International Telecommunication Union.

Accordingly, we aim to provide an overview, in a uniform manner, of the recent advances and new insights in multi-function RF systems and how they can deliver DFRC concepts. This tutorial proposal identifies the following objectives:

• Establish a unified view of radar and communication functionalities in promoting a paradigm shift to move beyond the competitive Radar vs Communications co-existence. The previously competing radar and communication operations can be jointly optimized to improve the efficiency and to reduce the costs, via the shared use of a single hardware platform and a joint signal processing framework;
• Highlight the key building blocks of a multifunctional RF system, the array of emerging applications it will be expected to support, and the fundamental functionalities it will need to offer;
• Stimulate a discussion and promote research to further ways of delivering multi-function RF systems in view of emerging applications such as smart cities, urban security, and intelligent transportation.

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T16: Distributed Detection, Estimation, and Resource Management in a Network Radar
Where: Colorado I
Presenters: Batu Chalise & Benjamin Kirk

Description

Due to an explosive growth of wireless devices and networks, the sub-6 GHz radio frequency (RF) band used by many radar applications is highly congested, which is one of the major bottlenecks for enabling effective operations and functionality of the conventional single platform-based radar systems. Emerging radar systems need to enhance their spectrum utilization capabilities by becoming resilient against interference. This goal can be achieved with a deployment of a radar network, in which nodes collaboratively perform distributed radar sensing and communications, such as dynamic spectrum sensing, resource (bandwidth, carrier frequency, waveform) allocation, detection, parameter estimation, and tracking. New algorithms, protocols, and experiments are required for distributed radar networks to achieve either optimal or close to centralized network performance, with only limited information sharing, and minimum algorithmic and system design complexity. The effects of communications link reliability and latency, imperfect synchronization, and cognitive capabilities on distributed radar sensing performance need to be thoroughly understood.

The objective of this tutorial is to provide participants with a comprehensive overview of the research on the state-of-the-art distributed radars, an in-depth understanding of new methodologies and solutions, and a summary, highlighting the prospects and key challenges on the implementation of distributed radar networks. The tutorial will cover following aspects of network radar: a) motivation and overview of the related work, b) network architecture, c) bandwidth and carrier frequency allocation algorithms for both radar sensing and communications, d) radar waveform optimization, e) distributed detection and target parameter estimation, f) impact of reliable communications on distributed radar sensing, and g) future research directions to overcome implementation challenges.

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T17: Noise Radar: Principles, Signal Processing, and Waveform Design
Where: Colorado J
Presenters: Mateusz Malanowski & Krzysztof Kulpa

Description

In the tutorial, the concept of continuous-wave radar emitting noise or pseudo-noise waveform will be presented. Noise waveforms have significant advantages over classical radar waveforms, as they do not have range nor Doppler ambiguities and can be used in dense electromagnetic environments without significant interferences with other devices using the same spectrum.

In the tutorial, the basics of noise radar will be presented. Problems typical for noise radar, such as the masking effect, will be identified, and solutions to those problems will be analyzed. Pulse noise radar will also be presented and compared with classical deterministic pulse radar. The possibilities of target identification using micro-Doppler, SAR, and ISAR imaging will be discussed. The waveform design for noise radar will be shown, including sidelobe reduction and spectrum shaping. Operation of the noise radar in MIMO configuration, both using co-located and spatially separated antennas, will be analyzed.

In the tutorial, numerous real-life result examples will be shown. Possible applications of noise radar will be analyzed.

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Technical Program – Tuesday, May 7

8:00 - 8:30
General & Technical Chair's Opening Remarks
Room: DENVER BALLROOM

8:30 – 9:15
Plenary Speaker: Dr. Alberto Moreira, *German Aerospace Center*
Room: DENVER BALLROOM

Space-based Synthetic Aperture Radar: Future Technologies and Mission Concepts

Dr. Alberto Moreira

German Aerospace Center

In a changing and dynamic world, high-resolution and timely geospatial information with global coverage and access is becoming increasingly important. Among many different space-based sensor technologies, Synthetic Aperture Radar (SAR) plays an essential role in this task as it is the only sensor technology which provides high-resolution imagery on a global scale independent of the weather conditions and solar illumination.

This talk will first provide an overview on the state of the art in spaceborne SAR. A prominent example is the TanDEM-X mission, the first bistatic radar in space consisting of two satellites in close formation flight. With a typical separation between the satellites of 150 to 400 m a global Digital Elevation Model (DEM) has been generated and is available for scientific and commercial applications since September 2016. All specifications for the final DEM product of TanDEM-X were achieved and even surpassed, confirming the excellent quality of the bi-static radar instruments, the interferometric processing and the data calibration.

The second part of this talk describes the paradigm shift is taking place in spaceborne SAR systems. The rapidly growing user community poses demanding requirements for data with higher spatial resolution, wider coverage and higher timeliness, which push the development of new technologies to achieve a wide-swath high-resolution imaging. New antenna and SAR instrument concepts with multichannel and digital beamforming will boost the performance of future SAR systems by at least one order of magnitude. Examples include ALOS-4 (JAXA), NISAR (NASA/ISRO), ROSE-L and Sentinel-1NG (ESA/EC).

Augmenting complex SAR missions with global coverage, low-cost, lightweight SAR systems based on NewSpace concepts are being implemented with the aim of imaging small areas with a very short revisit time. The combination of full-fledged SAR systems with disruptive NewSpace SAR concepts leads to new system approaches for multistatic SAR missions with enhanced imaging capabilities. One example is the MirrorSAR concept, which consists of a main satellite and several small, receive-only satellites using a space transponder concept. Further opportunities arise for distributed SAR system concepts using a multistatic configuration. By this, the information content in the multi dimensional data space is increased, opening the door to a new class of information products like 3D differential SAR interferometry, polarimetric SAR interferometry and tomography.

The talk concludes with a vision for spaceborne SAR. The ultimate goal for spaceborne SAR remote sensing is the deployment of a space-based sensor network consisting of a radar observatory with a constellation of satellites capable of providing real-time geospatial information as an essential contribution to solving global societal challenges related to climate change, sustainable development, resource scarcity, land use, food security, environmental protection, disaster monitoring, and civil and military security.

9:15 – 10:00
Plenary Speaker: Mr. Frank Sanders, *NTIA/ITS, U.S. Department of Commerce*
Room: DENVER BALLROOM

Adventures in Radar Spectrum, and Radar Coexistence in Today's World

Mr. Frank Sanders
NTIA/ITS, U.S. Department of Commerce

Of all the radio system types that occupy the electromagnetic spectrum, perhaps none are so important while also being so generally misunderstood, even within technical communities, as radars. Radar technology, the revolutionary innovation that the Allies leveraged to win the Second World War, gained a notoriety and reputation for mystery and secrecy in those years that it has never entirely shaken. To this day, radar systems are frequently the subject of poorly informed debates and exchanges regarding their spectrum use, their spectrum needs, and their potential for coexistence (or not) with other radio systems. This talk's introduction provides a historical perspective on radar spectrum use and engineering, beginning with some of the author's world-spanning adventures in measuring radar spectra and resolving radar-related interference problems from the 1980s to the present. Recognizing the unique characteristics of radars that distinguish them from all other radio systems (including the highest effective radiated power levels combined with the most exquisitely sensitive receivers), the author lays out the direction in which spectrum management and coexistence requirements between radars and other radio systems are now moving. The challenges to designing, developing and operating radars are far greater now than they have ever been in the past. Simultaneously, the collective needs for radars, in remote sensing; air and maritime traffic surveillance and management; surveillance and defense; and other applications are also greater than at any time in the past. The author concludes with his own outlook, and conclusions, on how to meet these needs and challenges as we move into a new world.

10:00 – 10:30
Coffee Break
Room: COLORADO A-E

10:30 – 11:15
Plenary Speaker: Dr. Tom Driscoll, *Echodyne*
Room: DENVER BALLROOM

Commercial Phased Array Radars: Opportunities, Challenges, & Progress

Dr. Tom Driscoll

Echodyne

The rapid increase in capability and prevalence of autonomous systems is driving demand for new and better sensors. Radar has always held a prestigious position among sensor suites as one of the only all-weather long-range modalities. However, the missions and environments for autonomous systems are now demanding higher performance than most traditional radars architectures can provide. Phased array radars – including MIMO phased arrays – are capable of the high performance required, but historically have been out of reach for all but the most exclusive systems, due to their cost and complexity. This talk will outline the growing opportunity for next-generation radar sensors across multiple markets. We will look at major trends and progress advancing phased array technology, as well as examine key challenges and inevitable design tradeoffs. We'll end with an optimistic outlook for areas that seem poised for breakthrough and market success.

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11:15 – 12:00
Industry Panel
Room: DENVER BALLROOM

12:00 – 13:10
Lunch
Room: COLORADO F-J

12:00 – 13:10
TAES Lunch (CLOSED)
Room: INDEPENDENCE

13:10 – 14:50
Classification
Room: DENVER BALLROOM 4
Session Chairs: Batu Chalise and Lorenzo Lo Monte

8299: Track-Oriented Self-Supervised Learning for Micro-Doppler Target Classification

Sigmund Rolfsjord{1}, Daniel Gusland{1}, Jörgen Ahlberg{2}
{1}Norwegian Defence Research Establishment, Norway; {2}University of Oslo, Norway

Deep learning's shift from supervised to unsupervised methods has revolutionized many applications, exemplified by innovations such as DALL-E-2 and Chat-GPT. This paper focuses on extending the application of self-supervised learning, specifically in the radar domain, by introducing a simple, yet effective approach to training self-supervised models inspired by SimCLR, but tailored for micro Doppler spectrograms. By using a target tracker we can, for a given track choose different contrastive samples by selecting spectrogram snippets from random time points along the whole track. This approach leverages the natural augmentation that occurs during a track sequence of a target. Despite its simplicity, this approach outperforms traditional augmentation techniques when training contrastive models. We demonstrated our approach by training a foundation model for radar classification and fine-tuning the model on two separate datasets. Our training approach improves classification performance significantly, and in a scenario where we have 100 times more unlabeled than labeled training samples, we boost performance with an impressive 24.79 pp., over a conventional supervised approach.

8306: Dynamic Graph Network Augmented by Contrastive Learning for Radar Target Classification

Han Meng, Yuexing Peng, Wenbo Wang
Beijing University of Posts and Telecommunications, China

The research on multi-aircraft recognition based on radar echo signals is an emerging field. However, how to effectively extract information from weak signals under complex environments continues to be challenging. Owing to the limited knowledge, the design of a suitable adjacent matrix is vital for graph convolution network(GCN) when it is an effective method for target recognition. In this paper, an intelligent and partly interpretable method termed Dynamic Graph Network augmented by Contrastive Learning (CL-DGN) is proposed for classifying the radar targets in a heterogeneous radar network under low signal-to-noise ratio (SNR). The Zhao-Atlas-Marks transform and Gated Recurrent Unit with attention mechanism method are used for semantic feature enhancement. The CL-based semantic similarity metric learning (SSML), adaptively constructs an adjacency matrix to realize dynamic networking. Then the GCN method uses the adjacency matrix generated by SSML extracts and fuses the target STF features to realize the recognition and classification of radar targets. The simulation results verify the effectiveness of the proposed method in the low SNR scenarios.

8082: High-Resolution Range Profile Target Recognition with Neuromorphic ADCs and Spiking Neural Networks

Sanjaya Herath{3}, Matthew Ziemann{1}, Kevin Wagner{2}, Christopher Metzler{3}
{1}DEVCOM Army Research Laboratory, United States; {2}U.S. Naval Research Laboratory, United States; {3}University of Maryland, College Park, United States

Traditional analog-to-digital converters (ADCs) often struggle to balance high sampling rates with power efficiency, limiting their effectiveness in advanced radar and communication systems. Neuromorphic ADCs capture samples only when a signal crosses a specific threshold. This asynchronous sampling strategy effectively compresses incoming datastreams, enabling neuromorphic ADCs to achieve higher sampling rates at reduced power consumption compared to conventional ADCs. However, existing algorithms are poorly suited for processing the asynchronous samples. Conventional techniques like matched filters are inapplicable and most established deep learning algorithms expect regularly sampled data. This work introduces a spiking neural network (SNN) architecture specifically designed for processing asynchronous radar samples. Our novel approach is applied to Radar High-Resolution Range Profile (HRRP) based target classification. Remarkably, our experiments demonstrate that combining a neuromorphic ADC with an SNN achieves performance on par with high-sample-rate conventional ADCs paired with Convolutional Neural Networks (CNNs) while reducing the overall sampling rate by more than 95%.

8152: Improving Micro-Doppler Target Classification by Fusing Spectrograms and Additional Target Features

Daniel Gusland{1}, Sigmund Rolfsjord{1}, Jörgen Ahlberg{2}
{1}Norwegian Defence Research Establishment, Norway; {2}University of Oslo, Norway

Machine learning has revolutionized radar target classification, primarily relying on convolutional neural network (CNN) models combined with an image representation of the target, such as a micro-Doppler spectrogram. By using only a spectrogram to represent a target, however, valuable information about the target is omitted. In this paper, we demonstrate a fused CNN- and feature-model that combine spectrograms with additional target features, namely radar cross section (RCS), range-change and azimuth-change. The efficacy of the approach is shown by comparing the combined model with featureonly, spectrogram-only, and ensemble models on two different datasets. The combined model shows performance improvements, particularly in the lower-scoring classes. The largest improvements are seen in airplane, helicopter and UAV with 15.6 pp, 15.3 pp and 6 pp respectively. We also explore how the combined model utilizes and balances the additional features and spectrogram by investigating the attribution score of each of the models. The attribution analysis reveals that the balance is highly dependent on class and signal to noise ratio (SNR).

8111: Distributed Radar Fusion for Extended Target Location and Velocity Reconstruction

Nicolas Kruse{1}, Ronny Guendel{2}, Francesco Fioranelli{1}, Alexander Yarovoy{1}
{1}Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands; {2}Technische Universiteit Delft, Netherlands

The application of distributed radar to human motion monitoring is considered. A novel sensor fusion method has been proposed that yields a two-dimensional map of reflection intensity and a vector field of reconstructed velocities in lieu of conventional Doppler spectrograms or radial velocity components. The method has been verified using experimental datasets in two case studies involving fall detection in sequences of activities, and arm motion discrimination for in-place activities. A true positive rate and precision of respectively 99.3% and 93.0% have been demonstrated for the fall detection task, and the output of the proposed method for arm motion characterisation indicates suitability for classification in future research.

13:10 – 14:50
Spectrum Sharing
Room: DENVER BALLROOM 3
Session Chairs: Christ Richmond and Patrick McCormick

8049: The Price of Information in OFDM-DFRC Systems

Nadia Bekkali, Stéphanie Bidon, Damien Roque, Meryem Benammar
Université de Toulouse, ISAE-SUPAERO, France

This paper investigates the performance of a mutual information (MI)-optimal waveform for dual-function radar-communication (DFRC) orthogonal frequency-division multiplexing (OFDM) systems. By design, the waveform is random to account for the varying (i.e., information-bearing) transmitted symbols. From a radar perspective, we examine the sacrifices made in target estimation to transmit information and demonstrate that using PSK symbols maintains performance as best as possible, unlike QAM or Gaussian symbols. As is well known, choosing a constellation to maximize the communication information rate follows an opposite recommendation, thus highlighting the radar-communication trade-off.

8204: Pilot-Assisted Ambient Backscatter Communications Exploiting Radar Clutter

Luca Venturino{2}, Emanuele Grossi{2}, Jeremy Johnston{1}, Marco Lops{3}, Xiaodong Wang{1}
{1}Columbia University, United States; {2}University of Cassino and Southern Lazio, Italy; {3}University of Naples Federico II, Italy

Radar-generated clutter has been already shown to be a suitable ambient signal for backscatter communications (even assuming no channel state information) primarily due to its relatively large coherence time as compared to the communication rates of interest. The present contribution takes one step forward and introduces semi-blind clutter-enabled multi-source backscatter communications, where pilot signals are intermingled with data so as to allow coherent decoding at the receiver. We propose simplified decoding schemes relying on regularized least squares and search relaxation, whose complexity per iteration scales only linearly with the data size. The proposed approach is validated through computer simulations, highlighting the coherence gain over the corresponding incoherent architectures.

8159: Remote Sensing with Constant-Modulus OFDM Signals from Complementary Sequences

Samuel Lavery, Tharmalingam Ratnarajah
University of Edinburgh, United Kingdom

Increasing commercial competition, desire for system redundancy, and convergence of technologies motivate the design of dual-function communications-radar (DFCR) systems. These individual systems perform both remote sensing and wireless communications through transmission of a singular waveform. Much of the literature examines use of orthogonal frequency-division multiplexing (OFDM) waveforms for this purpose, which suffer from high peak-to-average-power (PAPR) ratios, reducing the effectiveness of non-linear amplifiers. Herein, a technique for constructing constant-modulus (CM) OFDM signals from complementary sequences is exploited to perform DFCR operations. Advantages of this method of CM OFDM signal generation are discussed as well as trade-offs in attaining this desirable feature. Numerical simulations demonstrate differently constructed CM signals with processing gains within 7 dB of remote sensing using regular OFDM signals.

8313: Delay-Doppler Parameter Estimation for DFRC-OTFS Using 2D Root-MUSIC

Akshay Bondre{1}, Christ Richmond{2}, Nicolo Michelusi{1}
{1}Arizona State University, United States; {2}Duke University, United States

Orthogonal time frequency space (OTFS) is a modulation scheme based on transmitting information symbols over ideal pulse-Doppler radar signals. As a result, the pilot component of an OTFS transmitted signal can be designed to take the form of a desired pulse-Doppler radar signal. This property results in dual-function capabilities for OTFS, where in addition to the transmitted communications symbols, the pilot signal serves as a radar waveform. In this paper, a two-dimensional (2D) root-MUSIC approach is presented to estimate the delays and Doppler shifts corresponding to multiple targets using such an OTFS waveform. Particularly, the application of the 2D root-MUSIC method for an arbitrary pilot pulse is presented. A heuristic argument is presented that suggests that the widely-used linear frequency modulated (LFM) chirp provides a higher effective signal-to-noise ratio (SNR) as compared to the single-pilot case. Numerical results for the proposed method demonstrate that the LFM pulse, owing to its pulse compression properties, achieves a better estimation performance as compared to a single pilot for a given peak transmitted pilot power.

8208: Optimized Time-Frequency Allocation in MIMO NU-OTFS Radar for Enhanced Performance Under Spectral Constraints

Aitor Correas-Serrano{1}, Nikita Petrov{3}, Maria Gonzalez-Huici{1}, Alexander Yarovoy{2}
{1}Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany; {2}Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands; {3}NXP semiconductors, Netherlands

The performance of MIMO NU-OTFS radar with a high number of transmitters and limited spectral and temporal availability is investigated. NU-OTFS enables the implementation of OTFS communications with quasi-arbitrary distribution of time and frequency resources, increasing the usability of OTFS in spectrally congested scenarios. Moreover, the non-uniform sampling of time and frequency is beneficial for radar performance, as no decrease in resolution or unambiguous parameter estimation occurs. However, radar performance is dependent on the specific time-frequency sampling pattern. This work proposes an optimization framework based on the sidelobe level minimization of the joint ambiguity function of all the operating transmitters. Results show that a substantial sidelobe cancellation can be achieved with specific time-frequency patterns, resulting in viable radar systems with many transmitters in low spectral and temporal availability scenarios.

13:10 – 14:50
Tracking
Room: DENVER BALLROOM 5-6
Session Chairs: Kristine Bell and Alexander Charlish

8104: Joint Multi-Target Tracking and Identification for Distributed Radars Using Bayesian Binary Test

Ye Yuan, Shuoyang Ma, Wei Yi
University of Electronic Science and Technology of China, China

This paper introduces a joint multi-target tracking and identification (J-MTT-I) approach in distributed radar systems. In the tracking phase, we utilized the extended Kalman filter, cascading to covariance intersection fusion, for distributed estimation of target states. Addressing the target identification/recognition issue involves considering and formulating true-false target classification as a binary test problem. Subsequently, the naive Bayesian classifier was employed to model the posterior probability density function concerning target types and to extract target type information from tracking results. The proposed approach offers a practical method for training target classifiers and is anticipated to be applicable to real-world radar systems. Numerical simulations confirm that utilizing multi-dimensional state estimation information derived from the target tracker can further enhance the accuracy of target identification.

8178: The GMPHD Filter for Swarm Target Tracking Based on Gamma Gaussian Processes

Xi Cao, Yunlian Tian, Yiru Lin, Yunfei Liang, Wei Yi
University of Electronic Science and Technology of China, China

The swarm target involves numerous individuals with close proximity and uniform sizes, rendering their situation challenging to discern. Swarm target tracking (STT) aims to simultaneously estimate their shape, center state, cardinality, and other parameters using a limited-resolution sensor. To estimate the arbitrary and time-varying shapes of multiple swarm targets, we model them as star-convex and use a Gaussian process (GP) approach to estimate them recursively. Additionally, we utilize amplitude information to construct hypotheses and the Gamma distribution to estimate the cardinality of the swarm target. On this basis, we propose the Gamma GP probability hypothesis density (Gamma-GP-PHD) filter for STT and develop its Gaussian mixture (GM) implementation using merged polar measurements with amplitude. Some implementation issues and strategies are discussed. The performance of the proposed filter is validated in a scenario with multiple swarm targets of various shapes, and the results show its superiority of shape and cardinality estimation.

8203: Transformer-Based State Estimation for Tracking: Maneuvering Target and Multi-Target Capabilities

Valentin Sonntag{2}, Jean-Marc Le Caillec{1}, Alain Peres{2}, Stéphane Devaud{2}
{1}Lab-STICC, IMT Atlantique Bretagne-Pays de la Loire, France; {2}Thales Land and Air Systems, France

An exploration of a Transformer's behavior is proposed in the context of object tracking, with a particular emphasis on maneuvering targets. We compare the performance of our Transformer-based approach against established tracking methods, including the Kalman filter, Extended Kalman Filter, and Unscented Kalman Filter. The first experiment examines its performance in single-target maneuvering scenarios, revealing heightened reactivity without compromising accuracy during abrupt maneuvers and straight-line trajectory. In a second experiment, we showcase the method's multi-target associative capability. By leveraging the attention mechanisms inherent in Transformers, we capitalize on both spatial and temporal dependencies for accurate tracking. We introduce specific training strategies and modifications to the original Transformer architecture. Our proposed method underscores the Transformer's potential in maneuvering and multi-target scenarios, providing valuable insights into its efficacy for dynamic object motion estimation. We discuss the comparative results, highlighting performance gains over traditional approaches and addressing potential limitations.

8215: MEE-Based Adaptive State Estimator for Non-Gaussian Radar Measurement

Uday Kumar Singh{2}, Mohammad Alaee-Kerahroodi{1}, M. R. Bhavani Shankar{1}, Rama Rao Thipparaju{2}
{1}Interdisciplinary Centre for Security, Reliability and Trust, Université du Luxembourg, Luxembourg; {2}SRM Institute of Science and Technology, India; {2}SRM Institute of Science and Technology, Luxembourg

The proposed approach suggests combining the kernel recursive MEE (KRMEE)-based adaptive filter with the MEE-based EKF, resulting in a filter named EKF-KRMEE. The EKF-KRMEE filter adaptively estimates nonlinearity with each new radar measurement, and the evoked MEE criterion addresses the non-Gaussianity of the measurements. Extensive computer simulations are employed to demonstrate the superiority of the proposed EKF-KRMEE filter over conventional EKF and MEE-based EKF.

8267: Track-Before-Detect for Automotive Radar Using Multiple Frames with Time-Varying Fields of View

Qing Miao, Wujun Li, Wei Yi

University of Electronic Science and Technology of China, China

Track-before-detect (TBD) has been widely studied due to its superior detection performance for low-observable targets in complex environments. In existing works, traditional TBD methods are always considered for stationary radars and are based on an implicit assumption: the presence of the target is unchanged in the sliding window. However, for the extension of TBD to the automotive radar system, movements of the ego-vehicle will result in the field of view misalignment, and the target will fail to fall into the limited field of view temporarily in the sliding window. In order to solve the problems mentioned above, this paper presents an energy accumulation strategy based on motion compensation, and a multiple hypothesis detection method with adaptive threshold (AT). Simulation results for various scenarios are provided to corroborate that the AT-TBD method enables effective detection even in complex cases where target presence changes throughout the time horizon corresponding to the current sliding window.

13:10 – 14:50
Array Processing for Automotive Radar
Room: DENVER BALLROOM 2-1
Session Chairs: Shunqiao Sun and Shobha Sundar Ram

8302: Performance Characterization of Sparse Array Angle Finding Algorithms for Automotive Radars

Ryan Wu, Jun Li, Binbin Shi

NXP Semiconductors, United States

This study introduces two novel coherent-signal single-snapshot sparse array high resolution angle finding (HRAF) algorithms: the Binary Search Matching Pursuit (BSMP) and the Bayesian Linear Regression with Cauchy Prior (BLRC). To provide a comprehensive and quantitative evaluation of these HRAF algorithms, we develop four key performance indicators (KPIs): the probability of target separation, the 95th percentile direction-of-arrival (DoA) estimation error, the 95th percentile number of spurious targets, and the 95th percentile power of spurious targets. The analysis conducted in this study not only highlights the strengths and potential applications of the BSMP and BLRC algorithms but also sets a new benchmark for evaluating various HRAF algorithms in the context of advanced automotive radar systems.

8278: FMCW Radar Rx Channel Imbalance Estimation via Multiple Targets in the Same R-D Bin

Esmaeil Kavousi Ghafi{2}, Oliver Lang{2}, Matthias Wagner{2}, Alexander Melzer{1}, Mario Huemer{2}
{1}Infineon Technologies Linz GmbH & Co. KG, Austria; {2}Institute of Signal Processing, Johannes Kepler University Linz, Austria

In an automotive radar sensor, channel imbalance monitoring is an important task due to its effects on the estimation and detection performance of the radar. In this paper, we propose a method to estimate the gain and phase imbalances of the receive channels of a radar transceiver. This method is based on least squares estimation and uses object reflections in the radar scenery. However, it does not require knowledge of the locations of objects, which makes it a promising technique for online channel imbalance estimation. Furthermore, it permits the use of multiple objects that fall in the same range-Doppler bin, which speeds up the estimation process and makes it less scenario-dependent, compared to using only single objects. The obtained gain and phase imbalances are then applied to two applications: Rx channel calibration and solder ball break detection. Simulation and measurement results confirm the excellent performance of the proposed method.

8076: Virtual Array Transformation for Large Apertures in Cooperative Automotive Radar Networks

Lukas Sigg, Lucas Giroto de Oliveira, Zsolt Kollár, Thomas Zwick, Benjamin Nuss
Karlsruhe Institute of Technology, Germany

This paper introduces a transformation method to transform large aperture arrays with a wider gap between both subarrays into a virtual uniform linear array. Such a large aperture is often present in a cooperative automotive radar network. In order to transform the arrays, phase correction must be done. The calculation of this phase is one of the main topics introduced in this paper. Conducted simulations and measurements show the advantages of such a cooperative network in comparison to a single sensor node. The influence of a baseline error on the accuracy of the transformation is also discussed in this paper. This method can fullfill the current needs of automotive industry by achieving higher angular resolution without increasing the number of antenna elements of a single sensor.

8222: Discrimination of Transmitters in Equally-Spaced DDMA MIMO Radar Using a Correlation Feature and Neural Networks

Siegfred Balon{1}, Jian Wu{2}, Hongning Ruan{1}, Jinghu Sun{2}, Xiaojun Wu{1}
{1}Desay SV Automotive Co. Ltd., Singapore; {2}Desay SV Intelligent Transportation Technological Institute Research Co. Ltd., China

In this paper, we explore the use of neural networks in the discrimination of radar transmitters in frequency-modulated continuous wave (FMCW) multiple-input multiple-output (MIMO) radars. The transmitters are equally spaced in Doppler through the use of Doppler-division multiple access (DDMA). The transmitters are then separated during the signal processing to realize a wide virtual aperture. Although the equal Doppler spacing works well with single targets, this may produce partial or even full overlap when the difference in the Doppler shift of two targets is a multiple of the spacing. We separate the transmitters in both the single and the overlapping two-target scenarios by the use of a cross-correlation feature, implemented as a circular convolution operation, as an input to neural networks. Experimental results in a radar simulator and a traffic monitoring radar system show the effectiveness of the proposed transmitter discrimination.

8142: A Novel Concept for Vehicle 2D Pose Estimation Using Automotive SIMO FMCW Radar Sensors in a Bistatic Vehicle-to-Infrastructure Network

Patrick Fenske, Stefan Brückner, Tobias Kögel, Martin Vossiek
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

This paper presents an approach for the use of cooperative FMCW radar units for precise vehicle-to-infrastructure localization, orientation determination, and simultaneous estimation of synchronization errors between the involved wireless nodes. Our concept requires only one stationary SIMO radar node, which is integrated into the infrastructure and can be applied to conventional automotive radars. To enable real-time operation, an extended Kalman filter tracks the relative position and orientation, as well as the time and frequency offsets of the two radar units. The proposed algorithm is evaluated through various measurements. The results show a precise localization capability, with a 2D position RMSE of less than 1 cm. The achieved synchronization accuracy is in the range of 100 ps, with femtosecond precision.

14:50 – 15:20
Coffee Break
Room: COLORADO A-E

15:20 – 17:00
Special Session: Human Presence & Activities Monitoring
Room: DENVER BALLROOM 4
Session Chairs: Francesco Fioranelli and Sevgi Gurbuz

8160: Radar Based Joint Human Activity and Agility Recognition via Multi Input Multi Task Learning

Emre Kurtoğlu{2}, Moeness G. Amin{1}, Sevgi Zubeyde Gurbuz{2}
{1}Center for Advanced Communications, Villanova University, United States; {2}University of Alabama, United States

Radar-based recognition of human activities of daily living has been a focus of research for over a decade. Current techniques focus on generalized motion recognition of any person and rely on massive amounts of data to characterize generic human activity. However, human gait is actually a person-specific biometric, correlated with health and agility, which depends on a person's mobility ethogram. This paper proposes a multi-input multi-task deep learning framework for jointly learning a person's agility and activity. As a proof of concept, we consider three categories of agility represented by slow, fast and nominal motion articulations and show that joint consideration of agility and activity can lead to improved activity classification accuracy and estimation of agility. To the best of our knowledge, this work represents the first work considering personalized motion recognition and agility characterization using radar.

8256: Crowd Counting Measurements in a Festival Area Using a mmWave FMCW Radar

Adham Sakhnini{1}, Maxim Rykunov{1}, André Bourdoux{1}, Sofie Pollin{2}, Rafael Berkvens{3}
{1}imec, Belgium; {2}imec, Katholieke Universiteit Leuven, Belgium; {3}imec, University of Antwerp, Belgium

In this paper, we consider the problem of crowd counting using millimeter-wave radars. In contrast to conventional detect-and-track counting schemes, the method operates on a power metric derived from the range-Doppler maps. The system is evaluated at the VIP area in the Tomorrowland 2022 music festival. The analysis is carried out over crowd sizes of 0 to 1500 people, where we measure a 82.9% to 94.2% correlation with the bracelet crowd counting reference obtained from the access control system. The results suggest relative counting errors within ±50% for small crowds and within ±25% for large crowds as measured by the 95% percentile prediction intervals.

8081: Analysis of Processing Pipelines for Indoor Human Tracking Using FMCW Radar

Dingyang Wang, Francesco Fioranelli, Alexander Yarovoy
Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands

In this paper, the problem of formulating effective processing pipelines for indoor human tracking is investigated, with the usage of a Multiple Input Multiple Output (MIMO) Frequency Modulated Continuous Wave (FMCW) radar. Specifically, two processing pipelines starting with detections on the Range-Azimuth (RA) maps and the Range-Doppler (RD) maps are formulated and compared, together with subsequent clustering and tracking algorithms and their relevant parameters. Experimental results are presented to validate and assess both pipelines, using a 24 GHz commercial radar platform with 250 MHz bandwidth and 15 virtual channels. Scenarios where 1 and 2 people move in an indoor environment are considered, and the influence of the number of virtual channels and detectors' parameters is discussed. The characteristics and limitations of both pipelines are presented, with the approach based on detections on RA maps showing in general more robust results.

8226: A Millimeter-Wave MIMO Radar Network for Human Activity Recognition and Fall Detection

Ann-Christine Froehlich, Desar Mejdani, Lukas Engel, Johanna Bräunig, Christoph Kammel, Martin Vossiek, Ingrid Ullmann
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Falling is a major risk for elderly people. To enable independent living, fall detection and activity monitoring are desirable. Radar is a sensor principle that offers the possibility to detect falls in a contactless, privacy-preserving fashion. Therefore, in combination with deep learning, it has become a widely investigated technique for human activity recognition and fall detection. Current systems, however, come with some limitations: When using just one monostatic radar, it is impossible to measure lateral velocities. This motivates the use of a radar network consisting of two spatially orthogonal radars. Contrary to some previous works which applied similar radar networks, this paper introduces the first millimeter-wave multiple-input-multiple-output (MIMO) radar network with two orthogonal radars for human activity recognition and fall detection. Using millimeter-wave MIMO radars enables a higher resolution and the use of angular *information for the recognition task. First measurement results and deep-learning-based activity recognition are presented.*

8263: OFDM Based Joint Communications and Human Activity Monitoring with Gnu Radio

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

This paper implements an ac{OFDM} based system for joint communications and sensing. A sub-5 GHz software defined radio testbed is used to demonstrate communications aided sensing in a monostatic configuration. In traditional ac{OFDM} communication processing, ac{CSI} is estimated and corrected to decode modulated messages. This time-varying ac{CSI} contains Doppler information from human movements in the environment. The ac{CSI} can be analyzed via time-frequency analysis to reveal human micro-Doppler signatures. Utilizing the ac{CSI} to deduce information about human movements in the environment, in addition to processing the communication payload, can increase versatility of future generation wireless systems.

15:20 – 17:00
SAR Image Formation
Room: DENVER BALLROOM 3
Session Chairs: Julie Jackson and Brian Rigling

8045: True Time-Delay Minimum Entropy Autofocus Using a 2D Phase Error Overcomplete Basis

Joshua Kantor
MIT Lincoln Laboratory, United States

In previous work we developed SAR autofocus approaches capable of correcting for residual motion compensation errors exceeding a range resolution cell by applying 2D autofocus corrections in the spatial frequency domain that approximate pulse-level true time-delay motion compensation corrections. In this article we improve upon the approximations employed in our previous work, enabling the ability to estimate and compensate for large motion compensation errors (exceeding a resolution cell) by estimating and applying time-delays at the true pulse level to a complex SAR image. Our approach is based on minimizing entropy and exploits an overcomplete basis for the possible motion compensation errors to aid in convergence of the optimization.

8209: Low Complexity Geometrical Autofocusing Based on Subsequent Sub-Apertures Calibration

Pietro Grassi, Marco Manzoni, Stefano Tebaldini
Politecnico di Milano, Italy

Synthetic Aperture Radar (SAR) is an imaging technique capable of generating high-resolution images of the observed scene. Accurate knowledge of the platform's trajectory is crucial for achieving highly focused images. Failure to meet this requirement will result in phase errors, leading to blurring effects in the final image. This work presents a low-complexity autofocusing algorithm based on the geometrical compensation of phase errors. The total platform trajectory is divided into adjacent, non-overlapping sub-apertures, reducing phase error contribution and enhancing the effectiveness of calibration. The correction is propagated to adjacent sub-apertures, leveraging the targets' estimated position in the first calibrated sub-aperture. After each sub-aperture undergoes geometrical compensation, they are all coherently merged, enabling the retrieval of the un- blurred, full-resolution SAR image. In this paper, the algorithm is accurately described and validated using a simulated data set. Finally, the effectiveness of the approach is proved using real radar data.

8089: Phase-Encoded Linear Sampling Method Imaging of 3D Targets from Circular Synthetic Aperture Data

Matthew Burfeindt, Hatim Alqadah
U.S. Naval Research Laboratory, United States

We present a technique for imaging 3D targets from synthetic apertures using a variant of the linear sampling method (LSM). The rationale for an LSM-based approach is to mitigate simplifying assumptions used in many conventional RF imaging algorithms in order to achieve higher image fidelity. Our LSM variant, which we refer to as the phase-encoded LSM (PE-LSM), is formulated to overcome the principal challenge to synthetic-aperture-based LSM imaging - its need for copious multistatic channels. We apply the PE-LSM to simulated target data using only monostatic data from circular synthetic apertures. The results demonstrate improved image fidelity compared to results from a conventional backprojection-based algorithm.

8252: CMC-RMA: Compressed Multi-Coset Range Migration Algorithm for MIMO-SAR

Andrew Gigie, Rokkam Krishna Kanth, Achanna Anil Kumar, Tapas Chakravarty, Arpan Pal
TCS Research, India

This paper introduces the Compressed Multi-Coset Range Migration Algorithm (CMC-RMA) for near-field microwave imaging. CMC-RMA reduces the SAR acquisition time by compressed scanning, wherein a MIMO radar captures measurements by intermittently skipping blocks during SAR acquisition. The reconstruction of the microwave image typically involves utilizing the 2D Fourier Transform (FT) of the measurements. However, this process is impeded by the compressed scanning mechanism. Thus, to estimate the 2D FT, we employ a multi-coset framework making use of intermittent scanning and formulate a compressed sensing-based framework by leveraging block-sparsity constraints. Classical RMA is then employed on the estimated 2D FT to reconstruct the microwave image of the scene. Subsequently, a denoising convolutional neural network (DnCNN) is used to enhance and denoise this reconstructed microwave image to obtain the high-resolution image of the scene. Comparative analysis with existing methods using real experimental data reveals a significant 4dB increase in PSNR for identical compression factors, confirming the effectiveness of the proposed approach.

8235: Flexible and Seamless Factorised Processor for Long-Range Mono- and Bistatic UAV-Borne SAR

Mattia Giovanni Polisano, Marco Manzoni, Stefano Tebaldini
Politecnico di Milano, Italy

This work describes a seamless and versatile factorized focusing procedure dedicated to large-scale, high-resolution mono- and bistatic Synthetic Aperture Radar imaging. The algorithm deals with complex trajectories typical of Unmanned Aerial Vehicles (UAV). Efficiency and accuracy are two cornerstones of the algorithm to focus large-scale images at high resolution. Two scenarios are tackled. The first is a UAV-borne SAR with a short synthetic aperture and a wide field of view. We consider both monostatic and bistatic modes. In the latter case, with a still transmitter and a moving receiver. The second scenario is a stripmap UAV-borne SAR, with a receiver and transmitter moving with a fixed bistatic baseline. The entire processing scheme is based on a modified version of the Fast Factorized Back Projection, exploiting an ad-hoc reference system with constant resolution and minimal number of samples in the back-projection grid. The developed processor defines the best reference system and the strategies for the minimum computational cost. The theoretical performances of the entire workflow are derived as a rough number of complex operations required to focus an image.

15:20 – 17:00
Waveform Design
Room: DENVER BALLROOM 5-6
Session Chairs: Shannon Blunt and Bill Correll, Jr.

8288: Sum-of-Reciprocal Exact Descent: Waveform Design for Multi-Target Detection

Junho Kweon{1}, Fulvio Gini{2}, Maria Sabrina Greco{2}, Vishal Monga{1}
{1}Pennsylvania State University, United States; {2}University of Pisa, Italy

We consider the problem of multiple target detection in the presence of signal-dependent clutter for a Multiple-Input Multiple-Output (MIMO) radar. Specifically, we design transmit waveforms for each antenna to maximize the worst-case Signal-to-Interference-Noise-Ratio (SINR) over multiple targets. To ensure hardware compatibility, the essential constant modulus constraint (CMC) is posed. A hard max-min and fractional non-convex optimization problem emerges as a function of the transmit waveform. To address the difficulty of max-min optimization, we exploit SINR properties to develop a new sum of reciprocals cost function surrogate. Subsequently, we compute the exact gradient of each fractional term in the sum paving the way for a sum of reciprocals, exact descent (SRED) numerical optimization technique that preserves the CMC. Experiments over a well-known benchmark simulation scenario establishes the ability of SRED to outperform state-of-the-art alternatives both in worst-case SINR and desirable beampattern profiles.

8157: A Polar Optimization Search for CAZAC Sequences

Mark Magsino{2}, Bill Correll Jr{1}
{1}Maxar Intelligence, United States; {2}U.S. Naval Academy, United States

We report on a search for CAZAC sequences from the minimization of a trigonometric sum that arises from a polar substitution. Our computations produced new CAZAC sequences of lengths 14 and 15 and identified CAZAC sequences of both lengths having aperiodic peak sidelobe level and integrated sidelobe level below those of P4, Wiener, and Zadoff-Chu quadratic phase constructions. Our methods generalize naturally to CASAC sequences. The code and results of our search are publicly available through GitHub.

8265: Use of the Restricted Isometry Property for Assessing PRI Staggering Sequences

Callin Schone{2}, Nathan Goodman{1}
{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}University of Oklahoma, United States

RIP-based evaluation of staggered waveforms.

8286: Low PAPR Design for OFDM Symbols with Guard Bands and Baseband Filtering

André Bourdoux, Ruoyu Feng, Marc Bauduin
imec, Belgium

We address the problem of power amplifier (PA) non-linearity in OFDM radars. The usual metric to minimize the impact of PA non-linearities is the peak-to-average power ratio (PAPR). However, minimizing the PAPR without considering the effect of guard bands and analog lowpass filtering results in severe underestimation of the actual PAPR in continuous time. We propose an algorithm that takes guard bands and analog filtering into account in the PAPR minimization. Simulation is used to show that linear PAPR smaller than 1.3 (1.14dB) is achieved with our algorithm and that the peak sidelobe level in the range profile are reduced well below -50dB.

8207: Waveform Design for OFDM-Based ISAC Systems Under Resource Occupancy Constraint

Silvia Mura{1}, Dario Tagliaferri{1}, Marouan Mizmizi{1}, Umberto Spagnolini{1}, Athina Petropulu{2}
{1}Politecnico di Milano, Italy; {2}Rutgers University, United States

Integrated Sensing and Communication (ISAC) is one of the key pillars envisioned for 6G wireless systems. ISAC systems combine communication and sensing functionalities over a single waveform, with full resource sharing. In particular, waveform design for legacy Orthogonal Frequency Division Multiplexing (OFDM) systems consists of a suitable time-frequency resource allocation policy balancing between communication and sensing performance. Over time and/or frequency, having unused resources leads to an ambiguity function with high sidelobes that significantly affect the performance of ISAC for OFDM waveforms. This paper proposes an OFDM-based ISAC waveform design that takes into account communication and resource occupancy constraints. The proposed method minimizes the Cramér-Rao Bound (CRB) on delay and Doppler estimation for two closely spaced targets. Moreover, the paper addresses the under-sampling issue by interpolating the estimated sensing channel based on matrix completion via Schatten p-norm approximation. Numerical results show that the proposed waveform outperforms the state-of-the-art methods.

15:20 – 17:00
ECCM and Interference Cancellation
Room: DENVER BALLROOM 2-1
Session Chairs: Ric Romero and Rylee Mattingly

8259: Performance Analysis of OFDM Interference Mitigation via Demodulation/Remodulation Estimation and Extraction

Rylee Mattingly{2}, Nathan Goodman{1}, Justin Metcalf{1}
{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}University of Oklahoma, United States
Increased demand for sub-6 GHz electromagnetic spectrum access has led to the development of new techniques for dynamic spectrum access. Additionally, new regulatory frameworks have been proposed to allow for both cooperative and non-cooperative sharing of spectrum resources. When multiple users coexist in a frequency band, there is a risk of interference between the users. This work presents an active cancellation technique that demodulates an interfering communications signal using known orthogonal frequency division multiplexing (OFDM) parameters. The technique uses demodulated data to remodulate a reference signal that can then be used as an estimate of the interference and subtracted from the radar return data. This work presents a model for simulation and examines the interference power reduction that can be achieved with a pulsed radar system that loses data by blanking its receiver on transmit. This work concludes with an analysis of range-Doppler processing applied after interference mitigation and presents the output constant false alarm rate (CFAR) detection statistics.

8123: Coherent Subtraction of Short Pulsed Radio Frequency Interference: A Case Study

Joel Johnson{1}, Lee Potter{1}, Emre Ertin{1}, Andrew Harms{2}
{1}Ohio State University, United States; {2}University of Nebraska–Lincoln, United States
Interference from one radar system to another may compromise radar performance. For low-duty cycle pulsed sinusoidal interference, the interfering power is highly concentrated in the time domain (simplifying its detection) and occupies only a small fraction of a coherent integration period, making mitigation more feasible. While a flag-and-exclude approach can be applied to reduce the impact of this interference, such methods may impact downstream radar processing operations due to the absence of flagged data. To reduce the impact on downstream operations, it is more desirable to estimate and coherently subtract interference if possible. A case study of a coherent subtraction approach with data from NOAA's Advanced Technology Demonstrator (ATD) weather radar is presented in this paper that demonstrates reasonable performance and suggests avenues for continued advancement of the method.

8101: Deceptive Jamming in WLAN Sensing

Hasan Can Yildirim{2}, Musa Furkan Keskin{1}, Henk Wymeersch{1}, François Horlin{2}
{1}Chalmers University of Technology, Sweden; {2}Université Libree de Bruxelles, Belgium

Joint Communication and Sensing (JCAS) is taking its first shape in WLAN sensing under IEEE 802.11bf, where standardized WLAN signals and protocols are exploited to enable radar-like sensing. However, an overlooked problem in JCAS, and specifically in WLAN Sensing, is the sensitivity of the system to a deceptive jammer, which introduces phantom targets to mislead the victim radar receiver. Standardized waveforms and sensing parameters make the system vulnerable to physical layer attacks. Moreover, orthogonal frequency-division multiplexing (OFDM) makes deceptive jamming even easier as it allows digitally generated artificial range/Doppler maps. This paper studies deceptive jamming in JCAS, with a special focus on WLAN Sensing. The provided mathematical models give insights into how to design jamming signals and their impact on the sensing system. Numerical analyses illustrate various distortions caused by deceptive jamming, while the experimental results validate the need for meticulous JCAS design to protect the system against physical layer attacks in the form of deceptive jamming.

8192: Detection Performance of Enhanced Electronic Protection Mitigation in Space-Time Adaptive Processing Against Adaptive Shaped Interference

Isaac Lee, Ric Romero
Naval Postgraduate School, United States

This study introduces adaptive shaped interference such as the transmit waveform shaped noise jammer (TWS-NJ) into space-time adaptive processing (STAP) and assesses its impact on detection performance. Results from simulation demonstrate that the TWS-NJ has superior noise jamming performance over conventional noise jammer like the barrage noise jammer and causes a large degradation in detection performance. This degradation is even more apparent when the noise jammer is located with the target in the same clutter angle. The study then evaluates the effectiveness of the generalized matched filter in mitigating these advanced interferences. Results showed that the GMF exhibited superior performance against TWS-NJ when aided with an accurate estimate of the noise jammer covariance matrix, highlighting its efficacy in enhancing electronic protection for STAP.

18:00 – 12:00
Exhibitor Reception
Room: COLORADO A-E

19:00
RSP Panel Dinner (Closed)
Room: PENROSE 2

8:00 – 9:40
Special Session: Integrated RF Sensing and Communications
Room: DENVER BALLROOM 4
Session Chairs: Maria Sabrina Greco and Visa Koivunen

8018: Joint Sensing and UE Positioning in 5G-6G: PRS Range Estimation with Suppressed Ambiguity

Moeinreza Golzadeh{1}, Esa Tiirola{1}, Jukka Talvitie{2}, Lauri Anttila{2}, Kari Hooli{1}, Oskari Tervo{1}, Mikko Valkama{2}
{1}Nokia, Finland; {2}Tampere University, Finland

This paper focuses on cellular integrated sensing and communications (ISAC), with particular focus on downlink where the positioning reference signal (PRS) is the primary physical resource for high-accuracy delay estimation and ranging. The PRS allows for large bandwidths, and thus high ranging accuracy, however, the involved comb-like subcarrier patterns induce ambiguity challenges in both positioning and sensing. In this paper, alternative time-/frequency-domain solutions to resolve or relax the ambiguity challenges are described, discussed and proposed. Specifically, new irregular resource patterns are introduced, allowing for high-accurate downlink sensing with suppressed ambiguity while at the same time supporting also ordinary UE positioning services. Corresponding numerical results are also provided, evidencing and highlighting the benefits of the proposed approach.

8139: Cognitive Beamspace Algorithm for Integrated Sensing and Communications

Petteri Pulkkinen{2}, Majdoddin Esfandiari{1}, Visa Koivunen{1}
{1}Aalto University, Finland; {2}Aalto University, Saab Finland Oy, Finland

This paper presents a novel cognitive beamspace algorithm for integrated sensing and communications (ISAC) systems, focusing on the optimization of spatial resources. The proposed method operates in the beamspace domain that enables an orthogonal design between the sensing and communication functions. Additionally, the approach leverages the principles of Thompson sampling, known for effectively balancing exploration and exploitation in uncertain environments. It enables the ISAC system to dynamically adjust radar target search strategies based on environmental feedback while maintaining acceptable communication rates with the user equipment. We demonstrate the algorithm's effectiveness over traditional methods through numerical simulations. These simulations reveal significant improvements in radar search functionality while meeting the communications quality of service constraints.

8284: Radar Operating Metrics and Network Throughput for Integrated Sensing and Communications in Millimeter-Wave Urban Environments

Akanksha Sneh, Shobha Sundar Ram
Indraprastha Institute of Information Technology, Delhi, India

Millimeter wave integrated sensing and communication (ISAC) systems are being researched for next-generation intelligent transportation systems. Here, radar and communication functionalities share a common spectrum and hardware resources in a time multiplex manner. The objective of the radar is to first scan the angular search space for the detection and localization of mobile users/targets in the presence of discrete clutter scatterers.

Subsequently, this information is used to direct highly directional beams toward these mobile users for communication service. The choice of radar parameters such as the radar duty cycle and the corresponding beamwidth are critical for realizing high communication throughputs. In this work, we use the stochastic geometry-based mathematical framework to analyze the radar operating metrics as a function of diverse radar, target, and clutter parameters and subsequently use these results to study the network throughput of the ISAC system. The results are validated through Monte Carlo simulations.

8310: On the Similarity of Sidelobes Signal Embedding in DFRC Systems and Directional Modulations

Moeness G. Amin{1}, Aboulnasr Hassanien{2}
{1}Center for Advanced Communications, Villanova University, United States; {2}Wright State University, United States

Dual Function radar communication systems (DFRC) allow the two functions of radar sensing and information transmission to be performed simultaneously. When the radar beam is paramount to the sensing function, embedding the communication signals can be performed in the beam sidelobes. Designing multiple beams which exhibit desired common main beam shape and width and different sidelobe complex values at the different user positions is referred to as DFRC sidelobe signal embedding. Except from maintaining the main beam intact and satisfying a mandatory sidelobe level threshold constraint, sidelobe signal embedding at core amounts to directional modulation (DM) which puts more emphasis on communication security. In this paper, we tie in these two independently developed areas and compare them, in their basic forms, in relation to security. We examine the difference in signal constellations received by the intended users and eavesdroppers. The bit error rates are used to highlight the respective performance.

8326: Dual-Blind Deconvolution in ISAC Receiver Using Multi-Dimensional Beurling-Selberg Functions

Jonathan Arley Monsalve Salazar{2}, Edwin Vargas{2}, Kumar Vijay Mishra{1}, Brian Sadler{1}, Henry Arguello Fuentes{2}
{1}DEVCOM Army Research Laboratory, United States; {2}Universidad Industrial de Santander, Colombia

Recent interest in integrated sensing and communications (ISAC) systems has led to the development of innovative signal processing techniques to extract information from a shared radar-communications spectrum setup. We focus on a dual-blind deconvolution (DBD) problem, where the ISAC receiver admits a multi-carrier wireless communications signal overlaid with the radar signal reflected off multiple targets. Here, apart from the unknown radar and communications transmit signals, their channels characterized by continuous-valued range-time delays and Doppler velocities are also unknown. Previous efforts tackled the recovery of unknown channels and signals in this highly ill-posed DBD problem through atomic norm minimization. In this paper, we introduce an optimal joint separation condition through a novel approach of extremal functions derived from the Beurling-Selberg interpolation theory. Subsequently, we formulate DBD as a low-rank modified Hankel matrix retrieval problem and solve it through nuclear norm minimization. Our numerical experiments demonstrate the effectiveness of the proposed approach in a shared radar-communications spectrum environment.

8:00 – 9:40
SDR Platforms
Room: DENVER BALLROOM 3
Session Chairs: Daniel Bliss and Jonathan Owen

8084: First Results of an USRP-Based Multi-Function Real-Time Radar

Angel Slavov, Santiago Pérez Pérez, Peter Knott
Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany

This paper presents the first results of an real-time USRP-based multi function radio frequency system (MFRFS). An advantage of USRP-based systems is the universal hardware which allows multi-function radars to be realised on a single platform without a need to develop hardware for each subsystem. The MFRFS presented in this paper includes four different subsystems. The first subsystem is an FMiCW (frequency-modulated interrupted continuous wave) radar with instantaneous bandwidth of 10 MHz. The rest three subsystems classification, jamming and false target generator operate together offering electronic countermeasure to the MFRFS. Thus, the output of the classification subsystem is used as an input to the jamming and false target generator in order these subsystems to provide the corresponding response. Hence, MFRFS is able to generate a false target with predefined range and frequency shift masking the behaviour and the number of real targets.

8127: Real-Time Waveform-Diverse Pulse-Doppler Demo via Microwave Radar-in-a-Briefcase (MicRIB)

John Fraka{2}, Thomas Higgins{1}, Jonathan Owen{2}
{1}Navy Research Laboratory, United States; {2}University of Kansas, United States

Recent advancements in software-defined technology provide the foundation for radar systems that have balanced size, weight, power, and cost (SWaP-C). Here, an Nvidia Jetson AGX Orin and an Ettus B200mini are connected to establish a real-time pulse-Doppler radar. Enclosing the system in a carry-on case, the Microwave Radar-in-a-Briefcase (MicRIB) is a portable, low-cost test bench. The MicRIB is capable of arbitrary waveform transmission, data capture, and range-Doppler filtering in real-time while I/Q sampling at 45 MHz. The MicRIB may perform real-time spectrogram analysis at the same rate. The MicRIB performance is experimentally evaluated in an open-air setting, performing moving target indication (MTI) processing. To demonstrate system flexibility, waveforms including linear FM, nonlinear FM, and random FM are assessed. Pulse compression is performed with either a matched filter or least squares mismatched filter, and a slow time Taylor window is applied prior to Doppler processing. With a form factor of 4.4×4.4×3.1 inches and weight of 1.6 kg, the radar performs with an average power draw of 40 Watts and presently costs under $3600, excluding peripherals.

8210: Evaluation of UAV-Based ISAC SAR Imaging: Methods and Performances

Marco Manzoni, Stefano Moro, Francesco Linsalata, Mattia Giovanni Polisano, Andrea Virgilio Monti-Guarnieri, Stefano Tebaldini

Politecnico di Milano, Italy

This paper seeks to demonstrate the functionality of an Integrated Communication and Sensing (ISAC) system operating within the sub-6 GHz frequency range for SAR imaging from an UAV. The primary goal of this research is to determine the viability of generating SAR imagery of the environment while adhering to practical constraints and parameters defined by contemporary communication standards. These parameters include aspects such as maximum transmitted power, carrier frequency, occupied bandwidth, Pulse Repetition Frequency (PRF), the number of sub-carriers employed, and more. The paper provides a detailed explanation of the OFDM signal transmitted by the base station. Furthermore, it compares two potential methods for range-compressing the signal. An analysis of the Noise Equivalent Sigma Zero (NESZ) is proposed under classical line-of-sight conditions and in a more challenging environment, demonstrating the system's ability to detect targets under snow cover. The conclusion includes the presentation of simulated Impulse Response Functions (IRF) under various assumptions and actual SAR images of the environment captured using a UAV equipped with a software-defined radar (SDR).

8308: Implementation and Demonstration of Transmit Waveform Shaped Interference with COTS SDR

Stephen Sweetnich, Ric Romero

Naval Postgraduate School, United States

This paper outlines the transmit waveform shaped (TWS) interference model, hardware requirements of the shaped interference model, and implementation with low-cost, commercial-off-the-shelf (COTS) software-defined radio architecture. The demonstration utilizes open-source software and hardware to implement the TWS technique with linear frequency modulation (LFM) radar signal and root-raised cosine pulse shaped QPSK signal in real time. The research describes the software and hardware initialization steps and functions required to decrease latency and efficiency with large matrix operations. Using modular and low-cost tools (< $200), this paper describes a method for deployment of electromagnetic (EM) or radio frequency (RF) emission and testing on a broad range radar and communications systems. Furthermore, the paper describes how this low-cost open-source architecture provides a test bed for electromagnetic protection techniques.

8295: Low-Cost Measurement Setup for Power Amplifier Characterization and Digital Pre-Distortion: Challenges and Implementation

Adarsh A. Venkataramani{1}, Carl Morgenstern{1}, Yu Rong{1}, Pierre-Francois Wolfe{2}, Brian Janice{2}, Kenneth Kolodziej{2}, Daniel W. Bliss{1}

{1}Arizona State University, United States; {2}MIT Lincoln Laboratory, United States

This paper (a) experimentally evaluates power amplifier (PA) linearization using digital pre-distortion (DPD) on a low-cost commercial off-the-shelf (COTS) Ettus N320 software-defined radio (SDR) and (b) provides a comprehensive summary of solutions for calibration issues that stem during DPD on SDRs. Experimentally, a 16-QAM 1.5dBm input waveform drives the ZVE-8G+ amplifier into saturation. After a twelve-step calibration and using the indirect learning architecture (ILA) for DPD, we observe that the linearized output exhibits a -32dB adjacent channel power ratio (ACPR) and a -35dB error vector magnitude (EVM).

8:00 – 9:40
Radar Resource Management
Room: DENVER BALLROOM 2-1
Session Chairs: Raviraj Adve and Alexander Charlish

8054: Model-Based DRL for Task Scheduling in Dynamic Environments for Cognitive Multifunction Radar

Sunila Akbar{2}, Raviraj S. Adve{2}, Zhen Ding{1}, Peter W. Moo{1}
{1}Defence Research and Development Canada, Ottawa Research Centre, Canada; {2}University of Toronto, Canada

The uncertainty in the radar environment brings significant challenges to task scheduling in a cognitive multifunction radar (MFR). The recent radar task scheduling approaches assume the knowledge of the environment, which is unknown in real scenarios. To achieve online task scheduling for a cognitive radar which does not need to know the dynamics of the environment, this work investigates the model-based deep reinforcement learning (DRL), which learns the model of the environment to plan for scheduling tasks. The main idea of the model-based methods is to construct an abstract Markov- decision process (MDP) model such that planning in the abstract MDP is equivalent to planning in the real environment. Here, we tailor MuZero, proposed to learn to play games, to provide the needed model. Our numerical simulation results show the effectiveness of the proposed algorithm in MFR task scheduling while adapting to dynamic radar environments, without any a priori knowledge.

8319: Belief-Rewards to Learn Radar Scheduling Policies

Amos Hebb{2}, Raviraj S. Adve{2}, Zhen Qu{1}, Zhen Ding{1}
{1}Defence Research and Development Canada, Ottawa Research Centre, Canada; {2}University of Toronto, Canada

Beam-agile radars have the potential to learn schedul- ing policies requiring only a holistic belief constructed from past observations. Rewarding improvements to belief directly enables an agent to learn policies to track known targets, and search for unknown targets, without explicitly rewarding this behavior. In this paper, we model a radar controller as an information-gathering agent in a Belief Markov Decision Process. Using a Monte Carlo tree search reinforcement learning framework actions are chosen considering only belief and a model estimating the improvement in belief-reality distance. Importantly, our approach is agnostic to the number of targets and adapts to dynamic environments. We present preliminary results as proof of our underlying concept.

8268: Adaptive Radar Resource Management for All-Digital Multi-Function Phased Array Radar Using Proximal Policy Optimization

Brianna Witherell{1}, Tian-You Yu{1}, David Schvartzman{1}, Nathan Goodman{1}, Alexander J. Stringer{2}, Geoffrey Dolinger{2}

{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}US Air Force/AFSC/SW/76 SWEG, OC-ALC, University of Oklahoma, United States

This paper presents a novel approach to radar resource management (RRM) for multi-function phased array radars, specifically focusing on all-digital architecture with enhanced capabilities such as dynamic subarray allocation and adaptive digital beamforming. The core contribution of this paper lies in the application of the multi-agent proximal policy optimization (MAPPO) reinforcement learning algorithm to RRM, a significant shift from existing adaptive RRM strategies that predominantly employ deep Q-networks. The MAPPO algorithm's ability to balance exploration and exploitation, along with its stability and efficiency, makes it an ideal solution for the resource-constrained, real-time demands of RRM in all-digital MFRs. The algorithm is rigorously trained in simulations using realistic target motion models and is tested in scenarios involving single and multiple beams, taking advantage of the flexibility offered by all-digital MFRs. Results demonstrate the algorithm's capability to effectively search for targets, maintain target tracks in overloaded conditions, and cooperatively allocate tasks.

8167: Cognitive Radar Scheduler Architecture

Hoan Nguyen{2}, Joseph Guerci{2}, Sandeep Gogineni{2}, Jameson Bergin{2}, Erik Blasch{1}, Muralidhar Rangaswamy{1}

{1}Air Force Research Laboratory, United States; {2}Information Systems Laboratories, Inc., United States

A key feature of any cognitive radar is its ability to make "intelligent" decisions regarding the high-speed allocation of radar resources including energy, waveforms, beamwidth, look angles, timelines, and compute resources. In this paper, a radar scheduler and resource optimization architecture are developed and integrated into a high-fidelity RF modeling and simulation (e.g. RFView) framework to facilitate the assessment of its efficacy for a variety of challenging applications. Results demonstrate the scheduler to prioritize looks and tasks to support wide-area search, probing, and synthetic aperture radar (SAR) collection.

8109: Radar Resource Management for Active Tracking Using Split-Aperture Phased Arrays

Pepijn Cox, Wim van Rossum

Netherlands Organisation for Applied Scientific Research, Netherlands

Flexible front-end technology will become available in future multifunction radar systems to improve adaptability to the operational theatre. A potential concept to utilize this flexibility is to subdivide radar tasks spatially over the array, the so-called split-aperture phased array (SAPA) concept. As radars are generally designed for their worst-case scenario, e.g., small targets at a large range, the power-aperture budget can be excessive for targets that do not fall within that class. To increase efficiency of the time budget of the radar front-end, the SAPA concept could be applied. In this paper, the SAPA concept is explored to assign radar resources for active tracking tasks of many targets. To do so, we formulate and solve the radar resource management problem for the SAPA concept by employing the quality of service based resource allocation model (Q-RAM) framework. It will be demonstrated by a simulation example that a radar can maintain a larger numbers of active tracking tasks when using the SAPA concept compared to the case that only the full array can be used per task.

9:40 – 10:50
Coffee Break
Room: COLORADO A-E

9:40 – 10:50
Poster Session 1: MIMO and Antenna Arrays
Room: DENVER BALLROOM 5-6
Session Chair: Mike Picciolo

8063: Adaptation of the Apes Approach to DoA Estimation Problem in a Rotating Array Radar

Michal Meller
PIT-RADWAR S.A., Poland

The problem of direction of arrival in a radar system that employs mechanical scanning to estimate angle is considered. The presence of clutter and noise with unknown spectral characteristics and the absence of training data, i.e. inhomogeneous environment, are assumed. The proposed approach is a modification of the APES (Amplitude and Phase EStimator) spectrum estimator that takes into account the motion and the directional response of the array. Computer simulations show high accuracy of the method.

8321: Sparse Spatial Smoothing: Reduced Complexity and Improved Beamforming Gain via Sparse Sub-Arrays

Yinyan Bu{2}, Robin Rajamäki{2}, Anand Dabak{1}, Rajan Narasimha{1}, Anil Mani{1}, Piya Pal{2}
{1}Texas Instruments, United States; {2}University of California, San Diego, United States

This paper addresses the problem of single snapshot DOA estimation. A popular approach to achieve high angular resolution in single snapshot is via subspace methods using spatial smoothing. This involves leveraging spatial shift-invariance in the antenna array geometry—typically a uniform linear array (ULA)—to rearrange the single snapshot measurement vector into a spatially smoothed matrix that reveals the signal subspace of interest. However, conventional approaches can lead to a high computational complexity due to the large dimensions of the resulting spatially smoothed matrix. Hence, we propose to use sparse sub-arrays to reduce the computational complexity of spatial smoothing while retaining the aperture and identifiability of conventional ULA-based approaches. Interestingly, this idea also suggests a novel beamforming method which linearly combines multiple spatially smoothed matrices corresponding to different sets of shifts. This shift-domain beamforming method is demonstrated to boost the effective SNR, and thereby resolution, in a desired angular region of interest, enabling single snapshot low-complexity DOA estimation with identifiability guarantees.

8070: Waveform Degradation of the MIMO Virtual Array

Matthew Jackson{2}, William Melvin{2}, Douglas Williams{1}
{1}Georgia Institute of Technology, United States; {2}Georgia Tech Research Institute, United States

Under scenarios with sufficient signal power, coherent multiple-input multiple-output (MIMO) radar potentially offers enhanced detection and estimation performance compared to the traditional phased array because of the formation of a virtual array. While performance is well-documented for ideal orthogonal waveforms, these assumptions do not hold in deployment of realistic MIMO systems, where processing errors and waveform cross-correlation complex-valued cross terms are introduced. This paper highlights the effects of virtual array phase errors caused by unintended spatial interactions of non-orthogonal waveforms and provides considerations for MIMO array placement.

8158: Mismatched Complementary-on-Receive Filtering (MiCRFt) for MIMO Radar

Matthew Heintzelman, Christian Jones, Patrick McCormick, Shannon Blunt
University of Kansas, United States

While the suppression of range sidelobes has received considerable attention, with a variety of solutions now possible, the mitigation of cross-correlation sidelobes for multistatic/MIMO scenarios remains a difficult problem. Here, leveraging the recent MiCRFt method that was experimentally shown to achieve complementary receive cancellation, a multi-emitter extension is posed that provides the degrees-of-freedom necessary to reduce both auto- and cross-correlation sidelobes. The ensuing MIMO MiCRFt formulation is experimentally demonstrated using simulated, loopback, and open-air measurements obtained via random FM (RFM) nonrepeating waveforms.

8237: Sparse Array Placement for Bayesian Compressive Sensing Based Direction of Arrival Estimation

Lucas L. Lamberti{2}, Ignacio Roldan{2}, Alexander Yarovoy{1}, Francesco Fioranelli{1}
{1}Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands; {2}Technische Universiteit Delft, Netherlands

In this paper, an algorithm to find the optimal placement of sparse linear antenna arrays for Direction of Arrival (DoA) estimation in combination with Bayesian Compressive Sensing (BCS) is proposed. The proposed algorithms rely on the provided information inherent to BCS, i.e., the entropy of the recovered estimation vector, to place new sensor antenna elements in an initially empty array, so that the most additional information is gathered about the observed scene. It is shown by means of simulation and radar measurements that BCS methods for DoA estimation using sparse sensor arrays provide promising results in terms of detection probability and estimation accuracy. Furthermore, the proposed algorithms are able to generate sparse sensor arrangements which provide an improved performance when compared against randomly generated sparse arrays.

8021: Auto-Scanning Quantized, Power Law Frequency Diverse Arrays

Bill Correll Jr{1}, Brian Rigling{2}

{1}Maxar Intelligence, United States; {2}University of Dayton, United States

We extend earlier work with quantized-power-law, frequency diverse arrays by reincorporating linear frequency offsets. This provides a controllable scan pattern that is approximately linear over the range −45 degrees to 45 degrees. We give parametric design expressions for scan rate and peak-to-peak along-scan distance of the resultant FDA far field and present phase noise and frequency offset sensitivity analyses for a notional FDA that suggest uncertainty tolerances and scan range limits.

8225: Design of an Electronically Steered Phased Antenna Array for a CubeSat

Madison Crews, Lanche Grootboom

Stellenbosch University, South Africa

CubeSats are small satellites that make satellite-based research, exploration, and education significantly more accessible. Current CubeSat communications systems are limited by low-frequency, low-gain antennas with mechanical beam steering. This paper presents a comprehensive study on the development and design of an electronically steered phased antenna array to improve data transmission capabilities. The primary objective is to investigate and optimize the design by considering the antenna type, frequency band, number of elements, and inter-element spacing. The antennas are designed and simulated using Matlab and CST Studio Suite. The final design is a result of an iterative design procedure. A K-band 8x8 patch array with a coaxial line feed and a Dolph-Chebyshev amplitude distribution is shown to achieve electronic beam steering successfully and outperforms the other designs presented. The designs in this report provide a foundation to build and test a practical high-performance CubeSat antenna with the prospect of outperforming current commercial solutions.

9:40 – 10:50
Poster Session 1: Detection & STAP
Room: DENVER BALLROOM 5-6
Session Chair: William Melvin

8010: PMCW Signal Recovery via One-Bit FISTA with Time Varying Thresholds

Ethan Triplett, Andrew Harms

University of Nebraska–Lincoln, United States

Time-varying thresholds (TVT) have been shown to preserve more signal amplitude with one-bit resolution, but few-bit and TVT approaches have not been compared directly for the same algorithm. This paper explores an existing few-bit fast iterative shrinkage-thresholding algorithm (FISTA) implementation against a modified one-bit TVT FISTA to determine how each performs in detecting targets and estimating signal amplitudes.

8020: A Simplified Modified Axis Rotational Transform - Lv Transform (SMART-LvT) for High Speed and Accelerating Target Detection

Seema Sud
Aerospace Corporation, United States

There is a strong trend in the radar community to be able to detect maneuvering objects such as hypersonic vehicles (HVs) and missiles in real-time. Recently, an algorithm known as Modified Axis Rotation Transform-Lv's Transform (MART-LvT) has been developed, which can detect such targets at low SNR. But this algorithm requires several searches which make it computationally complex. In this paper, we propose using the Keystone Transform (KT) at the front-end of MART-LvT to provide a target range estimate for input to the MART-LvT, eliminating one of the searches. This reduces the computational complexity by a factor of L, the number of fast time samples, which can be 200 − 450 (23 − 26.5 dB) for many applications, with just a small increase from the KT (3 − 6 dB). Simulation results show that no performance hit occurs, because the KT can produce good range estimates at high target velocities and low SNR. The proposed algorithm performs well at about −12 dB SNR for target speeds up to Mach 8.

8037: Range Ambiguous Clutter Suppression for Airborne Radar Using Pulse Phase Coding

Zizhou Qiu, Jinjun He, Keqing Duan
Sun Yat-sen University, China

Airborne radars often operate at medium to high pulse repetition frequencies, inevitably leading to range ambiguity. When operating in non-side-looking modes, there is a variation in the Doppler frequencies of clutter at different ranges, indicating range dependency of the clutter. Such range ambiguity and range dependency significantly degrade the performance of traditional space-time adaptive processing (STAP). To address this issue, we introduce the application of pulse phase coding in airborne radar for suppressing range ambiguous clutter. At the receiver, using decoding that corresponds to the transmitted phase pulse coding prevents signals from other range regions from coherently accumulating and thus suppresses them, enabling the extraction of signals from a specific range region. This approach allows for the separate extraction of signals from each ambiguous range region, effectively resolving the range ambiguity of the signal. The clutter associated with range dependence in each range region is then addressed through Doppler compensation. Finally, STAP is employed to effectively suppress the clutter from each range region.

8097: Range Ambiguous Clutter Suppression with Azimuth-Elevation 2D Joint FDA-MIMO STAP for Bistatic Space-Based Early Warning Radar

Xingjia Yang, Zizhou Qiu, Keqing Duan
Sun Yat-sen University, China

This paper introduces a novel approach to address these challenges by exploiting the range dependence in both azimuth and elevation spatial frequencies of the bistatic SBEWR. Initially, our method employs multiple-input multiple-output (MIMO) radar with elevation frequency diverse array (FDA) to enhance the discrimination between elevation spatial frequencies associated with different range-ambiguous echoes. Subsequently, an elevation bandpass filter is applied to extract the desired range-ambiguous echoes while concurrently suppressing other range-ambiguous echoes out of band. However, the excessive width of the elevation bandpass filter leads to the persistence of residual echoes. To resolve this, azimuth FDA-MIMO is applied to extend the interval between azimuth spatial frequencies of the residual echoes. Following this, an azimuth bandpass filter is designed to selectively extract echoes associated with the to-be-detected ambiguous range. Finally, traditional space-time adaptive processing is employed to achieve effective clutter suppression. Experimental results validate the effectiveness of the proposed method.

9:40 – 10:50
Poster Session 1: Biomedical Sensing
Room: DENVER BALLROOM 5-6
Session Chair: Rachel Jarvis

8200: Quasi-Stationary Slice Detection-Based Robust Respiration Rate Estimation Under Large-Scale Random Body Movement

Chendong Xu, Shuai Yao, Haoying Bao, Chiyuan Ma, Qisong Wu
Southeast University, China

Radar-based non-contact respiration rate (RR) measurement has become increasingly popular due to its convenience, non-intrusiveness and low cost. However, it is still quite challenging to accurately acquire vital signs estimation in complex measurement scenarios with large-scale random body movements (RBM), particularly for RR estimation due to strong low-frequency interferences. To cope with the RBM challenge in RR estimation, we propose a novel two-stage vital signs estimation scheme that incorporates quasi-stationary slice detection within the deep neural network framework to achieve precise RR estimation in the presence of large-scale RBM. The proposed method holds promise for various application scenarios, including clinical diagnosis for patients and health assessment for sleeping individuals and drivers. In these contexts, it demonstrates the ability to robustly estimate RR and minimize the impact of RBM interferences.

8269: Animating Vital Signs in Radar Simulations: Comparing Physical Optics Against 28.5 GHz Channel Measurements

Swagato Mukherjee{2}, Benjamin Hardy{2}, Greg Skidmore{2}, Tarun Chawla{2}, Jihoon Bang{1}, Jack Chuang{1}, Jelena Senic{1}, Samuel Berweger{1}, Steve Blandino{1}, Camillo Gentile{1}

{1}National Institute of Standards and Technology, United States; {2}Remcom Inc., United States

Monitoring vital signs such as breathing or heart rates as well as other physical movements in complex environments is the basis for many emerging applications spanning from healthcare to autonomous vehicles. Designing Radar systems capable of remotely monitoring these movements necessitates measurement campaigns in combination with advanced machine-learning algorithms. Despite the compelling applications and the need for large and diverse data sets for validation of design, there are few examples of simulated human movement in multipath environments in the literature. To address this gap, the work presented here outlines a method to accurately simulate Radar back-scatter from time varying human movement. Specifically, we animate human breathing with anatomically accurate mathematical models through physical-optics-based simulation and validated them against monostatic Radar measurements with a 28.5 GHz channel sounder in a semi-anechoic chamber by the National Institute of Standards and Technology, capturing phase and path loss over time from a human breathing positioned 2 m away.

8294: Magic Mirrors: Active Frequency-Selective Surface Beacons for Synchronization, Communication, and Identification in Biomedical Radar

Alan Bannon{1}, Michael Woollard{2}, Matthew Ritchie{2}, Timothy Constandinou{1}

{1}Imperial College London, United Kingdom; {2}University College London, United Kingdom

This work presents the design and analysis of a series of active frequency-selective surface (AFSS) based beacons that can modulate their reflectivity in a controllable manner. Using this modulation with an on-off-keying (OOK) scheme and a communications protocol based on reversals and Barker codes, it is shown how these beacons may be located by a radar, and how information may be encoded and transmitted from beacon to radar without the need for clock synchronization. Several practical applications are explored, including identifying individuals and enabling clock synchronization between channel-separated radars.

8328: Microwave Lymphedema Assessment Using Deep Learning with Contour Assisted Backprojection

Yuyi Chang, Nithin Sugavanam, Emre Ertin

Ohio State University, United States

We present a method for early detection of lymphatic fluid accumulation in lymphedema patients based on microwave imaging of the limb volume across an air gap. The proposed algorithm uses contour information of the imaged limb surface to approximate the wave propagation velocity locally to solve the eikonal equation for implementing the adjoint imaging operator. This modified backprojection algorithm results in focused imagery close to the limb surface where lymphatic fluid accumulation presents itself. Next, a deep neural network based on U-Net architecture is employed to identify the location and extent of the lymphatic fluid. Simulation studies with various upper and lower arm profiles compare the focusing performance of the proposed contour assisted backprojection imaging with the baseline imaging approach that assumes homogeneous media. The empirical results of the simulation experiments show that the proposed imaging method significantly improves the ability of the deepnet model to identify the location and the volume of the excess fluid in the limb.

9:40 – 10:50
Poster Session 1: Tracking and Parameter Estimation
Room: DENVER BALLROOM 5-6
Session Chair: Dale Blair

8176: A Subspace-Based Azimuth-Range-Doppler Estimator with Super-Resolution for OFDM Radar

Xile Li, Wei Yi
University of Electronic Science and Technology of China, China

In this paper, a novel estimator based on a monostatic orthogonal frequency division multiplexing (OFDM) radar is derived, capable of performing joint azimuth-range-Doppler super-resolution estimation without the need of parameter matching. We establish multiple-antenna signal reconstruction observation matrices, and design a two-stage smoothing operation to increase the number of snapshots. We derived a spectral function via a subspace-based method and obtained estimates of multi-dimensional parameters simultaneously, effectively avoid the parameter matching problem. Moreover, this estimator is adaptable to various communication protocols and easy to expand to complex array configurations, making it suitable for future ISAC applications. Numerical results demonstrate that proposed method can achieve high accuracy even under conditions of limited bandwidth and small aperture.

8030: Efficient High Degree Continuous-Time Cubature Kalman Filters

Benjamin Davis
Hill Technical Solutions, United States

Sigma-point filters, including the Unscented Kalman Filter (UKF) and the Cubature Kalman Filter (CKF) are important modern non-linear estimation algorithms. The standard form of these algorithms are applied to discrete-time systems, however, continuous-time forms also exist. In previous work, the author developed a runtime optimization to sigma-point filters in discrete time called the Hybrid Sigma-point Extended Kalman Filter (HESKF). Using this technique, sigma-point integration is applied to “difficult” subspaces of the dynamics, whereas “easy” subspaces are treated with Jacobian linearization, resulting in a blended filter algorithm. This present work extends the HESKF technique to a continuous-time dynamics and demonstrates the improvement in runtime with an appropriate example.

8124: Rav4D: A Radar-Audio-Visual Dataset for Indoor Multi-Person Tracking

Yi Zhou{3}, Ningfei Song{3}, Jieming Ma{3}, Ka Lok Man{3}, Miguel López-Benítez{2}, Limin Yu{3}, Yutao Yue{1}
{1}Institute of Deep Perception Technology, China; {2}University of Liverpool, United Kingdom; {3}Xi'an Jiaotong-Liverpool University, China

Indoor multiple person tracking is a widely explored research field. However, publicly available datasets either are overly simplified or provide solely visual data. To address this gap, our paper introduces the RAV4D dataset, a novel multimodal dataset that encompasses data from radar, microphone arrays, and stereo cameras. This dataset stands out by providing 3D locations, Euler angles, and Doppler velocities. By integrating these diverse data types, RAV4D aims to leverage the synergistic and complementary capabilities of these modalities to enhance tracking performance. The creation of RAV4D tackles two primary challenges: sensor calibration and 3D annotation. A novel calibration target is designed to effectively calibrate the radar, stereo camera, and microphone array. Additionally, a visual-guided annotation framework is proposed to address the challenge of annotating radar data. This framework utilizes head locations, heading orientation, and depth information from stereo cameras and radar to establish accurate ground truth for multimodal tracking trajectories. The dataset is publicly available at https://zenodo.org/records/10208199.

8198: Online Multi-Object Tracking from a Bird's-Eye View by Fusion of Millimeter-Wave Radar and Vision

Qiang Zhang, Yuying Song, Zecheng Li, Fuyuan Ai, Chunyi Song, Zhiwei Xu
Zhejiang University, China

Existing Multi-Object Tracking (MOT) algorithms are facing challenges arising from the underutilization of sensor information, the neglect of sensor reliability, and the inability to effectively handle lost trajectories. This paper proposes a multi-sensor fusion algorithm based on millimeter-wave radar and vision, which utilizes the average height of objects to back-project the image bounding boxes onto the bird's eye view plane, uses appearance features and motion orientations to expand the similarity measure between targets, adopts multi-level data association method based on object fusion states to improve association accuracy and utilizes the occlusion prediction and recovery method to recover lost trajectories. For the performance evaluation, an urban environment dataset containing twenty sequences is collected through extensive experiments. The experimental results demonstrate that the proposed algorithm outperforms both the single-sensor tracking algorithm and traditional multi-sensor fusion tracking algorithm, in terms of tracking accuracy and robustness.

8279: Approximate Maximum Likelihood Estimation in Split-Dwell Pulse-Doppler Radar

David Tucker, Lee Potter
Ohio State University, United States

An approximate maximum likelihood estimator (MLE) is presented for computing velocity estimates in pulse-Doppler radar. We consider the special case of "split-dwell," or "staggered pulse repetition frequency" acquisition, in which two sequential coherent processing intervals employ different pulse repetition frequencies, resulting in two aliased velocity estimates that are then jointly unwrapped. In numerical simulations, the proposed estimator is shown to closely approximate the performance of the MLE with reduced computational complexity. The simulations also demonstrate improved estimation performance when compared to traditional velocity unwrapping via pulse pair processing coupled with a clustering algorithm.

10:50 – 11:50
Special Session: Integrated RF Sensing and Communications 2
Room: DENVER BALLROOM 4
Session Chairs: Maria Sabrina Greco and Visa Koivunen

8153: Localization with Monostatic ISAC System: LOS Detection and Parameter Estimation

Jiamin Long{1}, Le Zheng{1}, Marco Lops{3}, Fan Liu{2}, Chuanhao Zhao{1}
{1}Beijing Institute of Technology, China; {2}Southern University of Science and Technology, China; {3}University of Naples Federico II, Italy

In this paper, we address the line-of-sight (LOS) localization problem in a monostatic Integrated Sensing and Communication (ISAC) system based on colocated Multiple-Input Multiple-Output (MIMO) technology in the presence of multipath scenarios. Firstly, we derive Generalized Likelihood Ratio Tests (GLRTs) to distinguish LOS paths from NLOS paths based on full-rank and rank-deficient transmit waveform, providing closed-form expressions for false alarm probability and detection probability. Furthermore, in the case of unknown path parameters, we employ the GLRT philosophy, replacing the unknown parameters with carefully designed estimators. The angular parameters of both LOS and Non-Line-of-Sight (NLOS) paths are estimated using a sparsity-enforced Compressed Sensing (CS) approach, aiming at estimating angular parameters in the continuous domain. Finally, we compare the performance of full-rank and rank-deficient waveforms in different scenarios and demonstrate the effectiveness of the proposed detection-estimation solution through simulations.

8114: Selecting Transmission Entities of an IM-Based MIMO OFDM DFRC System by Using Pareto Front

Satwika Bhogavalli{1}, Eric Grivel{2}, K.V.S. Hari{1}, Vincent Corretja{3}
{1}Indian Institute of Science, India; {2}Institut Polytechnique de Bordeaux INP Bordeaux, France; {3}Thales Defence Mission Systems, France

Dual-function Radar and communication (DFRC) systems accommodate both Radar and communication functionalities by integrating them into a single hardware and using the same waveform. Recently, index modulation that transmits the information bits by activating fewer transmission entities (antennas, sub-carriers, etc.) during data transmission has been employed to improve the performance of DFRC systems. Considering the modified Cramer-Rao bound (MCRB) of the directions of arrival, ranges and velocities of the targets as the metrics, the Radar performance can be improved by selecting the combinations of the sub-carriers and antennas that can be activated. In this paper, to choose the best combination, we solve the multi-objective problem based on the MCRB of the target parameters using the Pareto front technique. This results in a set of non-dominated solutions. At that stage, depending on the user's priorities and practical considerations, one solution belonging to the Pareto front will be chosen.

8059: Massive MIMO Joint Communications and Sensing with MRT Beamforming

Nhan Thanh Nguyen{4}, Van-Dinh Nguyen{5}, Hieu Van Nguyen{3}, Hien Quoc Ngo{1}, A. Lee Swindlehurst{2}, Markku Juntti{4}

{1}Queen's University Belfast, United Kingdom; {2}University of California, Irvine, United States; {3}University of Danang, Vietnam; {4}University of Oulu, Finland; {5}VinUniversity, Vietnam

Joint communications and sensing (JCAS) is envisioned as a key feature in future wireless communications networks. In massive MIMO-JCAS systems, the very large number of antennas causes excessively high computational complexity in beamforming designs. In this work, we investigate a low-complexity massive MIMO-JCAS system employing the maximum-ratio transmission (MRT) scheme for both communications and sensing. We first derive closed-form expressions for the achievable communications rate and Cramér--Rao bound (CRB) as functions of the large-scale fading channel coefficients. Then, we develop a power allocation strategy based on successive convex approximation to maximize the communications sum rate while guaranteeing the CRB constraint and transmit power budget. Our analysis shows that the introduction of sensing functionality increases the beamforming uncertainty and inter-user interference on the communications side. However, these factors can be mitigated by deploying a very large number of antennas. The numerical results verify our findings and demonstrate the power allocation efficiency.

10:50 – 11:50
Detection
Room: DENVER BALLROOM 3
Session Chairs: Luke Rosenberg and Laura Anitori

8232: Non-Parametric Detection of Targets with Dynamic Fluctuation Behaviour

Keith Klein, Mario Coutiño, Wim van Rossum, Maaike Mol

Netherlands Organisation for Applied Scientific Research, Netherlands

This study presents an approach to radar detection that addresses the possible challenges posed by future targets utilizing sophisticated methods to decorrelate the scattered signal. The work focuses on the adaptive selection of appropriate Coherent Processing Intervals (CPI). A compound detector is derived that combines the output of several normalized fixed-CPI detectors using a point-wise maximum operation. A conservative approximation is given for the probability of false alarm, and the performance of the detector is evaluated through Monte Carlo analysis. The results highlight the ability of the compound detector to consistently outperform fixed-CPI detectors for fluctuating targets while mitigating potential performance losses for non-fluctuating targets. Overall, the conceptually simple proposed detector strikes a balance between robustness and detection performance, suggesting its utility for detecting targets with dynamic fluctuation behaviour.

8170: Bidirectional LSTM-Based Target Detection in Weibull and Gamma Clutter

Batu Chalise{1}, Kevin Wagner{2}

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

Radar target detection performance depends on how accurately clutter can be characterized. However, depending on applications, it is difficult to accurately predict clutter statistics and its parameters. The model-based detection algorithms that are optimized for one clutter scenario will fail to yield satisfactory results in another scenario. In this paper, we propose a bidirectional long short-term memory (LSTM) network to classify whether the received signal, in the presence of clutter, consists of target return or not. The key idea is to leverage the bidirectional LSTM's capability to learn from the time dependency of the input data sequence, both in forward and backward directions. The proposed network is trained using the outputs of the clutter independent energy detector (ED), matched filter (MF) detector, and generalized likelihood ratio test (GLRT) detector, as the features. Simulations results, conducted for Weibull and Gamma distributed clutter, show that the proposed bidirectional LSTM performs significantly better than the feed forward neural network (FFNN), especially when GLRT output is employed as a feature.

8205: Using DCFT for Multi-Target Detection in Distributed Radar Systems with Several Transmitters

Gokularam Muthukrishnan, S Sruti, K Giridhar

Indian Institute of Technology Madras, India

In distributed radar systems, when several transmitters radiate simultaneously, the reflected signals need to be distinguished at the receivers to detect various targets. If the transmit signals are in different frequency bands, they require a large overall bandwidth. Instead, a set of pseudo-orthogonal waveforms derived from the Zadoff-Chu (ZC) sequences could be accommodated in the same band, enabling the efficient use of available bandwidth for better range resolution. This, however, makes the detection of targets, which provide weak reflections at the receivers, difficult due to the ‘near-far’ problem. In this work, a scheme to detect multiple targets in such distributed radar systems is proposed. It performs successive cancellations (SC) starting from the strong, detectable reflections in the domain of the Discrete Chirp-Fourier Transform (DCFT) after compensating for Doppler shifts, enabling the subsequent detections of weaker targets which are not trivially detectable. Numerical simulations corroborate the efficacy and usefulness of the proposed method in detecting weak target reflections.

10:50 – 11:50
Component & Subsystem Technologies
Room: DENVER BALLROOM 2-1
Session Chairs: Lorenzo Lo Monte and Austin Egbert

8022: Asynchronous Continuous Time Pipeline Analog-to-Digital Converter

Patrick Jungwirth{1}, W. Michael Crowe{2}
{1}DEVCOM Army Research Laboratory, United States; {2}U.S. Army Combat Capabilities Development Command Aviation & Missile Center, United States

Continuous time systems offer a number of advantages over conventional digital signal processing. Conventional digital signal processing is limited by quantization error, frequency aliasing, and discrete time lag. Continuous time systems have no inherent quantization error, are free of frequency aliasing, free from discrete time lag, and provide a form of compressive sensing. For a 4-bit equivalent analog-digital-converter (ADC), Vezyrtzis and Tsividis demonstrated offline reconstruction of a continuous time signal with > 100 dB signal-to-noise-and-distortion (SINAD) ratio. A patent pending continuous time pipeline analog-to-digital converter is presented that overcomes many of the limitations present in conventional analog-to-digital converters. A continuous time ADC is not based on Shannon sampling, and it does not have the extremely low aperture jitter requirements found in conventional GHz speed ADCs. Continuous time pipeline analog-to-digital converters can potentially achieve 10 plus equivalent number of bits (ENOB) at greater than 10 GHz speeds.

8298: Fully Reconfigurable Power Amplifier Array Design

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}DEVCOM Army Research Laboratory, United States

As more radar and wireless communication systems access the electromagnetic spectrum, interference becomes more common. To increase robustness to interference, a fully reconfigurable array topology and optimization methodology is presented which can enable spectral mobility through live impedance tuning and signal equalization. Pulse-to-pulse optimizations allow efficiency maximization while maintaining array pattern integrity. This array is compatible with advanced digital beamforming techniques such as directional modulation, is highly modular, and is designed for forward compatibility. A demonstration of the proposed optimization for dual-function radar-communications is presented in simulation with a linear sixteen-element array, but it is easily scalable to larger arrays.

8051: An Integrated mmW Radar Transceiver Enabling Fast Multi-Chirp Coherent IF Stitching

Mykhailo Zarudniev{2}, Laurent Ouvry{1}, Cedric Dehos{1}, Alexandre Siligaris{1}
{1}CEA-Leti, France; {2}CEA-Leti, Université Grenoble Alpes, France

The FMCW radars in mmW bands represent the major part of short-range solutions. The wideband sensing and spectrum sharing have an increased interest in the context of growing indoor and outdoor applications of short-range radars. In this paper, we suggest the use of an original radar architecture that addresses the coherent wideband sensing and spectrum sharing using a FMCW fast chirping radar transceivers. Theoretical system design approach and measurements based on the original architecture implementation expose the performance of IF frequency stitching technique in the context of short-range radar applications.

11:50 – 12:50
Lunch
Room: COLORADO F-J

11:50 – 12:50
DEI Lunch
Room: PENROSE
Moderator: Jacqueline Fairley

12:50 – 14:10
Special Session: Beyond Linear Processing (BLiP)
Room: DENVER BALLROOM 4
Session Chairs: Frank Robey and Benjamin Epstein

8107: Challenges and Prospective Solutions for Non-Uniform Radar Waveforms in a Shared Spectrum

Jason Harrington{2}, Shannon Blunt{3}, Nathan Goodman{1}, Justin Metcalf{1}, Jonathan Owen{3}, Christian Jones{3}, Callin Schone{4}, Rylee Mattingly{4}
{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}STR, United States; {3}University of Kansas, United States; {4}University of Oklahoma, United States

The purpose of this paper is to provide an overview of challenges and methods to design and process a non-uniform radar waveform in a shared spectrum with computationally efficient algorithms to mitigate co-channel interference and enable standard constant false alarm rate detection and tracking approaches.

8138: Sample-Starved Wavefront Adaptive Sensing and GLRT for MTI Radar

Elliot Mueller, Michael Martinez, Christ Richmond, Jeffrey Krolik
Duke University, United States

Moving target indicator (MTI) radars can suffer signal-to-noise ratio (SNR) losses due to: 1) the use of heavy non-adaptive tapers, and/or 2) poor estimation of space-time adaptive weight vectors. In this paper, blind source separation (BSS) which exploits the different Doppler spectra of targets versus clutter is employed to obtain target-free training data using only the space-time data from each range cell-under-test. Two methods using BSS outputs are presented: 1) a wavefront adaptive sensing (WAS) beamformer for suppressing clutter with subsequent matched filtering in the Doppler domain, and 2) a clutter-subspace based optimal generalized likelihood ratio test (GLRT) detection statistic. WAS is used here with non-recurrent (e.g. multi-pulse-frequency-repetition) waveforms to permit detection of targets otherwise masked by Doppler-aliased clutter. Simulation results for a 2-D ground-based S-band phased array MTI radar are presented which demonstrate significant SNR gain versus conventional methods.

8122: Tracking Sparse Detections from a Phased Array Radar

Samuel Pine, Larry Cole, Alex Burwell, Gregory Arnold
Matrix Research, Inc., United States

The goal of our project, as part of DARPA's Beyond Linear Processing (BLiP) program, is to investigate and demonstrate the potential gain of implementing nonlinear and iterative signal processing for radio frequency (RF) systems. Specifically, given National Oceanic and Atmospheric Administration (NOAA) radar data, our goal is to demonstrate gains while decreasing cost and power to apertures. This is a phased array radar, and this paper discusses the use of sparsity to enable tracking in low signal regimes by taking advantage of multiple measurements. This is challenging because of the radar scan time and both moving and stationary clutter in the scene.

8161: Iterative Slepian Cancellation with Track Before Detect in Radar Processing String

Lisa Osadciw{2}, Aaron Skewes{4}, Samuel Stone{4}, Charles J. Roberts{4}, Alexander Thornton{4}, Dominic DiPuma{4}, Harrison Stanton{4}, Nguyen Nguyen{4}, Coleman Delude{1}, Anthony Murray{3}, Mark Davenport{1}, Justin Romberg{1}
{1}Georgia Institute of Technology, United States; {2}Lockheed Martin, United States; {3}Lockheed Martin Advanced Technology Laboratories, United States; {4}Lockheed Martin Rotary and Mission Systems, United States

This project is part of DARPA Beyond Linear Processing (BLiP) that proposes integrating compressive sensing techniques, artificial intelligence, machine learning, and track-before-detect algorithms into a comprehensive processing string for radar systems. This effort focuses on the control, interfaces, and impact each algorithm has on the system's processing. The challenges result from designing the algorithms to work together cohesively to minimize signal loss that has been traditionally accepted within existing radar systems. The objective is the ability to reduce the antenna or front-end hardware, which is the prime cost driver in fielding radars today. Integrating processing from recent signal processing advances is a cost-effective alternative to improve a radar's sensitivity, accuracy, and volume coverage.

12:50 – 14:10
Passive Radar
Room: DENVER BALLROOM 3
Session Chairs: Fabiola Colone and Piotr Samczynski

8262: Polarimetric Diversity in Reference-Free Amplitude-Based Wi-Fi Sensing

Carlo Bongioanni{3}, Fabiola Colone{4}, Marco Di Seglio{1}, Francesca Filippini{4}, Francesco Fioranelli{2}
{1}Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany; {2}Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands; {3}Ministero della Difesa, Centre for Defense Higher Studies, Italy; {4}Sapi

Passive sensing exploiting Wi-Fi as an illuminator of opportunity has attracted considerable interest for the ubiquitous presence of Wi-Fi systems in many environments, and the relative low cost & complexity of related passive solutions. In this paper, we consider a reference-free, amplitude-based sensing strategy exploiting Wi-Fi signals of opportunity and we investigate the potential advantage conveyed by the use of polarimetric diversity on receive. Specifically, we exploit the data collected by a dual-pol receiver to experimentally demonstrate that the joint availability of the signals collected by differently polarized antennas (H and V) could remarkably enhance the detection performance of the resulting Wi-Fi sensor, even if based on such a simple and cost-effective reference-free sensing approach. Moreover, we analyze the characteristics of the target signatures extracted by the considered amplitude-based approach for either single and dual-pol receivers, in order to investigate their suitability for detecting and recognizing different human movements, in view of future applications for automatic classification.

8053: Passive Radar Imaging Based on Multistatic Combination of Starlink and OneWeb Illumination

Rodrigo Blázquez-García, Thomas Hauschild, Philipp Markiton, Martin Ummenhofer, Viktor Seidel, Diego Cristallini
Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany

This paper presents an approach for passive multistatic radar imaging exploiting both Starlink and OneWeb satellite signals in order to address some limitations revealed by the first experimental results of passive radar imaging exploiting these novel LEO constellations, which are also presented in this paper. With respect to Starlink constellation, full 240 MHz-channel signals were not persistently received during measurements. Furthermore, when received, these signals showed a predominantly pulsed structure, hindering the integration gain, and resulting in back-projected images with reduced signal-to-noise ratios (SNR). However, narrow-band pilot signals were persistently received during Starlink satellite passes. On the other hand, OneWeb satellites have been experimentally verified to provide a persistent wide-bandwidth illumination, but the satellite orbits result in persistent areas imaged with spatial ambiguities and very limited cross-range resolution. To address those limitations, the proposed multistatic approach, whose effectiveness is evaluated via simulated data, is based on back-projection for both narrow-band Starlink signals and wide-band OneWeb signals.

8243: Enabling DPCA via Supervised Reciprocal Filter in OFDM Radar Onboard Moving Platforms

Andrea Quirini, Fabiola Colone, Pierfrancesco Lombardo
Sapienza Università di Roma, Italy

This paper introduces an innovative displaced phase center antenna (DPCA) technique to enable clutter cancellation and slow-moving target detection in Continuous Wave (CW) OFDM radar systems installed onboard moving platforms. The DPCA approach exploits two receiving antennas displaced along the platform motion direction and provides cancellation of the stationary scene by subtracting properly delayed versions of the range compressed signals obtained at the two channels. In principle, CW operation should allow to select an appropriate delay to effectively suppress clutter echoes, based on the platform velocity and the array inter-element distance. However, without setting very strict constraints on the platform velocity, this delay might not be a multiple of the OFDM symbol duration, which forces the range compression stage to operate using batches of arbitrary length. To tackle this issue, we propose a DPCA approach that exploits a supervised version of the reciprocal filter, jointly supervising the two receiving channels. The new approach works with arbitrary batch durations, thus enabling an efficient application of the DPCA approach independently of the platform velocity.

8230: Passive Radar Using a Non-Cooperative Over-the-Horizon Radar as an Illuminator - First Results

Karol Abratkiewicz, Piotr Samczyński, Gustaw Mazurek, Michał Bartoszewski, Jakub Julczyk
Warsaw University of Technology, Poland

This paper presents the preliminary results of target detection using a passive radar using skywave over-the-horizon radar (OTHR) as an illuminator of opportunity. First, the receiving station is shown. Next, the results of the radar pulse recognition and reconstruction are presented. The final results presented in this paper confirmed that pulse signal passive radar processing allowed for the detection and tracking of a non-cooperative target, which paved the way for the further development of OTHR-based passive radars.

12:50 – 14:10
Antenna Arrays
Room: DENVER BALLROOM 2-1
Session Chairs: Jeffrey Herd and Mark Yeary

8199: Design of an Extended Phased Antenna Array for Beam Steering Applications on a CubeSat

Carl Smith, Lanche Grootboom
Stellenbosch University, South Africa

Phased array antennas offer several advantages when used on a CubeSat. These include, amongst others, the ability to electronically, and precisely, steer the main beam towards the ground station on Earth. This reduces the need for mechanical attitude control and establishes a more reliable connection. This paper presents the design of an extended planar array antenna for a CubeSat which includes deployable auxiliary panels. The additional panels increase the number of radiating elements in the array which results in a wider beam steering range and an increased antenna gain. Simulations done in CST Studio Suite 2023 reveal that the design achieves a beam steering range of 107° for a maximum side lobe level (SLL) of −10 dB and a minimum gain of 11.4 dBi using a uniform amplitude excitation. The range can be further extended to 125° using a Binomial amplitude distribution at the expense of a 3 dB scan loss and a lower gain.

8062: Experimental Test of a Frequency Diverse Array Radar Target Detection System Using SDRs: Preliminary Results

Nicholas Munson{2}, Bill Correll Jr{1}, Ram Narayanan{2}, Travis Bufler{3}
{1}Maxar Intelligence, United States; {2}Pennsylvania State University, United States; {3}Pennsylvania State University Applied Research Lab, United States

Frequency diverse arrays (FDA) can be made to simultaneously scan in both range and angle using small frequency offsets across radiating elements. The theoretical abilities of these systems have been explored in the literature, yet we know of only two FDA prototypes built since 2009. This work describes a fully coherent and highly flexible FDA radar at 2 GHz that uses software defined radios. Data collected using far field probes and target return echoes confirms theoretical properties of the far field pattern and demonstrates utility of the prototype for use as a beacon or for volume scanning. The proposed system would continue experimental work on FDA radars having linearly progressive frequency offsets and support a new avenue of experimental research using frequency offset schemes that have been theoretically shown to de-couple the range-angle information and produce beam patterns having user-specified features.

8330: A Conformal L-Band Array with Multi-Polarization Digital Beamforming and Sidelobe Suppression

Peizhuo Yang, Gong Chen, Koen Mouthaan
National University of Singapore, Singapore

A 4 × 1 L-band conformal receiving array with fully digital beamforming for four simultaneous polarizations and sidelobe suppression is presented. The array is based on a reconfigurable quad-polarization antenna featuring four primary patches with secondary patches to enhance bandwidth. The resultant 16 channels are combined into eight channels through hybrid couplers which introduce the required fixed phasing. The eight channels are digitized and processed in an AMD radio frequency system-on-chip (RFSoC). The polarizer for the four polarizations (V, H, LHCP, and RHCP) and the beamformer are implemented in the RFSoC as well. Suppression of side lobe level (SLL) is implemented as well. The beamforming performance of the conformal array is demonstrated for several beamsteering cases.

8163: UAS-Based Antenna Pattern Measurements of the Fully Digital Horus Phased Array Radar

Antonio Segales{2}, David Schvartzman{1}, Khuda Burdi{1}, Matthew Herndon{1}, Robert Palmer{1}
{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}University of Oklahoma, United States

The RFSonde, a novel UAS-based system, demonstrates significant advancements in accurately measuring antenna patterns of phased array radars (PAR), particularly the S-band Horus system. Utilizing a custom-built UAS equipped with a 3-axis gimbal, the RFSonde performs pre-defined flight paths to evaluate power and reconstruct radiation patterns in the far-field region. This approach, aligning with the Ludwig-3 definition of cross-polarization, enhances measurement accuracy by minimizing probe misalignment errors. Field tests confirm the RFSonde's ability to accurately measure both co-polar and cross-polar patterns. This system sets the stage for future work in developing calibration methods for polarimetric observations in PAR systems, potentially revolutionizing on-site radar calibration and validation.

14:10 – 15:20
Coffee Break
Room: COLORADO A-E

14:10 – 15:20
Poster Session 2: AI/ML for Radar
Room: DENVER BALLROOM 5-6
Session Chairs: Shobha Sundar Ram and Justin Metcalf

8092: CNN-Based Children Counting in Real-World Using Multiple IR-UWB Radars

Aejin Park, Kyungphil Ryoo, Sangyeop Lee, Suchun Park, Wonjong Lee, Kyoungwoo Lee
Yonsei University, Korea

We propose the people counting method using IR-UWB radar as the most efficient and adaptable solution in real-world environments. While previous research using IR-UWB for estimating the number of people has largely been conducted in controlled experimental environments, real-world settings present challenges, such as numerous obstacles and the multipath effect. To address these, our approach involves the use of multiple IR-UWB radars. Furthermore, to validate our method, we set up a challenging experimental environment to classify the number of children in restrooms. Since children have a lower RCS value compared to adults, distinguishing them from multipath signals using a single IR-UWB radar presents a significant challenge. In this paper, we propose a method that visualizes multiple IR-UWB radar signals into single image, counting the number of children in restrooms using CNN. Based on our experiments, our approach achieves a 95% accuracy rate in categorizing child counts as 'none', 'single', or 'many'. Furthermore, when distinguishing counts of 0 to 4 children, we reached a 77% accuracy rate.

8120: Active Learning for Radar System Performance Verification

Mario Coutino{2}, Pepijn Cox{2}, Zoe Lascaris{1}
{1}KLM Royal Dutch Airlines, Netherlands; {2}Netherlands Organisation for Applied Scientific Research, Netherlands

This paper studies active learning methods for the verification of radar systems. Verification is based on evaluating the system for varying parameters-observation pairs. To reduce the number of observation, an evaluation-learning-selection cycle is introduced for radar systems aimed to reduce the number of samples by on-the-fly sampling. Emphasis is given to define a framework in which various strategies can be used to select the next-sample on-the-fly. The framework subdivides the sampling domain into subdomains to select the next-sample, gauging discrepancy levels within these areas to guide the selection of subsequent parameters. Additionally, we proposed a set of uncertainty-quantifier functions for the various regression methods employed in the learning stage. By comparing these methods using a radar detection performance example, the competitiveness of cost-effective approaches in adaptive sampling for the verification of the radar system performance is illustrated.

8125: Deep Reinforcement Learning-Based Jamming Against Multiple Frequency Agile Radars

Yu Cheng, Ye Yuan, Haicheng Xu, Wei Yi
University of Electronic Science and Technology of China, China

To tackle the ever-growing complexity of radar systems in modern electronic warfare, there is an urgent requirement for more effective and adaptable electronic countermeasure systems. In practical terms, current electronic warfare systems encounter difficulties in simultaneously combating multiple frequency agile radars (FARs). Herein, we present a intelligence jamming methodology for jamming aircraft that utilizes deep reinforcement learning (DRL). The jamming system can allocate resources intelligently by observing the radar's operating modes and adapting accordingly using DRL techniques. In the proposed approach, we first introduce a jamming system model that employs a pulse-by-pulse jamming technique, combining spot jamming and frequency sweeping jamming. Then, the temporal and energy resource allocation decisions for the jamming system when jamming against a group of radars are modeled as a Markov decision process (MDP). We utilize the deep deterministic policy gradient (DDPG) algorithm, which is well-suited for solving MDP in continuous action spaces, to train and determine the optimal strategy for the jamming system.

8182: Enhancing Indoor Radar Detection: An FMCW Radar System for Distinguishing Human Presence and Swinging Blinds

Xiangyuan Peng{1}, Miao Zhang{2}, Lorenzo Servadei{2}, Robert Wille{2}
{1}Infineon Technologie AG, Germany; {2}Technische Universität München, Germany

This paper introduces an innovative indoor presence detection system with Frequency-Modulated Continuous-Wave (FMCW) radar, specifically engineered to address the challenge posed by swinging blinds in indoor environments. A prevalent issue in radar human detection for smart homes is the striking similarity between the motion of blinds swayed by natural wind and the moving patterns linked to human respiration. To surmount this challenge, our approach integrates motion frequency information using a Three-Dimensional Convolutional Neural Network (3D CNN) and utilizes deep metric learning to effectively distinguish between highly similar data from different classes. Remarkably, our model has achieved a classification accuracy rate of 96.85%, significantly surpassing the performance of existing state-of-the-art reconstruction-based methods. Additionally, our model is optimized for high operational efficiency, delivering real-time predictions every three seconds. This advancement highlights a contribution to the field of indoor radar presence detection, offering a more robust and efficient solution for smart home environments.

8229: Physics-Informed Machine Learning for Prediction of Sea Ice Dynamics Derived from Spaceborne Passive Microwave Data

Younghyun Koo, Maryam Rahnemoonfar
Lehigh University, United States

Spaceborne passive microwave (PMW) images have been used as primary data sources to obtain sea ice concentration (SIC) and sea ice drift (SID) information in the polar oceans. Based on the PMW satellite observations and meteorological air temperature and wind data, we develop a fully convolutional neural network to predict daily SIC and SID. When training this deep learning model, instead of using a fully data-driven approach, we integrate physical knowledge about sea ice dynamics to regulate the prediction results into physically valid values. This physics-informed learning is conducted by including the physics loss function, which is independent of the data loss function. Our experiment shows that the physics loss function improves SIC and SID predictions for most of the Arctic Ocean and winter seasons. The enhancement by the physics loss function appears more substantial when we predict SID with a small number of training samples.

8251: Comparing Optical Transfer Learning and Autoencoder Pretraining for Radar Bird-Drone Discrimination

Daniel White{2}, Mohammed Jahangir{2}, Chris Baker{2}, Jeyan Thiyagalingam{1}, Michail Antoniou{2}
{1}Science and Technologies Facilities Council, United Kingdom; {2}University of Birmingham, United Kingdom

Radar drone surveillance radars are dependent on reliable classification of targets for useful operation. Deep learning approaches advance such sensors operation in real, unpredictable environments, but data is scarce in radar and domain translation from optically trained models carry inherent performance uncertainties. This work compares classification effectiveness of a convolutional neural network that was pretrained with optical data, with pretraining using real or synthetic radar data. Radar-only trained classifiers via an unsupervised, autoencoder approach out-performed a significantly more resource heavy optical transfer learning comparison. Autoencoder pretraining repeated with synthetic micro-Doppler data was demonstrated yielding near identical classification results which opens up the possibility to utilize greater amounts of synthetic data for pretraining deep learning models. A brief inspection of the latent distribution of the simple symmetric, unregularized autoencoder showed minor preservation of features in the learned representation.

8057: A Nonparametric Error Model for Pulsed Waveform Feature Extractors

Matthew Scherreik, Christopher Ebersole
Air Force Research Laboratory, United States

Simulated pulse features (PFs) are commonly employed to develop signal exploitation algorithms for classification, clustering, and other applications. Typically, an arbitrary constant error model is applied to the simulated PFs to represent errors in the feature extraction process. But we show that PF extractors can impart SNR-dependent errors on PFs, making the traditional naive approach unrealistic. To produce more realistic errors, raw signal data can be simulated and passed through a receiver model to produce PFs that are corrupted by realistic errors. However, the signal generation process is computationally expensive and could be avoided by leveraging an appropriate PF error model. To this end, we propose a nonparametric model for pulsed waveform feature extractors based on Gaussian process regression (GPR). We additionally show that SNR-dependent errors can be modeled as a heteroscedastic random process. In this work, we employ the GPR framework to build a heteroscedastic data-driven error model that can be applied to PF simulations, empirically demonstrate the model's effectiveness, and provide suggestions for further improvements of the models in future efforts.

8156: Wide-Angle Augmentation for SAR Imaging via Generative Spatial-Frequency Models

Hatim Alqadah, Raghu Raj, Matthew Burfeindt
U.S. Naval Research Laboratory, United States

In this work we present a K-space augmentation algorithm based on the use of deep generative models to improve cross-range resolution for monostatic synthetic aperture radar (SAR). The approach is based on the use of weighted adversarial training in the spatial-frequency domain. Initial efficacy of the approach is established through computational electromagnetic simulations of conducting targets in 2D.

8206: Radar-Based Recognition of Static Hand Gestures in American Sign Language

Christian Schuessler, Wenxuan Zhang, Johanna Bräunig, Marcel Hoffmann, Michael Stelzig, Martin Vossiek
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

In HCI and VR, automatic gesture recognition is vital, especially for intuitive navigation in applications. Radar sensors, as a privacy-friendly alternative to cameras, excel in low-light conditions without capturing identifiable details. While prior work focuses on Doppler-based dynamic gesture recognition, our approach prioritizes spatial information using an imaging radar. Generating large training datasets for neural networks is challenging; hence, we explore synthetic data from a radar ray-tracing simulator. Despite exclusive synthetic data training, our NN exhibits promising real-world performance, showcasing the practicality of our methodology in addressing data scarcity challenges and advancing automatic gesture recognition in VR and HCI.

8264: Reinforcement Learning Based Agile Transmission Strategy for Netted Radar Anti-Jamming

Zhongxin Zhang, Wei Yi, Ye Yuan
University of Electronic Science and Technology of China, China

In this paper, considering the single target detection problem under a self-defense spot jamming environment, a reinforcement learning based agile transmission strategy is investigated. The method can quickly learn the adversary's strategy and initiate countermeasures, overcoming the inefficiency of conventional methods. Finally, simulation results show that the strategy, through intelligent transmission and hopping, can help the radar system to achieve better detection probability and higher data rate.

8266: Anti-Jamming Strategy Design Based on Deep Q-Network for Slope-Varying LFM Signal

Shubo Chen, Weibo Huo, Cui Zhang, Jifang Pei, Yin Zhang, Yulin Huang, Jiahao Shen
University of Electronic Science and Technology of China, China

Radar systems with anti-jamming capability have become extremely important in the complex electromagnetic environment. In this paper, an anti-jamming strategy generation method based on deep Q-network (DQN) is proposed for slope-varying linear frequency modulation (SV-LFM) signals. First, the radar-jammer confrontation scenario is modeled as a Markov decision process. Subsequently, a reward function is designed by combining the positive reward for suppressing interference and the negative reward for constraining pulse width. In particular, the positive reward is decided by the correlation peak between the jamming and target signals, and the negative reward is determined by the signal energy and the probability of the signal being intercepted. Following the obtained anti-jamming strategy, radar systems can suppress jamming while also avoiding low signal-to-noise ratio (SNR) and high signal interception probability caused by drastic variations in pulse widths.The simulation results verify the effectiveness of the proposed method.

8333: FACTUAL: A Novel Framework for Contrastive Learning Based Robust SAR Image Classification

Xu Wang{2}, Tian Ye{2}, Rajgopal Kannan{1}, Viktor Prasanna{2}
{1}DEVCOM Army Research Laboratory, United States; {2}University of Southern California, United States

Deep Learning (DL) Models for Synthetic Aperture Radar (SAR) Automatic Target Recognition (ATR) have been shown to be quite vulnerable to adversarial attacks. Existing works improve robustness by training models on adversarial samples. However, by focusing mostly on attacks that manipulate images randomly, they neglect the real-world feasibility of such attacks. In this paper, we propose FACTUAL, a novel Contrastive Learning framework for adversarial training and robust SAR classification. FACTUAL consists of two components: 1) Differing from existing works, a novel perturbation scheme that incorporates realistic physical adversarial attacks (such as OTSA) to build a supervised adversarial pre-training network. This network utilizes class labels for clustering clean and perturbed images together into a more informative feature space 2) A linear classifier cascaded after the encoder to use the computed representations to predict the target labels. By pre-training and fine-tuning our model on both clean and adversarial samples, we show that our model achieves 99.7% accuracy on clean samples, and 89.6% on perturbed samples, both outperforming previous state-of-the-art methods.

8119: RadarCNN: Learning-Based Indoor Object Classification from IQ Imaging Radar Data

Stefan Hägele, Fabian Seguel, Driton Salihu, Marsil Zakour, Eckehard Steinbach
Technische Universität München, Germany

Radar sensors operating in the mmWave frequency range face challenges when used as indoor perception and imaging devices, primarily due to noise and multipath signal distortions. These distortions often impair the sensors' ability to accurately perceive and image the indoor environment. Nevertheless, this sensor offers distinct advantages over camera and LiDAR sensors. We introduce a machine learning-based mmWave MIMO FMCW imaging radar object classifier designed to identify small, hand-sized objects in indoor settings, utilizing only radar IQ samples as input. This system achieves 97-99% accuracy on our test set and maintains approximately 50% accuracy even under challenging conditions, such as increased background noise and occlusion of sample objects, without the need for adjusting training or pre-processing. This demonstrates the robustness of our approach and offers insights into what needs to be improved in the future to achieve generalization and very high accuracy even in the presence of significant indoor perturbations.

8155: SAR Image Synthesis with Diffusion Models

Denisa Qosja, Simon Wagner, Daniel O'Hagan
Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany

In recent years, diffusion models (DM) have become a popular method for generating synthetic data. By achieving samples of higher quality, they quickly became superior to generative adversarial models (GANs) and the current state-of-the-art method in generative modeling. However, their potential has not yet been exploited in radar, where the lack of available training data is a long-standing problem. In this work, a specific type of DMs, namely denoising diffusion probabilistic model (DDPM) is investigated and designed to generate new SAR images. We perform a study on how Gaussian noise impacts the SAR image generation, by exploiting different variance schedulers. Additionally, we argue the choice of the network and the specific diffusion parameters. By class-conditioning the DDPM, in our work, we obtain labelled synthetic data, useful for supervised learning. Finally, our results are compared with GAN-based generated SAR data, and we prove our superiority with qualitative and quantitative evaluations.

8052: A PixelCNN Based Method for Rough Surface Clutter Reduction in GPR B-Scan Images

Yan Zhang{2}, Enmao Diao{1}, Dryver Huston{2}, Tian Xia{2}
{1}Duke University, United States; {2}University of Vermont, United States

In GPR sensing, ground surface clutter is the main source of interference, often obscuring or distorting subsurface target signals. We propose a deep autoencoder-based method to mitigate rough surface clutter by treating it as an anomaly detection problem. Firstly, the rough surface region in a B-scan image is partitioned into small patches, which act as the training dataset for the deep autoencoder. Through the training process, the autoencoder learns and captures the patterns associated with the rough surface patches. Following training, the entire B-scan image is divided into small patches of the same size as the training patches, and each of them is fed into the autoencoder to compute an anomaly score. To reconstruct a clutter-reduced B-scan image, we employ a weighted sum approach to aggregate all patches based on their anomaly scores. We evaluate our method against conventional subspace projection techniques using simulated and field-collected B-scans. The results clearly indicate that our approach surpasses these subspace methods. Furthermore, we employ t-SNE analysis to gain deeper insights into our method's effectiveness in reducing rough surface clutter.

8188: Ship Formation Identification Method for HFSWR Based on Deep Learning

Jiaqi Wang, Aijun Liu, Changjun Yu
Harbin Institute of Technology, China

In this paper, we propose a novel ship formation identification method for high-frequency surface wave radar (HFSWR). And there is less difference in range domain and Doppler domain between sub-targets in the formation than HFSWR resolution. we first establish a matching HFSWR ship formation signal model. Then, we design a deep learning network connected by convolutional neural network (CNN) and extreme learning machine (ELM) to identify two densely distributed ship formations from inhomogeneous clutter and single-ship targets. Meanwhile, we propose a CNN-ELM transfer learning model to achieve deformed formation recognition. The layer-by-layer freezing method is introduced to improve training efficiency. The experimental results based on real HFSWR background prove that the proposed CNN-ELM is effective in formation identification, achieving an accuracy of 97.63%. The proposed CNN-ELM transfer learning model can effectively improve the classification accuracy of deformed formation, achieving an accuracy of 96.25% with limited training samples.

8073: Design and Evaluation of Interference Detectors Based on Range-Doppler Image Classification Methods for Sky-Wave OTH Radar

Shican Li{1}, Zhongtao Luo{1}, Hua Li{1}, Yuanyuan Zheng{2}, Kun Lu{2}

{1}Chongqing University of Posts and Telecommunications, China; {2}Nanjing Research Institute of Electronics Technology, China

This paper proposes to design the interference detector based on RD image classification in sky-wave OTH radar.As this is the first to design the RD image classifier, our work follows the way of image recognition and emphasizes on the database construction, the classification algorithm, and the performance test. Interference models are developed to construct the simulated database for training. Real data from OTH radar is used to construct the real database for evaluation the detectors. Performance results show that the KNN and the CNN classifiers achieve classification accuracy and detection probability over 96%. It demonstrates the effectiveness of interference detection based on RD image classification. Our detector can be used as a robust tool for interference detection before conventional interference localization and suppression.

14:10 – 15:20
Poster Session 2: Precipitation & Moisture Estimation
Room: DENVER BALLROOM 5-6
Session Chair: Venkatachalam Chandrasekar

8043: Measuring the Moisture Content of Wood Sheathing with Continuous Wave Radars

Stephen Killough, Philip Boudreaux, Rui Zhang

Oak Ridge National Laboratory, United States

Radars were studied for measuring the moisture content of wood-based materials because of their non-destructive nature and their ability to measure the moisture content of several layers at once. These convenient characteristics enable a quick and non-invasive method to find areas of high moisture content in building envelopes so that problems can be fixed before the structure degrades. The need to operate the radar at millimeter ranges required the development of new techniques and methods for analyzing and calculating the moisture content of individual layers of building material. The techniques are providing accurate results for oriented strand board, and efforts are continuing for investigating other construction materials, meeting FCC requirements, and building a system that will be easy to deploy.

8065: Impact of WSR-88D MESO-SAILS Usage on MRMS-Based Quantitative Precipitation Estimation

James Kurdzo, Michael Donovan, John Cho, Betty Bennett
MIT Lincoln Laboratory, United States

Quantitative precipitation estimation (QPE) is a critical aspect of the United States' operational Weather Surveillance Radar 1988--Doppler (WSR-88D) network. By estimating QPE accurately, radar data can be fed into hydrological models to provide near-real time flash flood guidance to forecasters issuing life-saving warnings. Among the most commonly used tools by forecasters are the Multi-Radar Multi-Sensor (MRMS) QPE products, which utilize WSR-88D data to re-process QPE as a mosaic that is corrected by ground-based rain gauges. As part of ongoing WSR-88D upgrades, enhancements, and service-life extension plans, the National Weather Service (NWS) Radar Operations Center (ROC) regularly adds new Volume Coverage Pattern (VCP) options to the network. In the past decade, this has included the option for supplemental adaptive intra-volume low-level scans (SAILS), as well as the multiple elevation scan option for SAILS (MESO-SAILS), which include additional base scans within a volume. It is shown that since additional base scans at higher temporal resolution decreases the integration period for QPE, errors in QPE decrease as the number of SAILS scans increases.

8134: Radar Reflectivity Simulation with a Numerical Cloud-Resolving Model for Dual-Frequency Terahertz Weather Radar

Takeshi Maesaka{2}, Ryohei Kato{2}, Hidehiko Fujii{1}, Yasushi Aoyama{1}
{1}KEYCOM Corporation, Japan; {2}National Research Institute for Earth Science and Disaster Resilience, Japan

We proposed the dual-frequency terahertz weather radar to observe the distribution of cloud water and water vapor by using machine learning approach. The radar reflectivity data observed by W- and D-band radar were simulated by using the output of the CRM (CReSS) . This method can be used to generate the training data for the machine learning. Our case study (one summer cloud around Tokyo, Japan, on 3 August 2018) indicated that dual-frequency terahertz radar which we are developing could detect the non-precipitating cloud, and that the DFR could be analyzed. However, some weak radar echoes around the edge of the cloud could not be detected because of the severe attenuation. The radar network, which consists of multiple radars, is needed to cover the attenuated area complementary by each other.

15:20 – 17:00
Special Session: History of Radar
Room: DENVER BALLROOM 4
Session Chair: Gregory Coxson

8026: How Two Industrial Mathematicians at AT&T Helped Spur Waveguide Research in the 1930s

Gregory Coxson{2}, William Haloupek{1}
{1}Raytheon, United States; {2}U.S. Naval Academy, United States

Radar development in the lead-up to World War II benefitted from a number of discoveries made while pursuing other goals. We discuss the background of one such discovery in the Summer of 1933, by two industrial mathematicians at AT&T, Sergei Schelkunoff at Bell Labs and Sallie Pero Mead at AT&T Development and Research. They found a mode in circular waveguides for which attenuation decreased with increasing frequency. This gave hope that waveguides might provide low-loss transmission of microwave transmissions, helping spur waveguide work at AT&T in the critical period before the second world war.

8191: The Story of Cavity Magnetron No. 12

David Michelson
University of British Columbia, Canada

In the summer of 1940, following the breakthrough work of John Randall and Harry Boot at the University of Birmingham earlier that year, cavity magnetron no. 12 was assembled by Eric Megaw and his collaborators at GEC Laboratories in Wembley, UK. According to James Phinney Baxter III, Official Historian of the U.S. Office of Scientific Research and Development, "When the members of the Tizard Mission brought [cavity magnetron no. 12] to America [later] in 1940, they carried the most valuable cargo ever brought to [American] shores." The complete story of cavity magnetron no. 12, from its initial assembly at GEC Laboratories to its current home in the Canada Museum of Science and Technology (CMST) in Ottawa is widely dispersed amongst both published and unpublished sources. Here we present the results of our efforts to compile the complete story and thereby help to resolve some of the minor contradictions between various published accounts and add value to one of the most important items in CMST's collection.

8044: Death Rays and Radar: The Myth of Early British Radar History

David Zimmerman
University of Victoria, Canada

This paper explores the myth story of Robert Watson Watt's invention of radar in Great Britain in 1934-5. Rather than a straightforward and logical application of radio science to aircraft detection, it shows that even after radar was invented that the British Air Ministry continued to explore fantastic and improbable technologies such as Death Rays to solve the air defense dilemma.

8218: The History of Oceanographic High Frequency Radar at Rutgers University

Hugh Roarty, Josh Kohut, Tim Stolarz, Michael Smith, Jacquelyn Veatch, Ethan Handel, Scott Glenn
Rutgers University, United States

Oceanographic High Frequency radars (HFR) have been mapping currents in the U.S. Mid-Atlantic Bight since 1998 when two stations were installed in New Jersey at Brant Beach and Brigantine as part of the Rutgers University Long term Ecosystem Observatory (LEO-15). Twenty-five years later, that seminal duo has grown into the 41-site Mid Atlantic HFR network providing continuous current maps along more than 1,000 km of coastline from Cape Cod to Cape Hatteras. The expansive gridded current velocities serve a variety of stakeholders including federal agencies like the U.S. Coast Guard for search and rescue and oil spill response and ocean scientists developing both short-term forecasting applications as well as longer term, multi-decadal changes in coastal circulation. Long-term archives are now available with calculated decadal mean, annual and seasonally averaged surface currents. This paper provides a history of the network to date and a glimpse towards the future

15:20 – 17:00
Digital Beamforming
Room: DENVER BALLROOM 3
Session Chairs: David Schvartzman and Ram Narayanan

8068: An Optimal Baseband Delay-Based Beam Squint Removal Scheme Across a Range of Steering Angles for Digital Wideband Beamformers in Radars

Neeraja P. K., Bindiya T. S., Raghu C.V.
National Institute of Technology Calicut, India

This paper is an attempt to mitigate the beam squint happening due to frequency-dependent phase shifts in the wideband beamforming scenario, specifically in radar applications. The estimation of direction of arrival is significant for precise target detection in radars. The undesirable beam-squint effect due to the phase shift-only mechanism in the conventional phased array systems, which becomes exacerbated when dealing with Wide-bandwidth signals is analyzed for a large set of steering angles in this paper. An optimum baseband delay combined with the phase shift technique is proposed for wideband radar beamforming to mitigate beam squint effectively. This technique has been demonstrated to function properly with 1-GHz carrier frequency for signals with wide bandwidths of upto ±250 MHz and for steering angles ranging from 0 to 90 degrees.

8060: Digital Beamforming of Subarrays of Unequal Size

Mark Leifer
Ball Aerospace, United States

This paper examines the special weighting required to perform digital beamforming of data streams from digital receivers attached to analog subarrays of unequal sizes. The need arises because signals from the antenna elements in each analog subarray are summed in power with RF power combiners while the digital beamformer sums voltages linearly. We show that the digital data from the rth subarray with Mr elements must be weighted by a correction factor of sqrt(Mr) prior to summation in the digital beamforming processor if the proper array output is to be obtained. The SNR and dynamic range of the array is then computed using these correction weights. The AESA for the Airborne Phased Array Radar (APAR) weather observation system, where each row of the array comprises a subarray, is used as an example.

8003: Pattern Synthesis and Digital Beamforming Capabilities of the Fully Digital Horus Radar

David Schvartzman, Robert Palmer, Matthew Herndon, Mark Yeary

Advanced Radar Research Center, University of Oklahoma, United States

The Horus radar was designed by the OU-ARRC with support from the NOAA National Severe Storms Laboratory. It consists of a mobile, fully digital, polarimetric, S-band Phased Array Radar (PAR) developed from its inception to achieve demanding mission-critical observational requirements for next-generation weather surveillance. In this paper, we present antenna pattern synthesis methods exploiting beamforming capabilities of Horus. The measured Horus embedded element patterns are used in the synthesis to account for practical antenna performance. We investigate phase-only and constrained-loss magnitude/phase pattern synthesis methods to shape the transmit beam in different ways, including intentional beam broadening (spoiling) and beams with multiple simultaneous peaks in different directions. Key results indicate that using synthesized beams with multiple simultaneous transmit peaks in different directions helps improve sidelobe isolation, producing two-way patterns similar to those from a conventional single-beam operation.

8189: Hybrid MVDR Beamformer for Subarray Architecture with Sparse Recovery and Manifold Optimization Methods

Batu Chalise{2}, Moeness G. Amin{1}

{1}Center for Advanced Communications, Villanova University, United States; {2}New York Institute of Technology, United States

Fully connected hybrid beamforming (F-HBF) reduces power consumption and transceiver complexity by employing a smaller number of radio frequency (RF) chains than the number of antennas. The cost and complexity of the F-HBF can be further reduced with subarray-based HBF (S-HBF), which does not require a splitter, and uses a smaller number of phase shifters than demanded by the F-HBF. This paper proposes a joint optimization of analog and digital beamformers for obtaining minimum variance distortionless (MVDR) beamformer solution. We show that this non-convex joint optimization can be efficiently solved by leveraging the concepts on manifold optimization and sparse signal recovery. Computer simulations are used to compare the proposed S-HBF approach with full DBF and partial DBF, in terms of the beamformer signal-to-noise-and interference ratio (SINR). The performance results show that, in general, S-HBF is inferior to full DBF, and the manifold optimization performs better than the sparse recovery approach.

8091: Self-Calibration of the Horus All-Digital Phased Array Using Mutual Coupling

Matthew Herndon{1}, David Schvartzman{1}, Caleb Fulton{2}, Mark Yeary{1}

{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}University of Oklahoma, United States

An operational implementation of mutual coupling calibration has been developed to calibrate the fully digital Horus radar system, and has now been fielded many times to support a variety of data collection experiments. This paper discusses our implementation and summarizes results from several experiments aimed at assessing calibration quality. Our results confirm the efficacy of the methods through ground-truth experiments at different array scales. It also validates beamforming post-calibration through precise far-field patterns measured from an uncrewed aerial system (UAS) which strongly agree with simulated patterns to within 0.15 dB at boresight. We believe that this is the first demonstration of holistic experiments assessing mutual coupling calibration performance in a large digital array.

15:20 – 17:00
Cognitive Radar
Room: DENVER BALLROOM 2-1
Session Chairs: Laura Anitori and Phillip Corbell

8110: A Reinforcement Learning Approach for Multisensor Tracking

Kilian Barth{2}, Roland Oechslin{1}
{1}Armasuisse, Switzerland; {2}Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany

We introduce a framework for learning a policy to track a target in a multisensor scenario. By using deep reinforcement learning in conjunction with POMDPs, the scenario itself does not have to be made known to the agent that controls the sensor network. This is a distinct difference to other state of the art alorithmes adapting to the environment. To illustrate the described methods and algorithms, an example consisting of two sensors illuminating a common area with an opaque obstacle is presented. Finally, the proposed RL approach is compared to a state of the art cognitive approach, where we can show that it performance similarly or up to 50% better.

8069: Voronoi Progressive Widening for Cognitive Radar Tracking with Large Waveform Libraries

Brian Rybicki, Jill Nelson
George Mason University, United States

We apply an improved variant of Monte Carlo Tree Search (MCTS), MCTS with Voronoi Progressive Widening (VPW), to cognitive radar tracking. Because cognitive radar systems have unparalleled waveform agility across an immense parameter space, reinforcement learning techniques must deal with large, multi-dimensional action spaces. Prior applications of MCTS are inefficient because they uniformly explore new actions without regards to available information. We demonstrate how a Voronoi partitioning based scheme improves on the exploration of new waveforms leading to better combined tracking performance and radar resource usage in a standard benchmark tracking scenario.

8143: Masking the Sensing Plan for Multifunction Radar in an Adversarial Setting

Shashwat Jain{2}, Vikram Krishnamurthy{2}, Muralidhar Rangaswamy{1}, Bosung Kang{4}, Sandeep Gogineni{3}

{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 aims to devise a technique for masking the sensing plan of a Multifunction Radar (MFR) within an adversarial setting, utilizing the Fisher Information criteria. Our objective is to thwart adversaries from accurately estimating the underlying parameters of the radar controller's sensing plan. In our proposed approach, we quantify the estimation accuracy of a closed-loop stochastic decision-making system, modelled using Markov Decision Process (MDP), by employing the Fisher information matrix (FIM). This approach is distinctive, considering that the FIM has traditionally been associated with open-loop stochastic systems.

8140: Evaluation of Cognitive Radar Networks with Joint Adaptive Beamforming for Multipath Effect Mitigation

Junhyeong Bae{1}, Chris Baker{2}, Michail Antoniou{2}
{1}Agency for Defense Development, Korea; {2}University of Birmingham, United Kingdom

This paper evaluates the performance of cognitive radar networks using joint transmit-receive adaptive beamforming for multipath mitigation. Two monostatic radars are combined to form a cognitive radar network capable of mitigating multipath efficiently. The cognitive radar network senses the radar environment and turns on joint adaptive beamforming only when the multipath signals are expected to result in multipath nulls. Simulation results show that the cognitive radar network with joint adaptive beamforming achieve significant performance improvements in target signal to noise ratio (SNR) under strong multipath. This is achieved by sustaining a multipath gain and successfully suppressing nulls.

8273: Waveform Optimization for Channel Matrix-Based Cognitive Radar/Sonar

Touseef Ali{1}, Christ Richmond{2}
{1}Arizona State University, United States; {2}Duke University, United States

Cognitive radar systems, driven by adaptive waveform design, enhance target detection and tracking in complex environments. In the context of channel matrix-based cognitive radar, the asymptotic distribution of the generalized likelihood ratio test (GLRT) for adaptive target detection exhibits a noncentral chi-square distribution. We formulate this problem as a semidefinite programming instance and propose a waveform optimization algorithm that maximizes the non-centrality parameter and hence enhances the probability of detection of the target. The proposed algorithm also incorporates power and peak-to-average power ratio (PAPR) constraints, which are crucial for ensuring practical and efficient radar operation.

18:00 – 19:00
Pre-Dinner Reception
PREFUNCTION SPACE

19:00 – 22:00
Banquet Dinner
COLORADO F-J and PENROSE

8:00 – 9:40
Special Session: AI/ML for Radar
Room: DENVER BALLROOM 4
Session Chair: Sevgi Gurbuz

8042: CNN-Based In-Vehicle Occupant Sensing Using Millimeter-Wave Radar

Jayson Van Marter{2}, Anil Mani{1}, Anand Dabak{1}, Sandeep Rao{1}, Murat Torlak{2}
{1}Texas Instruments, United States; {1}Texas Instruments, India; {2}University of Texas at Dallas, United States

In-vehicle occupant sensing seeks to perform three primary tasks: detect one or more occupants in a vehicle, localize a detected occupant to a seat, and classify the detected occupant. While in-vehicle occupancy detection is very reliable using millimeter-wave radar, occupant localization and classification per seat are more challenging due to limited radar resolution, ambient reflections, and multipath reflections within the vehicle. In this paper, we propose a novel deep-learning method for high-accuracy occupant seat localization and classification. Our deep learning model extracts spatial features through a 3D convolutional neural network (CNN) and temporal features through a recurrent neural network (RNN), showing considerable improvement in accuracy as more data becomes available over time. Testing our proposed deep learning model on new groups of participants unseen during training and validation, we demonstrate an accuracy of 95.5% for occupant seat localization and an accuracy of 85.1% when classifying as baby, child, or adult.

8186: Deep Learning Based High-Resolution Frequency Estimation for Sparse Radar Range Profiles

Sabyasachi Biswas, Ali C. Gurbuz
Mississippi State University, United States

Generating radar range profiles for linear frequency modulated radar systems is such a case where spectral analysis is used to estimate target ranges. Conventional methods like FFT are the golden standard in frequency estimation, despite its Rayleigh resolution limit and high sidelobe levels. To address such limitations this paper introduces HRFreqNet; a DNN architecture for high-resolution frequency estimation from 1D complex time domain data consisting of multiple frequency components. Our DL architecture consists of an auto-encoder block to improve SNR, a frequency estimation block to learn frequency transformations to generate pseudo frequency representations(FR), and finally, a 1DUNET block to reconstruct high-resolution FR. Experimental results on synthetically generated data show enhanced performance in terms of resolution, estimation accuracy, and ability to suppress noise. Achieved range profiles are also sparser with lower sidelobe levels. The proposed HRFreqNet is evaluated over both synthetic and experimental real-world radar data and it is observed that accurate, sparse, high-resolution range profiles are obtained compared to existing approaches.

8112: RF-Pointer: A Novel Approach to Radio-Frequency Driven Pointer Technology for HCI

Elvis Dsouza{2}, Kevin Chetty{1}, Shelly Vishwakarma{2}
{1}University College London, United Kingdom; {2}University of Southampton, United Kingdom

This paper introduces the RF-Pointer, an innovative radio-frequency-based interaction framework designed for real-time tracking and projection of hand movements in virtual spaces. The system can provide a hands-free and distinctive interaction experience suitable for emerging domains like virtual reality and augmented reality. In this study, we delve into the architectural and operational dynamics of the RF-Pointer, utilizing a prototype equipped with a 77 GHz radar sensor. Initial tests reveal an average tracking error of 2.5 cm in estimating the pointer's location. To further illustrate the efficacy of the proposed architecture, we conduct a qualitative comparison, presenting the results in the form of tracked trajectories corresponding to both ground truth and the RF-Pointer estimated trajectories. The tracking results demonstrate that RF-Pointer trajectories closely align with ground truth trajectories.

8048: UWBCarGraz Dataset for Car Occupancy Detection Using Ultra-Wideband Radar

Jakob Möderl, Stefan Posch, Franz Pernkopf, Klaus Witrisal
Graz University of Technology, Austria

We present a data-driven car occupancy detection algorithm using ultra-wideband radar based on the ResNet architecture. The algorithm is trained on a dataset of channel impulse responses obtained from measurements at three different activity levels of the occupants (i.e. breathing, talking, moving). We compare the presented algorithm against a state-of-the-art car occupancy detection algorithm based on variational message passing (VMP). Our presented ResNet architecture is able to outperform the VMP algorithm in terms of the area under the receiver operating curve (AUC) at low signal-to-noise ratios (SNRs) for all three activity levels of the target. Specifically, for an SNR of −20 dB the VMP detector achieves an AUC of 0.87 while the ResNet architecture achieves an AUC of 0.91 if the target is sitting still and breathing naturally. The difference in performance for the other activities is similar. To facilitate the implementation in the onboard computer of a car we perform an ablation study to optimize the tradeoff between performance and computational complexity for several ResNet architectures. The dataset used to train and evaluate the algorithm is openly accessible.

8179: Sparse Array Configuration Analysis and Deep Learning Classifications for Beamfornming

Moeness G. Amin{1}, Syed Ali Hamza{3}, Kyle Juretus{2}
{1}Center for Advanced Communications, Villanova University, United States; {2}Villanova University, United States; {3}Widener University, United States

Sparse arrays offer additional spatial degrees of freedom associated with nonuniform inter-element sensor spacing over the array aperture. This flexibility enables the array configuration and array weights to play important roles, separately or entwined, in optimum beamforming. In this paper, we examine sparse array configuration when decoupled from the array weight design. Array configuration is optimized to orthogonalize the desired source and the interference subspace, with the array weights only assuming the desired source steering vector. We consider a two-source scenario and analyze the specific and most frequently sparse configurations chosen by the orthogonalization criterion, in lieu of Capon beamforming. This is shown beneficial in reducing the number of labels when designing sparse arrays in dynamic environment based on deep learning (DL).

8:00 – 9:40
Localization and AoA Estimation
Room: DENVER BALLROOM 3
Session Chairs: Braham Himed and Brian Cordill

8016: Optimal Sensor Placement Using Combinations of Hybrid Measurements for Source Localization

Kang Tang{2}, Sheng Xu{1}, Yuqi Yang{4}, He Kong{3}, Yongsheng Ma{2}
{1}Shenzhen Institute of Advanced Technology, China; {2}Shenzhen Key Laboratory of Intelligent Robotics and Flexible Manufacturing Systems, China; {3}Southern University of Science and Technology, China; {4}University of Nottingham, United Kingdom

This paper focuses on static source localization employing different combinations of measurements, including time-difference-of-arrival (TDOA), received-signal-strength (RSS), angle-of-arrival (AOA), and time-of-arrival (TOA) measurements. Since sensor-source geometry significantly impacts localization accuracy, the strategies of optimal sensor placement are proposed systematically using combinations of hybrid measurements. Three novel contributions are made in this letter. (1) The optimal sensor placement for source localization problem using combinations of various measurements, including TDOA, RSS, AOA, and TOA, are formulated systematically. (2) The theoretical smallest Cramer-Rao bound (CRB)s of the different hybrid measurement combinations are derived. (3) To achieve the optimal estimation bounds, optimal sensor placement strategies are proposed. Specifically, the constraints of the optimal geometries deduced by specific measurement, i.e., TDOA, AOA, RSS, and TOA, are found.

8164: DOA Estimation Exploiting Distributed Array with Arbitrary Subarray Orientations

Yimin Zhang{3}, Md Waqeeb Chowdhury{3}, Yanwu Ding{4}, Dan Shen{2}, Khanh Pham{1}, Erik Blasch{1}, Genshe Chen{2}
{1}Air Force Research Laboratory, United States; {2}Intelligent Fusion Technology, Inc., United States; {3}Temple University, United States; {4}Wichita State University, United States

This paper considers a two-dimensional direction-of-arrival (DOA) estimation problem from a collaborative, distributed antenna array where each subarray is a distributed sensing node that is arbitrarily oriented. While the relative locations of the subarrays are not precisely known, it is assumed that the configuration of each subarray is locally calibrated whereas the cross-covariance matrix between a pair of distributed nodes includes an unknown phase difference. Without explicitly estimating such unknown phase difference, subspace-based DOA estimation methods fail to coherently utilize the subarrays to locate the DOAs of the impinging signals. We propose a group sparsity-based approach to achieve accurate DOA estimation that is resilient to unknown phase disparities between subarrays. Simulation results clearly illustrate the effectiveness of the group sparsity-based approach using group LASSO, and the superiority over subspace-based methods, such as the MUSIC algorithm, is demonstrated.

8261: Low-Complexity 2D DOA and Polarization Estimation via Linear Nested COLD Array with Vertical Motion

Yunlong Yang{1}, Mengru Shan{1}, Yu Li{2}, Guojun Jiang{2}
{1}Donghua University, China; {2}East China University of Science and Technology, China
In order to obtain two-dimensional direction-of-arrival and polarization estimation with high-precise and low-complexity, we present a linear nested polarization sensitive array with vertical motion, and then propose an ESPRIT-based estimation method. The original physical array consists of cocentered orthogonal loop and dipole antennas. Owing to the concept of difference coarray based on block submatrices, the closed-form expressions of signal model and increased degree of freedoms are provided for the resulting vertical synthetic planar array. Depending on it, the idea of ESPRIT is only utilized once, and then four parameters (i.e., azimuth angle, pitch angle, polarization angle and polarization phase delay) of each signal can be estimated and automatically paired. The computational complexity of the proposed method is analyzed theoretically. Numerical results are shown to verify the superiority of the proposed array and method in terms of multi-parameter estimation.

8190: Iterative Detection and Estimation of Coherent Narrowband Signals in Colored Noise

Radu Visina{2}, Nalini Ravishanker{3}, Peter Willett{3}, Jameson Bergin{1}
{1}Information Systems Laboratories, Inc., United States; {2}Information Systems Labs, United States; {3}University of Connecticut, United States
This paper proposes an algorithm to simultaneously estimate the presence, count, frequencies, amplitudes, and phases of coherent narrowband signals (i.e. complex plane waves) in correlated, Gaussian noise whose autocorrelation matrix is unknown, at a very low signal-to-noise ratio. Such a model is applicable to resolving radar multipath propagation with unknown, spatially-correlated currupting noise in the environment. The unique advantage of the proposed algorithm is that it does not require numerical/gradient search as conventional methods have. Instead, the iterative method is a series of ESPRIT frequency estimation, closed-form maximum likelihood amplitude estimation, signal reconstruction, noise isolation, and spectral pre-whitening, followed by MDL model order selection. The paper derives the closed-form Maximum Likelihood amplitude estimator for spatially-smoothed data matrices, a required step for the iteration.

8325: Deep Learning-Based Direction-of-Arrival Estimation with Covariance Reconstruction

Ahmed Manavi Alam, Cemre Omer Ayna, Sabyasachi Biswas, John T. Rogers, John E. Ball, Ali C. Gurbuz
Mississippi State University, United States
Accurately determining DOA is pivotal for various applications such as wireless communication, radar, and sensor arrays. Low SNR and limited number of snapshots pose formidable challenges to accurate DoA estimation. Both conventional model-based techniques and recent DL based DoA estimation models that map sample covariance matrices to DoA spectrum estimations struggle in such environments. In this study, we introduce a comprehensive DL framework that leverages sample covariance as input to predict the corresponding DoA jointly with the estimation of the true covariance matrix. The proposed architecture comprises two main components that employ CNN. The first part focuses on covariance reconstruction, aligning with the true covariance of a specific sample, and the second part applies multi-label classification for the DOA estimation step. The proposed overall framework integrates the MSE loss for the true covariance matrix reconstruction, to enhance model performance, particularly in low SNR and snapshot number scenarios, coupled with the BCE and MSE losses for angle estimation. This combination improved robustness and performance compared to existing CNN-based approaches.

8:00 – 9:40
Estimation
Room: DENVER BALLROOM 2-1
Session Chairs: Stephanie Bidon and Francesco Fioranelli

8216: Beyond FFT: Precision Vibration Tracking with FMCW Radar and Kalman Estimators

Thomas Moon
University of Illinois at Urbana and Champaign, United States

This paper introduces a novel approach to fast and precise vibration tracking using Frequency Modulated Continuous Wave (FMCW) radar augmented with Kalman estimators. The escalating demand for high-precision sensing across diverse applications underscores the need for radar systems capable of tracking dynamic targets with unprecedented accuracy. Traditional FFT-based FMCW radars often fall short in achieving the requisite speed and precision for real-time fine vibration tracking. Leveraging the inherent advantages of FMCW radar and Kalman estimators, we propose an innovative solution to address this challenge. This paper details the state-space equations for FMCW radar, outlining the integration of FMCW radar with Kalman estimators and analyzing the lower and upper bounds of the trackability. Simulation results validate the efficacy of the approach, demonstrating significant advancements in tracking dynamic targets.

8023: Demodulation and Chirp Spectrogram Combined Approach for Nonlinear Time Frequency Analysis

Bingcheng Li
Lockheed Martin, United States

Polynomial chirplet transform (PCT) has received a great attention recently in radar, acoustic and vibration signal processing fields because of its high frequency concentration and high accuracy for nonlinear time frequency analysis. The iterative fitting of spectrogram ridge points has been developed to implement PCT. However, the termination rule of the iterative fitting for conventional methods does not work well for noisy signals. Furthermore, the spectrogram ridge point extraction for the existing methods is limited to the assumption of the constant or close to constant frequency in local windows while many application cases may not follow this assumption. In this paper, an iterative demodulation and chirp spectrogram (Chirogram) combined technique is proposed to perform PCT and solve these two issues. Simulation test results show that the proposed approach significantly improves the energy concentration and estimation accuracy of instantaneous frequencies for noisy signals.

8025: High-Accuracy Range Estimation for FC-FMCW Radar Using Phase Evaluation in Static Scenarios

Theresa Antes, Zsolt Kollár, Thomas Zwick, Benjamin Nuss
Karlsruhe Institute of Technology, Germany

High-accuracy range estimation provides valuable information about an environment, especially in the industrial context. Using radar sensors, this can be achieved independently of lighting conditions or pollution. A system and processing model for high-accuracy range estimation with a fast chirp frequency-modulated continuous wave (FC-FMCW) radar is presented. The results are validated through simulations as well as measurements. Just by signal processing, µm-accuracy is accomplished without the need of complex and costly hardware. To do so, the concept of combined frequency- and phase-based range estimation is applied in FC-FMCW radar, offering benefits over the classical FMCW approach. Different possibilities for phase evaluation are discussed, influence factors on the achieved accuracy are investigated, and the results are contextualized using the Cramér-Rao lower bound (CRLB).

8183: Efficient Range-Doppler MMSE Estimation for Pulse Agile Radar

Daniel Herr, Pranav Raju, Matthew Heintzelman, James Stiles
University of Kansas, United States

Radars that employ pulse agile transmit waveforms must contend with coupling introduced between the range and Doppler dimensions, known as range sidelobe modulation (RSM). With traditional matched filter based range-Doppler processing, RSM presents itself as an increased signal-to-interference-plus-noise ratio (SINR) floor across all Doppler that is proportional to the total scattered energy in the scene. In this work, the minimum mean squared error (MMSE) estimator is formulated for the problem of range-Doppler estimation and is shown to effectively suppress estimation error introduced by RSM. To realize practical radar operation, a computationally efficient frequency-domain MMSE formulation is proposed, which leverages the spectral inverse filter method. The efficacy of this efficient MMSE estimator is demonstrated in simulated and open air experimental data and is shown to improve SINR relative to the matched filter in signal limited scenarios.

8106: Radar-Network-Based Odometry and Elevation Estimation

Francesco Trombetta, Adnan Albaba, Marc Bauduin, Hichem Sahli, André Bourdoux
imec, Belgium

In this paper, the 3D ego-motion parameters estimation problem using radar-network odometry (RNO) is presented. A pipeline for RNO-based 3D ego-motion parameters estimation is proposed and demonstrated. Moreover, two different radar-network-based algorithms for elevation estimation of targets are analyzed and utilized to improve the accuracy of the RNO-based 3D ego-motion parameters estimation. The performance of the proposed solutions is quantitatively evaluated with different simulated scenarios. Finally, the proposed solutions are tested in a scenario of forward-looking synthetic aperture radar image reconstruction for high resolution radar imaging.

9:40 – 10:50
Coffee Break
Room: COLORADO A-E

9:40 – 10:50
Poster Session 3: Automotive Radar
Room: DENVER BALLROOM 5-6
Session Chair: Faruk Uysal

8009: Open-RadVLAD: Fast and Robust Radar Place Recognition

Matthew Gadd, Paul Newman
University of Oxford, United Kingdom

Radar-based robotics tasks are often solved with invariance properties of Fourier or Fourier-Mellin transforms, etc. In place recognition, this has recently been done with a combination of the Radon, Fourier, and inverse Fourier transform - starting with a polar-to-Cartesian conversion. We, however, show that the polar representation is sufficient and that a simple Fourier Transform along radial returns achieves translation invariance. We also achieve rotational invariance and a very discriminative descriptor space by building a vector of locally aggregated descriptors - and, in contrast to existing vision-based work, we do this directly on the input modality, rather than at some deep neural network layer or in the space of hand-crafted gradient-based point features. Our method is more comprehensively tested than all prior radar place recognition work to date - over an exhaustive combination of all pairs of trajectories from 30 sequences of the Oxford Radar RobotCar Dataset. Code and results are provided at github.com/mttgdd/open-radvlad, an open implementation and benchmark for future work in this area.

8036: MIMO Imaging Method with Extrapolation-Iterative Adaptive Approach-Based Super-Resolution Technique for Automotive Radar

Bongseok Kim{1}, Jonghun Lee{1}, Sangdong Kim{1}, Ram Narayanan{2}
{1}Daegu Gyeongbuk Institute of Science and Technology, Korea; {2}Pennsylvania State University, United States

This paper proposes a MIMO imaging method that leverages an extrapolation-iterative adaptive approach to achieve super-resolution capabilities for automotive radar applications. In recent years, autonomous vehicles have incorporated 4D imaging radar systems to attain high-resolution data. The MIMO technique finds application in the design of compact vehicle radars, enabling the adoption of radar-based imaging technology. However, the conventional MIMO imaging approach, relying on the FFT algorithm, encounters challenges in realizing higher resolutions. To overcome this limitation, we propose a MIMO radar implementation founded upon a super-resolution algorithm. Specifically, we investigate the combination of extrapolation and iterative adaptive approach, an iterative algorithm that has gained popularity as a means to mitigate the complexity drawbacks associated with super-resolution techniques. Through simulations and experiments, we validate this method, showcasing its immense potential in enhancing the accuracy and precision of vehicle radar systems.

8055: Modeling Motion Compensated Radar Doppler Uncertainty for Autonomous Driving

Shubhendra Chauhan, Xiufeng Song
Latitude AI, United States

Automotive radars play a prominent role in enhancing the safety of vehicles by providing advanced driver assistance capabilities. An automotive radar measures the range, angle, and Doppler of a radio reflection point in the sensor frame, while autonomy applications such as tracking and sensor fusion are processed in the vehicle frame. To account for representation mismatch, a spatial transformation is necessary to convert measured quantities like Doppler. Motion compensation is an essential step to accurately extract motion information from a target, as the Doppler is a relative measurement. While there are existing studies on removing the vehicle's contribution, uncertainties from both the vehicle and radar sensor have yet to be explored.This work closes the gap by extensively studying and providing sources of uncertainties in the compensated Doppler. Our approach involves deriving uncertainty formulas and proposing approximation methods that take into account computing constraints. The accuracy and efficiency of our approximations are validated with Monte-Carlo simulations under different autonomous driving scenarios. Our approximation results are close to the 99% of true values.

8071: Experimental Verification of Rainfall Impact on Sparse Array Radar

Takuya Kawaguchi{1}, Kazuki Shinotsuka{1}, Stefan Malterer{2}
{1}Fujikura Ltd., Japan; {2}Fujikura Technology Europe GmbH, Germany

Recently, mm-wave radars have been adapted as sensors for vehicles. Generally, radars are better than optical sensing modalities in adverse weather such as rainy and foggy conditions. Basically, autonomous driving systems require radar to achieve higher angular resolution. Sparse array radar is a practical approach to achieving higher angular resolution without ambiguity. However, because the amount of information acquired by sparse array radars is less than the amount acquired by conventional radars, signal quality might deteriorate if the sparse array radar is utilized in adverse weather. This might degrade the sensing results, which does not occur on the conventional radars. Nevertheless, the impact of adverse weather on sparse array radars yet to be reported. Hence, this study verified this impact experimentally, especially, the impact on range and azimuth information acquired by the sparse array radar by experiments in a chamber, which can create rainfall close to natural rainfall.

8079: Improved Accuracy for 3D Ego-Motion Estimation Using Automotive FMCW MIMO Radar

Sen Yuan{2}, Dingyang Wang{1}, Francesco Fioranelli{1}, Alexander Yarovoy{1}
{1}Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands; {2}Technische Universiteit Delft, Netherlands

The problem of 3D ego-motion velocity estimation using multichannel Frequency Modulated Continuous Wave (FMCW) radar sensors has been studied. Special attention is given to presence of moving targets in the scene. These targets are first distinguished by the difference between the measured Doppler, and the Doppler calculated with an initial rough estimation of the vehicle ego-velocity. Then, an iterative algorithm is proposed to reduce the influence of the moving targets in the ego-motion estimation procedure, thus improving the overall accuracy. The performance of the proposed algorithm is compared with state-of-the-art alternatives based on simulated data, and superior performance has been demonstrated.

8141: Implementation of Deep Learning-Based Kick Gesture Recognition Using 60 GHz Radar Sensor

Hyo-In Baek{1}, Younghwan Chae{1}, Hae-Seung Lim{1}, Jae-Eun Lee{1}, Seongwook Lee{2}
{1}bitsensing Inc., Korea; {2}Chung-Ang University, Korea

In the realm of automotive technology, hands-free trunk operation systems have emerged as a cornerstone of convenience and functionality. Predominantly reliant on ultrasonic and camera-based sensors, these systems, however, falter in adverse weather conditions such as rain, snow, and fog, and are limited by short detection ranges and susceptibility to false alarms due to unintentional movements. Addressing these limitations, this paper proposes an innovative solution utilizing a 60 GHz frequency-modulated continuous wave radar sensor. This system is resilient in various weather conditions and has a robust detection mechanism for kick gestures. By employing two-dimensional fast Fourier transform for range and velocity analysis and an antenna array system for azimuth angle extraction, our radar sensor effectively discerns kick gestures. The data, once processed, is channeled through controller area network flexible data-rate communication to a deep learning classifier. This classifier, tested for accuracy, successfully identifies valid kick gestures with a remarkable 99.75% accuracy.

8172: A Joint Design of Sparse Array Layout and DOA Algorithm for mmWave FMCW Radar

Hongning Ruan{1}, Siegfred Balon{1}, Jian Wu{2}, Qingping Liu{2}, Jinghu Sun{2}, Xiaojun Wu{1}
{1}Desay SV Automotive Co. Ltd., Singapore; {2}Desay SV Intelligent Transportation Technological Institute Research Co. Ltd., China

Sparse distribution of array elements is commonly employed to increase the virtual aperture size for improved angular resolution. However, it can lead to elevated levels of sidelobe and grating lobes that introduce angular ambiguity and false detections. This paper proposes a joint design approach of sparse array layout design and the direction-of-arrival (DOA) algorithm. The objective is to address angular ambiguity in sparsely distributed arrays using a low-complexity DOA algorithm to facilitate real-time processing. The approach involves incorporating the principle employed in the DOA processing into the cost function during the antenna array synthesis. Experimental results obtained from a two-chip cascaded frequency-modulated continuous wave (FMCW) mmWave radar demonstrate an achieved resolution with accuracy validating the effectiveness of the proposed methodology.

8202: Radar in the Rain: Understanding and Simulating Environmental Effects on ADAS Radar Sensors

Diogo Wachtel Granado{2}, Thomas Rothmeier{2}, Tetmar von Dem Bussche{2}, Werner Huber{2}, Martin Vossiek{1}

{1}Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; {2}Technische Hochschule Ingolstadt, Germany

Advanced driver assistance systems (ADAS) depend heavily on clear and precise environmental perception. Environment sensors play a pivotal role in enabling these functions by perceiving the surroundings of the ego vehicle. Radar sensors, operating in different frequency ranges, offer a partial solution by overcoming some limitations associated with vision-based environmental perception. Simulation has become an invaluable tool for validating driving functions and sensors within a virtual environment, offering the capability to replicate critical scenarios and systematically adjust weather conditions for testing. This work analyses two radar sensors' measured radar cross section (RCS) under several rain conditions and proposes a model to simulate the rain effects on the radar rays. The results revealed that not only does the rain intensity play a role in the radar detection, but the asphalt condition, whether dry or wet, increases the multipath effect, reducing the accuracy of the radars. The proposed model confirms the possibility of simulating the power-loss impact by matching the limits of real measurements.

8236: Impact of Urban Street Geometry on the Detection Probability of Automotive Radars

Mohammad Taha Shah{1}, Ankit Kumar{1}, Gourab Ghatak{1}, Shobha Sundar Ram{2}

{1}Indian Institute of Technology Delhi, India; {2}Indraprastha Institute of Information Technology, Delhi, India

Prior works have analyzed the performance of millimeter wave automotive radars in the presence of diverse clutter and interference scenarios using stochastic geometry tools instead of more time-consuming measurement studies or system-level simulations. In these works, the distributions of radars or discrete clutter scatterers were modeled as Poisson point processes in the Euclidean space. However, since most automotive radars are likely to be mounted on vehicles and road infrastructure, road geometries are an important factor that must be considered. Instead of considering each road geometry as an individual case for study, in this work, we model each case as a specific instance of an underlying Poisson line process and further model the distribution of vehicles on the road as a Poisson point process - forming a Poisson line Cox process. Then, through the use of stochastic geometry tools, we estimate the average number of interfering radars for specific road and vehicular densities and the effect of radar parameters such as noise and beamwidth on the radar detection metrics. The numerical results are validated with Monte Carlo simulations.

8165: Automotive Radar Sensing with Sparse Linear Arrays Using One-Bit Hankel Matrix Completion

Arian Eamaz{2}, Farhang Yeganegi{2}, Yunqiao Hu{1}, Shunqiao Sun{1}, Mojtaba Soltanalian{2}

{1}University of Alabama, United States; {2}University of Illinois Chicago, United States

The design of sparse linear arrays has proven instrumental in the implementation of cost-effective and efficient radar systems for high-resolution imaging. This paper investigates the impact of coarse quantization on measurements obtained from such arrays. To recover azimuth angles from quantized measurements, we leverage the low-rank properties of the constructed Hankel matrix. In particular, by addressing the one-bit Hankel matrix completion problem through a developed singular value thresholding algorithm, our proposed approach accurately estimates the azimuth angles of interest. We provide comprehensive insights into recovery performance and the required number of one-bit samples. The effectiveness of our proposed scheme is underscored by numerical results, demonstrating successful reconstruction using only one-bit data.

9:40 – 10:50
Poster Session 3: Waveforms and Spectrum Sharing
Room: DENVER BALLROOM 5-6
Session Chair: Cenk Sahin

8080: Spectrally Compatible Unimodular Waveform Design for MIMO Radar via Manifold Optimization

Ye Yuan{2}, Jinfeng Hu{2}, Kai Zhong{2}, Guolong Cui{2}, Jun Liu{1}, Yuankai Wang{1}
{1}41st Institute of China Electronics Technology Group Corporation, China; {2}University of Electronic Science and Technology of China, China

Spectrally compatible unimodular waveform design of beampattern shaping is essential for the coexistence of Multiple Input Multiple Output (MIMO) radar systems and wireless communication systems. Existing methods primarily address the issue through the Semidefinite Programming (SDP) framework with non-strict unimodular waveform, or the Alternating Directions Method of Multipliers (ADMM) framework with objective function relaxation. Different from these methods, we propose an Inequality Constrained Manifold Optimization (ICMO) framework to solve the problem without objective function relaxation. First, we convert the spectral energy constraint into a penalty function by smoothing technique, resulting in an optimization problem with the unimodular constraint. Then, we note that the complex circle manifold (CCM) naturally satisfies the unimodular constraint, we derive a conjugate gradient descent (CGD) algorithm based on CCM to solve the converted problem without relaxation. Simulation results show that the proposed method outperforms the existing methods in terms of Integrated Sidelobe Level Ratio (ISLR), spectrum nulling, and execution time.

8130: On Detection of Tangential Maneuvering Target via Transceiver Design for Airborne Radar

Jingyi Xiong, Guolong Cui, Tao Fan, Xianxiang Yu
University of Electronic Science and Technology of China, China

This paper deals with the detecting problem of tangential maneuvering target for airborne radar. To this end, we develop a transceiver design method via ambiguity function shaping which minimizes the clutter echo power under constant modulus, target peak-matching and signal-to-noise ratio loss constraints. Afterwards, we transform it into two subproblems, solving them alternatively to monotonically decrease the clutter echo power. Simulation results demonstrate that the proposed transceiver design method can successfully achieve tangential maneuvering target detection in range-ambiguous clutter without prior information of clutter.

8175: Multi-Sub-Chirp Signal Synthesis for Millimeter-Wave Radar Based on Dechirp Processing

Biao Xue{1}, Gong Zhang{1}, Henry Leung{2}, Maria Sabrina Greco{3}, Fulvio Gini{3}
{1}Key Lab of Radar Imaging and Microwave Photonics, Ministry of Education, NUAA, China; {2}University of Calgary, Canada; {3}University of Pisa, Italy

Due to the limitation of hardware, the transmission bandwidth of the miniature millimeter-wave (mmW) radar is restricted. This paper considers a signal composed of multiple sub-chirps to synthesize wide-bandwidth chirp signals based on dechirp processing. However, dechirp operation results in undesirably high sidelobe peaks and sidelobe shape distortion due to the discontinuities caused by chirp interference between the simultaneous presence of multiple sub-chirps. In the short-time Fourier transform (STFT) domain, we utilize an autoregressive (AR) model to reconstruct the interference regions between the sub-chirps by linear prediction (LP), to reduce the influence after dechirp processing. The proposed method is robust to low SNR and large gap width, and does not need to know the target number in advance. Further, by adjusting the chirp rate of each sub-chirp of the transmitted waveforms, it can be further applied to mmW multiple-input multiple-output (MIMO) radars. The simulation results verify the effectiveness of the method in this paper.

8309: Phase-Attached Determinstic/Random Waveform (PADRa) for SAR Applications

Heath Vann, Cameron Musgrove
IERUS Technologies, Inc., United States

Synthetic Aperture Radar (SAR) systems have used deterministic waveform modulation schemes, such as linear frequency modulation (LFM), effectively for many years. LFM spectral shaping via amplitude tapering makes LFM a desirable choice in SAR image processing, significantly reducing high sidelobe levels. Random frequency modulation (RFM) waveforms provide unique waveforms for every pulse with low cross-correlation, but suffer from high-sidelobe levels that are not easily reducible. This study aims to show how the phase-attached deterministic/random (PADRa) waveform can be utilized to spectrally shape a subclass of RFM waveforms, providing sidelobe reduction while still producing unique waveforms with low cross correlation.

8312: Parameter Estimation of Pseudo-Random Optimized Dolph-Chebyshev Window Waveforms Using the Gauss-Newton Method

Brian Carlton{2}, Russell Kenney{2}, Justin Metcalf{1}, Jay McDaniel{2}
{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}University of Oklahoma, United States

The problem of estimating the parameters of the radar return from a waveform with a tunable Dolph-Chebyshev power spectral density is considered. Specifically, the gradients of the Dolph-Chebyshev window are derived for use with the Gauss-Newton method for determining the multiple parameters of a received waveform. The radar waveform is designed using the pseudo-random optimized frequency modulation technique. The performance of this nonlinear-least squares technique is compared to the Gauss-Newton method using gradients derived from a sinc function (as would be the case for a linear frequency modulated waveform), as well as an interpolation method. Further, the complexity of the above techniques is discussed.

8074: An Efficient Waveform Design Method with Spectral Coexistence and Pulse-Like Autocorrelation Function

Cui Zhang, Jifang Pei, Yujie Zhang, Yin Zhang, Weibo Huo, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

In this paper, we propose an efficient unimodular waveform design method for joint spectral coexistence and pulse-like autocorrelation optimization. An iterative algorithm is developed to deal with the non-convex problem arising from the proposed design framework which minimizes the energy spectral density (ESD) stopband under multiple constraints. In particular, we solve the variable coupling problem by analyzing the Karush-Kuhn-Tucker (KKT) conditions. Additionally, tedious breakpoint partition functions and variable range selection are avoided by constructing the new design framework and introducing the proximal algorithm. The proposed method not only achieves the simultaneous optimization of spectral coexistence and pulse-like autocorrelation but also reduces the computational complexity and improves the efficiency of waveform design. Numerical simulation results have shown the effectiveness of the proposed method in terms of running time and waveform properties.

8105: Robust Design of Transmit Beamforming for RadCom System Under Direction Uncertainties

Junhui Qian{2}, Zhuoran Sun{2}, Chao Zhang{2}, Zhuoheng Xie{1}, Guobing Qian{3}, Shiyuan Wang{3}
{1}Chongqing Southwest Integrated Circuit Design Co., Ltd., China; {2}Chongqing University, China; {3}Southwest University, China

In this paper, we investigate a RadCom transmit beamforming framework under direction uncertainties. The performance indicators including the radar desired beampattern and the multi-user communication signal-to-interference-plus noise ratios (SINRs), we introduce a well-considered weighted scheme to optimize relevant figures of merit. The optimization problem is inherently non-convex due to the fractional problem and constraints related to transmit power. To overcome this challenge, an iterative procedure is formulated within the framework of Dinkelbach's approach, employing a sequential optimization procedure (Dinkelbach-SOP). Additionally, the minorization-maximization is integrated within the alternating direction method of multipliers (MM-ADMM). Numerical demonstrations substantiate the efficacy of the proposed design and highlight its ability to mitigate the impact of direction mismatch and optimize performance metrics under various constraints.

8099: An Enhanced Radar and Communication Coexistence Scheme with Spatio-Temporal Design

Junhui Qian{3}, Jinru Zhang{3}, Gaojie Chen{4}, Jingjing Wang{1}, Yanhui Wu{2}
{1}Beihang University, China; {2}Chongqing Southwest Integrated Circuit Design Co., Ltd., China; {3}Chongqing University, China; {4}University of Surrey Guildford, United Kingdom

A spatio-temporal co-design framework for simultaneous optimization of the performance of radar and communication system in spectrum coexistence scenario is developed. We use the signal-to-interference-plus noise ratio (SINR) on the radar side and the communication rate on the communication side as the performance indicators of the two subsystems, and obtain the original nonconvex optimization problem under the energy and spectrally compatible constraints. Considering the complexity of the original trivariate nonconvex problem, a sequential iterative optimization framework with more design degrees of freedom is presented to transform the nonconvex problem into several single-variable subproblems. Then, the alternating direction method of multipliers (ADMM) method and minimum variance distortionless response criteria are adopted to solve the transformed subproblems. Finally, the superiority of the proposed design has been substantiated through simulation results.

9:40 – 10:50
Poster Session 3: Resource Management
Room: DENVER BALLROOM 5-6
Session Chair: Alexander Charlish

8103: Online Route Planning for Airborne Radar Networks with Multi-Target Tracking

Ye Yuan, Jianwei Wei, Wei Yi
University of Electronic Science and Technology of China, China

This paper presents an online route planning strategy for airborne radar networks (ARN) with the task of multitarget tracking (MTT). A distributed covariance intersection rule is employed for tracking processing to reduce the computation and communication costs associated with data fusion. The posterior Cramer-Rao lower bound (PCRLB) regarding maneuvering parameters, including velocities and courses of airborne radars, is derived as the metric of tracking performance. By using the MinMax criterion (i.e., minimizing the PCRLB of the target with the worst predicted tracking performance), the route planning for ARN is formulated as a series of sequential optimization problems along with the tracking process. A sequential one-dimensional search algorithm with polynomial complexity is presented to solve the problems efficiently. Numerical results show that the proposed strategy can obtain a better overall MTT performance by comparing it with benchmarks.

8250: Deployment of Airborne Distributed MIMO Radar for Task Reinforcement

Chuhan Wang, Xiaolong Li, Mingxing Wang, Zhao Zhang, Guolong Cui
University of Electronic Science and Technology of China, China

Airborne radar deployment optimization significantly enhances the utilization ratio of resources such as flight loss and strengthens the target detection capability. This article investigates a deployment optimization method of airborne distributed multiple input multiple output (MIMO) radar for task reinforecement. In order to improve detection ability and reduce flight loss, we use effective coverage rate and total flight cost as objective functions and develop a multi-objective optimization model. Considering that the problem has more than one objective and dimension, we propose a multi-objective particle swarm optimization with dynamic weight relative crowding distance (MOPSO-DWRCD) algorithm. Compared to traditional MOPSO, MOPSO-DWRCD exhibits better performance in global optimal solution selection in each iteration. Finally, simulation results are provided to verify the effectiveness of the proposed algorithm.

8270: Radar Task Scheduling with Gaussian Random Shifted Start Time

Zhen Ding{2}, Petar Przulj{1}, Zhen Qu{2}, Peter W. Moo{2}
{1}Defence Research and Development Canada Ottawa Research Centre, Canada; {2}Defence Research and Development Canada, Ottawa Research Centre, Canada

A radar task scheduling algorithm, Gaussian random shifted start time (GRSST), is proposed. The algorithm shifts each task's start time by a Gaussian distribution instead of a uniform distribution within the time window which was used in the random shifted start time (RSST) algorithm. Each task's priority is used to calculate its distribution variance. The random search is not related to the priorities. A higher priority task will have a smaller variance, so that its movable range is less than that of a lower priority task. Similar to the RSST, multiple searches help to find the solution with the lowest cost. Monte Carlo simulations show that the GRSST reduces the cost significantly with much less searches, which saves a lot of computation time too. The GRSST with 50 searches provides a better solution which costs around 2 times less than the RSST with 350 searches. The GRSST's average computation time is reduced to 1ms from 7ms.

10:50 – 11:50
Special Session: RF Sensing for Space Domain Awareness
Room: DENVER BALLROOM 4
Session Chairs: Marco Martorella and Gregory Hogan

8133: Long Baseline Bistatic Radar for Enhanced Space Domain Awareness at Geosynchronous Orbits

Andrew Kintz, Sarah Welch, Alexander Kobsa, Gregory Hogan
MIT Lincoln Laboratory, United States

Long baseline bistatic radars herald enhanced sensitivity, characterization, and metric accuracy for clustered objects in Geosynchronous orbits and beyond. Radio telescope arrays in particular feature large apertures, low noise temperatures, and stable, synchronized clocks. Pairing radio-telescope arrays with high power-aperture radars creates new opportunities for detecting small targets, rapidly determining orbits, resolving closely spaced objects, and characterizing tumbling or maneuvering targets. Enhancing these aspects of space situational awareness is the focus of NATO's SET-293 Research Task Group. In this paper, we report on long baseline bistatic measurements using the Millstone Hill Radar in the USA and the Westerbork Synthesis Radio Telescope in the Netherlands. Bistatic link budgets were calculated and validated through multiple data collections. In addition, narrowband characterization of geosynchronous satellite clusters by the long-baseline bistatic radar yielded metrics suitable for space object identification and change detection.

8228: First Results of Attitude Estimation Using RCS Time Series for Space Domain Awareness

Detmer Bosma, Faruk Uysal
Netherlands Organisation for Applied Scientific Research, Netherlands

This paper presents the first results of a novel approach for estimating the attitude of tumbling targets by utilizing radar cross section (RCS) time series data from monostatic and bistatic radar systems. For manmade space objects, we propose the use of target models to simulate RCS time series and compare them with the radar data collections. This comparison of synthesized and measured RCS time series resolves ambiguities in unknown model estimates and enables the estimation of the object's attitude. The effectiveness of the proposed approach is demonstrated using real data collected from the intercontinental Long Baseline Bistatic Radar (LBBR) systems. Due to its simplicity, this method can be easily applied in the fields of tumbling behavior analysis and non-cooperative malfunctioning satellite assessments.

8300: Exploring the Feasibility of Detecting LEO Space Objects in Passive Radar Without Prior Orbit Parameter Information

Konrad Jędrzejewski{2}, Krzysztof Kulpa{2}, Mateusz Malanowski{2}, Mariusz Pożoga{1}, Piotr Wójtowicz{2}
{1}Space Research Centre, Polish Academy of Science, Poland; {2}Warsaw University of Technology, Poland

One of the crucial factors allowing the passive observation of Low-Earth Orbit (LEO) objects is the compensation of their motion. Previous authors' research assumed that the information about orbital parameters of the considered object, and its approximate trajectory, are known. This paper presents the results of studies on the possibility of detecting space objects moving in LEO using passive radar without the knowledge of their orbital parameters. Apart from theoretical considerations, the results of real-life experiments are discussed. The experiments were performed using the astronomical LOw-Frequency ARray (LOFAR) radio telescope as a surveillance receiver, and terrestrial commercial digital radio transmitters operating in the VHF band employed as an illuminator of opportunity. The large antenna array of the LOFAR radio telescope enables receiving very weak echo signals reflected from LEO objects. The results of the experiments confirm the feasibility of observation of the selected fragment of space and detection of the LEO objects moving in this fragment of space without knowledge of their orbital elements, which are usually given in the Two-Line Element (TLE) format.

10:50 – 11:50
Weather Radar
Room: DENVER BALLROOM 3
Session Chairs: Robert Palmer and James Kurdzo

8201: Estimating Liquid Water Content Using Dual-Frequency Radar and Bayesian Neural Network

Zheng Wen, Dingjie Peng, Xun Su, Yousuke Ohya, Kazuhiko Tamesue, Hiroyuki Kasai, Wataru Kameyama, Takuro Sato
Waseda University, Japan

This study explored a novel approach to estimating the Liquid Water Content of cloud layers from radar observational data by utilizing dual-frequency radar in tandem with Bayesian Neural Networks. The dual-frequency radar utilizes differential attenuation between the two distinct frequencies to directly assess the LWC in clouds, with the variance proportionate to the overall LWC in the surveyed volume. However, due to atmospheric perturbations and other factors, standalone radar observations might not suffice for high-precision LWC evaluations. To address this, we incorporated the BNN, capable of handling the inherent uncertainties in radar data and offering a more accurate estimation for LWC. Preliminary results demonstrate that the combination of dual-frequency radar and BNN can effectively assess the LWC of cloud layers, showcasing superior accuracy and resolution compared to conventional methods. This methodology provides a potent tool for a deeper understanding of cloud physical processes and further refinement of climate models.

8283: Simultaneous Observations from in Situ Ground-Based and Airborne Radars at Multiple Frequency Bands Over Winter Storms

Venkatachalam Chandrasekar{1}, Eunyeol Kim{1}, Sounak Biswas{1}, David Wolff{2}, Matthew McLinden{2}, Francesc Junyent{1}, Jim George{1}
{1}Colorado State University, United States; {2}NASA Goddard Space Flight Center, United States

A comprehensive understanding of various microphysical processes underlying precipitation formation can be achieved through simultaneous measurements from ground-based and airborne radar systems at different frequencies.This work focuses on precipitation observing remote sensing instruments, namely the D3R operating at Ku/Ka bands, airborne radars at frequencies X, Ku, Ka, and W bands aboard NASA's ER-2 flight, and instruments on NASA's P-3 flight during IMPACTS. RHI scans from the D3R along the flight track are used for simultaneous observation of a snowstorm event on February 28, 2023. Cross-validation procedures are performed, accounting for differences in spatial resolution and viewing geometry through volume matching. The ground based disdrometer is used to project the level of inter-comparison expected between radar measurements at different frequencies. The inter-comparison between the D3R and the airborne radar systems revealed consistent measurements. Additionally, this study provides an assessment of distinct ice crystal habits observed during the storm based on radar measurements, corroborated by corresponding observations from microphysics probes aboard the P-3 flight.

8211: Evaluation of Phased Array Architectures for Weather Observations with Space-Time Processing

Yoon-Sl Kim{1}, David Schvartzman{1}, Robert Palmer{1}, Tian-You Yu{1}, Feng Nai{2}, Christopher Curtis{2}
{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}Cooperative Institute for Severe and High-Impact Weather Research and Operations, United States

Phased Array Radar (PAR) technology holds promise for advancing atmospheric observations with its unique capabilities. Space-time processing emerges as a novel method to enhance weather observation by addressing clutter in Doppler and spatial domains through joint filter responses. The study investigates the performance of space-time adaptive processing (STAP) and non-adaptive space-time processing (STP) on simulated weather data in cluttered environments. STAP, with its adaptive space-time weights, improves clutter mitigation and detection, albeit with increased computational complexity. To address this challenge, a subarray architecture is proposed, reducing data volume while maintaining data quality. The study delves into trade-offs, particularly grating lobes, associated with subarray systems. An optimized transmit beam pattern is introduced to mitigate challenges related to grating lobes, optimizing system performance. This research aims to provide insights into the efficacy and challenges of STAP, STP, and subarray architectures in enhancing PAR technology for atmospheric observations.

10:50 – 11:50
Machine Learning for Activity Detection
Room: DENVER BALLROOM 2-1
Session Chairs: Ali C. Gurbuz and Justin Metcalf

8187: 5G-Based Passive Radar Sensing for Human Activity Recognition Using Deep Learning

Manu Dwivedi{2}, Ian Ellis Hulede{2}, Oscar Venegas{2}, Jonathan Ashdown{1}, Amitav Mukherjee{2}
{1}Air Force Research Laboratory, United States; {2}Tiami Networks, United States

Wireless sensing and human activity recognition is an important research direction for next-generation wireless communications systems as they evolve towards Integrated Sensing and Communications (ISAC) using a single waveform. This paper explores the utilization of 5G NR as an illuminator of opportunity to perform passive radar detection and activity recognition. It proposes leveraging the synchronization signal block (SSB) signal of 5G, which is emitted periodically, for processing in passive coherent location (PCL) systems. We develop a signal processing pipeline involving processing of the SSBs that are transmitted at regular intervals to extract the Channel State Information (CSI) between the transmitter and the receiver. The CSI data which provides the characteristics of the radio channel is fed into a Deep Learning (DL) model to discern specific gestures. Experimental results with an over-the-air 5G signal collection campaign show excellent classification results across five categories of activities.

8293: Gamification of RF Data Acquisition for Classification of Natural Human Gestures

Emre Kurtoğlu{2}, Kenneth Dehaan{1}, Caroline Kobek Pezzarossi{1}, Darrin J. Griffin{2}, Chris Crawford{2}, Sevgi Zubeyde Gurbuz{2}
{1}Gallaudet University, United States; {2}University of Alabama, United States

In recent years, there have been significant developments in radio frequency (RF) sensor technology used in human-computer interaction (HCI) applications. Although extensive research has been conducted on these subjects, most experiments involve controlled settings where participants are instructed on how to perform specific movements. However, when such experiments conducted on sign language recognition they lack of capturing dialectal and background-related diversities. In this work, we explore the differences in RF datasets acquired under controlled experimental settings and in free form where users were not constrained by the experimental instructions and limitations. We show that directed (i.e., controlled) data acquisition approaches result in over-optimistic performances which do not perform well on naturally acquired data samples in a real-world use case. We evaluate different approaches on generating synthetic samples from directed dataset, but show that such methods do not offer much benefit over collecting natural data. Therefore, we propose an interactive data acquisition paradigm through gamification.

8185: Deep Learning-Based High-Resolution Radar Micro-Doppler Signature Reconstruction for Enhanced Activity Recognition

Sabyasachi Biswas, Ahmed Manavi Alam, Ali C. Gurbuz
Mississippi State University, United States

µD signatures play a crucial role in activity classification using radar. Conventional methods for µD generation, such as the STFT, suffer from several limitations, such as the resolution limit, sensitivity to noise, and the need for parameter tuning. To overcome these challenges, we introduce a novel DL based approach that directly reconstructs high-resolution µD from 1D complex time-domain signals. The DL architecture comprises three key components: an autoencoder block to enhance the SNR, a STFT block to acquire the knowledge of frequency transformations necessary for generating pseudo-spectrograms, and a UNET block for the reconstruction of high-resolution spectrogram images. We conducted evaluations of the proposed method using both synthetic and real-world datasets. For real-world data, A radar-based dataset, consisting of 20 ASL signs are used, to assess the classification performance achieved with µD generated by the proposed approach. Our results demonstrated a 3.34% increase in classification accuracy compared to traditional STFT-based µD. Both synthetic and experimental µD revealed that our approach effectively learns to reconstruct higher-resolution spectrograms.

11:50 – 12:50
Lunch
Room: COLORADO F-J

11:50 – 12:50
Handoff Lunch (Closed)
Room: HOMESTEAD

12:50 – 14:10
Sparse Arrays
Room: DENVER BALLROOM 4
Session Chairs: Pierfrancesco Lombardo and Andre Bourdoux

8282: Tensor Reconstruction-Based Sparse Array Interpolation for 2-D DOA Estimation of Coherent Signals

Md. Saidur Pavel{2}, Yimin Zhang{2}, Braham Himed{1}
{1}Air Force Research Laboratory, United States; {2}Temple University, United States
This paper proposes a tensor-based two-dimensional (2-D) direction-of-arrival (DOA) estimation method for coherent sources using a 2-D coprime array. The proposed method preserves the structural characteristics of multi-dimensional signals with multiple snapshots by constructing a covariance tensor of the received signal. To address the issue of rank-deficiency of the covariance tensor due to the coherency of the impinging signals, a structural tensor reconstruction method is employed to decorrelate the covariance tensor. Additionally, the use of a coprime array results in a non-contiguous difference coarray, leading to missing measurements in the reconstructed covariance tensor. To fully leverage the aperture provided by the coprime array, the missing correlations are interpolated by solving a convex optimization problem. The canonical polyadic decomposition method is applied to the interpolated covariance tensor to detect the coherent sources. The conditions for source resolvability are also analyzed.

8181: IRELAX: Interpolated Relax Algorithm for Enhanced Direction-of-Arrival Estimation

Fauzia Ahmad{2}, Moeness G. Amin{1}
{1}Center for Advanced Communications, Villanova University, United States; {2}Temple University, United States
We propose interpolated RELAX (IRELAX) which is a RELAX algorithm incorporating a spatial frequency interpolation method to provide enhanced source direction-of-arrival (DOA) estimation. IRELAX is implemented in the coarray-domain of fully-augmentable sparse arrays. The interpolation method approximates the periodogram peak by a parabola and employs three discrete Fourier transform samples around the peak to refine the DOA estimates. Due to the simplicity and efficiency of the interpolation method, the proposed variant allows low-complexity, fast DOA estimation of multiple sources. We provide supporting simulation results with a minimum redundancy array which demonstrate the superior DOA estimation performance of the proposed algorithm over RELAX.

8086: Mixed Near- and Far-Field 2D Imaging with Sparse Arrays

Gabriel Schnoering{2}, Takuya Kawaguchi{1}, Christian Höller{2}
{1}Fujikura Ltd., Japan; {2}Fujikura Technology Europe Switzerland AG, Switzerland
The advent of a new generation of radar arrays, topologically sparse and with wide apertures, has emerged in the field of automotive sensors aimed at autonomous driving. These wide and coherent radar sensors aim at providing a high angular resolution to perform accurate imaging frontwards. However, a larger aperture increases the near-field region boundary to tens of meters. There imaging methods are more demanding than in the far-field. Here, we propose a mixed near- and far-field processing approach that preserves a high imaging capacity across the field-of-view. To this end, the signal space is separated and processed adequately on each subspace. This mixed imaging approach is illustrated in a 2D range-azimuth configuration and paves a way to real-time imaging capabilities for extended radar apertures.

8098: Beamspace Matrix Completion in Subarray-Based Sparse Linear Array for High-Resolution Automotive MIMO Radar

Kawon Han, Marc Bauduin, André Bourdoux
imec, Belgium

This paper presents a high-resolution automotive multi-input multi-output (MIMO) radar with sparse arrays using beamspace matrix completion. Sparse arrays, while offering a larger aperture than uniform arrays with an equivalent number of antenna elements, suffer from higher sidelobe levels due to missing elements (holes). To address this issue, an array interpolation technique employing low-rank matrix completion through a Hankel matrix formation has been proposed. However, the computational demands of this approach make it impractical for low-cost automotive radar sensors. To overcome this challenge, we propose a subarray-based beamspace approach, reducing the dimensions of the Hankel matrix for efficient matrix completion in sparse arrays within automotive MIMO radar systems. Numerical simulations validate the effectiveness of our approach, focusing on a one-dimensional sparse linear array (SLA) and assessing various performance metrics.

12:50 – 14:10
Phenomenology and Modeling
Room: DENVER BALLROOM 3
Session Chairs: Mark Davis and Sandeep Gogineni

8002: Evaluation of Automotive Radar Simulation Tools for Adverse Weather Conditions: A Comparative Analysis of Real Measurement, HFSS and Monte-Carlo GO Methods

Diogo Wachtel Granado{2}, Christian Schuessler{1}, Tetmar von Dem Bussche{2}, Thomas Rothmeier{2}, Martin Vossiek{1}, Werner Huber{2}
{1}Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; {2}Technische Hochschule Ingolstadt, Germany

Creating a near-to-reality radar model is complex because of the various factors influencing electromagnetic wave propagation, such as surface roughness, temperature, material composition, and thickness. These factors contribute to the complexity of multi-path propagation in radar simulations. This study conducted real measurements and simulations with a high-frequency structure simulator (HFSS) and a Monte-Carlo geometrical optics (Monte-Carlo GO) implementation on various dry and wet samples. The results were calibrated and compared, and they revealed that HFSS moderately outperformed the Monte-Carlo GO method's overall accuracy; nevertheless, the latter requires less computing capability and fewer triangles compared with HFSS; therefore, it may still be a vital choice for specific applications that require a lot of simulation data. Furthermore, the results showed that some materials change reflectivity because of humidity, and they must be adjusted in the simulations.

8131: Modelling Micro-Doppler Signature of Drone Propellers in Distributed ISAC

Heraldo Cesar Alves Costa, Saw James Myint, Carsten Andrich, Sebastian Wilhelm Giehl, Christian Schneider, Reiner Thomä

Technische Universität Ilmenau, Germany

Integrated Sensing and Communication (ISAC) comprises detection and analysis of non-cooperative targets by exploiting the resources of the mobile radio system. In this context, micro-Doppler is of great importance for target classification, in order to distinguish objects with local movements. For developing algorithms for target classification, it is necessary to have a large amount of target signatures. Aiming to generate these data, this paper proposes a mathematical model for the micro-Doppler of drone rotating propellers, and validate the proposed model by comparing it to measured micro-Doppler. Results show that the proposed mathematical model can generate micro-Doppler data very similar to those from measurement data.

8307: An Inverse Modelling Framework for SAR Imagery Analysis Built on SARCASTIC v2.0

Michael Woollard, Hugh Griffiths, Matthew Ritchie

University College London, United Kingdom

The analysis and interpretation of SAR imagery is widely recognised to be a challenging problem. The number and nature of non-intuitive effects often complicate human visual analysis, whilst the wide variation of target scattering behaviour over extended operating conditions is well-known to hinder automated processing. In this paper, we demonstrate how the SARCASTIC simulation engine is being extended to support answering analytical questions which would typically require significant input from expert analysts through inverse modelling approaches. This is a critical step towards enabling the exploitation of SAR collections at scale, which will become increasingly important as New Space continues to increase the number of taskable sensors on orbit. A case study examining an unusual urban target is presented, utilising real SAR collection data from an Umbra SAR satellite and matching simulations produced using the SARCASTIC toolset. An example analytical approach is demonstrated, and several opportunities for model-aided exploitation are identified. Preliminary results demonstrate promising correlation between the real and synthetic datasets.

8019: Crossover Analysis for the Radiometric Calibration of Radar Depth Sounder Data Products

Hara Madhav Talasila, John Paden

Center for Remote Sensing and Integrated Systems, University of Kansas, United States

Data from airborne radar depth sounders have been a valuable asset for polar research groups for decades. Due to the lack of absolute radiometric calibration in many of these datasets, data users only have access to relatively calibrated datasets. System and processing variations over time confound radiometric analysis of the data. Radiometric analysis is important to the mapping of basal characteristics such as the presence of liquid water and bed type. To solve the calibration problem, we present a data-dependent calibration solution that depends on natural targets that have known radar scattering characteristics (smooth lake and sea surfaces) and crossovers (intersecting flight paths with an opportunity to link calibration from one flight line to another). Our approach generates a system of linear equations which we can use to estimate the unknown calibration coefficients and use the residuals to provide an error analysis. The crossover analysis uncovered issues with the data products which we address in this work. We also present some interesting waveform properties dependent on crossover parameters such as altitude differences and the angle between the crossing flight paths.

12:50 – 14:10
SAR/ISAR ATR
Room: DENVER BALLROOM 2-1
Session Chairs: Nathan Goodman and Ethan Lin

8095: A Multi-View CNN for SAR ATR

Katherine Banas{2}, Chris Kreucher{1}
{1}KBR Government Solutions, University of Michigan, United States; {2}Radar Applications, Inc., KBR Government Solutions, University of Michigan, United States

This paper describes an approach for exploiting 3D information to improve synthetic aperture radar (SAR) automatic target recognition (ATR) performance. Historically, SAR ATR is performed using a single look, where an individual SAR image formed over a particular azimuth dwell is used as input to a classification algorithm. Recent data collection and processing developments enable techniques which exploit information from multiple looks simultaneously. Using more information from distinct geometries promises to improve algorithm robustness and overall classification performance. Our approach to using this additional information is to adopt techniques for 3D image recognition from the natural image literature and adapt them to the SAR modality. We find SAR ATR performance can be improved substantially using a multi-view network employing a backbone architecture known to perform well on SAR ATR and enhanced with SAR-specific data preprocessing and augmentation.

8034: Augmentation of Maritime SAR Imagery Using Realistic Motion Models

Luke Rosenberg
STELaRLab, Lockheed Martin Australia, Australia

The use of convolutional neural networks (CNNs) for automatic detection and recognition of ships using synthetic aperture radar (SAR) imagery can be challenging as the amount of labelled training data available is often insufficient. Techniques such as transfer learning and data augmentation are therefore required to achieve sufficient classification performance. This paper addresses the latter technique by transforming images of focussed ships into rotated and blurred versions based on realistic motion. Two approaches are demonstrated with motion added to the entire SAR image and then to the dominant scatterers extracted using the CLEAN technique. The technique works on both real and complex data and is demonstrated using data from ICEYE's extended spotlight SAR mode.

8285: A Methodology for Assessing Data Augmentation Effectiveness for Target Classification in SAR Images

Hugo T. Da Silva, Dimas Irion Alves, Renato Machado, Angelo Passaro
Instituto Tecnológico de Aeronáutica, Brazil

This work considers a methodology for evaluating data augmentation effectiveness for target classification in synthetic aperture radar (SAR) images. For the analysis, it is considered a dataset of oil platform SAR medium-resolution images. The training dataset of two classification algorithms, namely logistic regression and neural network, was gradually increased with synthetic SAR images. In some cases, the results revealed rising trends in average accuracy as the number of synthetic images increased. By using 50% synthetic images with the application of the data augmentation technique, we achieved the highest average accuracy of the neural network algorithm, reaching 95%, with a standard deviation of less than 5%.

8241: Target Recognition by Means of 3D ISAR Images

Alberto Lupidi{1}, Elisa Giusti{1}, Sonia Tomei{1}, Selena Ghio{1}, Marco Martorella{2}
{1}RaSS National Laboratory, CNIT, Italy; {2}University of Birmingham, United Kingdom

In this paper we will compare two different target recognition algorithms based on the exploitation of 3D Interferometric ISAR (InISAR) in a maritime environment. The first algorithm uses a model-based approach benefiting of a 3D CAD database, while the other uses a silhouette-based approach based on 2D shapes of the target model. This goes beyond the simple classification of the general type of target, going deeper into the recognition of targets among the same type of class (a database of ships). Real data acquired during two measurement campaigns with a swarm of drones and a system emulating a shipborne platform will be used. The recognition outcome of the two methodologies will be compared to provide their strength and limitations.

14:10 – 15:20
Coffee Break
Room: COLORADO A-E

14:10 – 15:20
Poster Session 4: Classification and Recognition
Room: DENVER BALLROOM 5-6
Session Chair: Braham Himed

8039: Class Ambiguity Regularized Adversarial Domain Adaptation for Cross-Resolution SAR ATR

Yuchun Lu, Jifang Pei, Yi Liu, Yin Zhang, Weibo Huo, Yulin Huang, Jianyu Yang, Jianqi Wu
University of Electronic Science and Technology of China, China

Automatic target recognition (ATR) plays a critical role in synthetic aperture radar (SAR) applications. However, existing SAR ATR methods usually assume that the training and test SAR samples have the same imaging resolution but it is hard to satisfy in practice due to the complexity of the SAR imaging process, which results in the discrepancy between different resolution domains and degrades the performance of ATR method. To this end, we propose a class ambiguity regularized adversarial domain adaptation method for cross-resolution SAR ATR. First, the feature extractor and domain discriminator are designed with the idea of adversarial learning to eliminate the domain discrepancy. Then, the classifier is used to learn the class information of labeled SAR images, enabling the accurate identification on the labeled domain before adapted to unlabeled target domain. Finally, the class ambiguity regularization is introduced to minimize recognition error over unlabeled resolution domain. Extensive experimental results based on the moving and stationary target acquisition and recognition (MSTAR) dataset have shown the superiority of the proposed method on cross-resolution SAR ATR.

8078: Intra-Pulse Modulation Recognition Method of Radar Signals Based on GFSE-InRes2Net Under Multipath Effects

Yang Luo, Yujie Zhang, Weibo Huo, Jifang Pei, Yin Zhang, Yulin Huang, Caiyu Liang
University of Electronic Science and Technology of China, China

In modern complex electromagnetic environments, the received radar signals are often affected by multipath effects. The distortion and noise of the multipath signals make it difficult to recognize the intra-pulse modulation of radar signals. To address this issue, a gram angular field-fusion Inception-Res2Net with squeeze-and-excitation (GFSE-InRes2Net) is proposed. Firstly, in addition to the conventional input of time-frequency domain, gram angular field (GAF) is utilized to convert the multipath radar signals into the polar coordinate domain. This allows for the extraction of additional information regarding the multipath signals, such as angle and phase. Then, within the Inception serving as a multi-scale feature extraction module, the Res2 basic block is employed in lieu of traditional convolution operations, allowing for the representation of features at a granular level. Finally, the squeeze-and-excitation (SE) block is used to weight feature channels, which mitigate the impact of multipath features. The comparison and ablation experiments demonstrate the effectiveness of the proposed method.

8128: Multi-Stroke Air-Writing Recognition Using Temporal-Spatial Interferometric MIMO Radar

Hengfeng Liu{1}, Xiangrong Wang{1}, Moeness G. Amin{2}, Victor Chen{3}
{1}Beihang University, China; {2}Center for Advanced Communications, Villanova University, United States; {3}VCC R&D Consultants, United States

This paper proposes a novel temporal-spatial interferometric Multiple-Input Multiple-Output (MIMO) radar for tracking multi-stroke air-writing trajectories. Accurate trajectory tracking mandates high-resolution positioning of the target in both distance and azimuth. To avoid demands on the radar bandwidth and array aperture, we propose a temporal and spatial interferometry approach to estimate the distance and azimuth displacements, respectively. Additionally, the elevation displacement is exploited to distinguish the alphanumerical trajectory from artifacts, which arises due to the continuous motion articulation in the air-writing. This is achieved by utilizing the subtle elevation change induced by hand lifts among different strokes. Experimental results validate the effectiveness of the proposed multi-stroke air-writing trajectory tracking using temporal-spatial interferometric MIMO radar. The proposed method offers a promising solution for accurate and efficient multi-stroke air-writing recognition. Multi-stoke writing underlies many alphabets, and is dominant in the Arabic language.

8144: Radar Usage-System Joint Inference Based on Gray Correlation Fusion and Hierarchical Confidence

Kejia Guo{2}, Ruiyang Li{1}, Yujie Zhang{2}, Weibo Huo{2}, Yin Zhang{2}, Yang Luo{2}, Jifang Pei{2}, Yongchao Zhang{2}

{1}Southwest China Research Institute of Electronic Equipment, China; {2}University of Electronic Science and Technology of China, China

Accurate inference of radar usage and system is of great importance for radar emitter identification and threat level assessment. However, the overlap of various radar signal parameters makes it increasingly difficult to recognize the usage and the system of radar emitters. In this paper, a joint inference method is proposed for radar usage and radar system based on gray correlation fusion (GCF) and hierarchical confidence (HC). Firstly, the similarity degrees between the to-be-tested unknown radar signal and each record of the radar knowledge base are obtained by gray correlation analysis method. Subsequently, the gray correlation similarities are fused using Dempster-Shafer (D-S) evidence theory to obtain the classification result of radar usage. Finally, a hierarchical confidence reasoner is designed to derive the judgment result of radar system. The proposed method leverages the comprehensive support from multiple feature parameters to reduce the sensitivity to individual feature fluctuation. Numerical experimental results demonstrate that the proposed method can perform accurate joint inference of radar usage and system.

8184: FMCW Radar Range Profile and Micro-Doppler Signature Fusion for Improved Traffic Signaling Motion Classification

Bidya Debnath, Iffat Ara Ebu, Sabyasachi Biswas, Ali C. Gurbuz, John E. Ball

Mississippi State University, United States

Human activity recognition plays a crucial role in Advanced Driver-Assisted Systems (ADAS). Recognizing these gestures poses a considerable challenge for autonomous vehicles. This study focuses on leveraging a dataset of traffic signaling motions obtained through mmWave radar, a technology commonly used in the US traffic system. In this paper, we developed a multimodal CNN, considering both data fusion and feature fusion of radar range profiles and μD signatures, and compared the results with Unimodal CNNs on range profile and μD signatures. The findings indicate that the fusion-based CNNs outperform unimodal CNNs based on individual radar range profiles and μD signatures by about 10% and 6.5% respectively. The accuracy achieved through multimodal CNNs reached around 92% and 96% for data-level and feature-level fusion respectively, showcasing the effectiveness of combining information from both modalities in enhancing human gesture recognition in traffic-directing scenarios.

8195: Deinterleaving Pulse Trains via RPMA-TConv for Parameter-Agile Radar

Caiyu Liang, Han Tang, Weibo Huo, Yin Zhang, Jifang Pei, Yulin Huang
University of Electronic Science and Technology of China, China

Radar pulse trains deinterleaving is a challenging task in modern electronic reconnaissance. The RPMA-TConv model based on multi-branch atrous convolution and feature reconstruction is proposed to solve the problem of deinterleaving parameter-agile emitters. The time of arrival (TOA), center frequency (CF) and pulse width (PW) are used to characterize the relative position and variation pattern of pulse trains. Multi-branch atrous convolutions with different receptive fields are applied to extract multi-scale temporal patterns, ensuring a comprehensive representation of agile parameter characteristics. The feature reconstruction module reconstructs the pulse train information through a learnable process and attributes each pulse to the corresponding emitter. The proposed method can correlate multiple modes of pulse trains generated by the same parameter-agile emitter. Compared with the traditional methods, it will not cause the problem of more clusters than emitters. The method performs well in scenarios with parameter overlap and noise. Experimental results based on interleaved parameter-agile pulse trains are provided to demonstrate the effectiveness and robustness of the method.

8224: Comparison Between Wi-Fi-CSI and Radar-Based HAR

Ajaya Dahal{1}, Sabyasachi Biswas{1}, Sevgi Zubeyde Gurbuz{2}, Ali C. Gurbuz{1}
{1}Mississippi State University, United States; {2}University of Alabama, United States

RF sensors in systems centered around humans, such as human-computer interfaces or smart environments, is an emerging field that aims to recognize human motion in real-time. While various RF sensors such as radar, transceivers at various center frequencies and wifi, are used in this area of research, their performance have not been compared under the same scenarios. To address this gap, this study collects datasets using mmWave Radar and Wi-Fi, creates spectrograms, and conducts a side-by-side comparison to assess the efficiency of both systems for the same scenarios. The dataset is obtained using 77 GHz mmWave FMCW TI Radar and a Raspberry Pi 3B+ equipped with Nexmon firmware, and both the datasets and the associated code are made publicly accessible. The findings reveal that the Radar accuracy outperforms the Wi-Fi in terms of a 7-class human activity recognition scenario by 32.7%. These results underscore the superiority of radar technology in the field of Human Activity Recognition (HAR) while also highlighting the potential of Wi-Fi for indoor activity monitoring.

8331: A Dual-Mode Radar Signal Sorting Method Based on Adaptive Density Peak Clustering

Aijiong Yang, Weibo Huo, Gengchen Xu, Yujie Zhang, Yulin Huang, Jifang Pei, Yin Zhang, Yi Liu
University of Electronic Science and Technology of China, China

Radar signal sorting is a key component in electronic support measures (ESM). Adaptive sorting algorithms are a type of method that does not require prior understanding of radar information in the sorting scenario. However, these methods have consistently faced the issue of high runtime costs. To address this problem, in this paper, a dual-mode radar signal sorting method based on density clustering is presented. Adaptive density peak clustering (ADPC) is used as the initial algorithm for sorting and extracting radar information from the sorting results, which is defined as prior knowledge. The prior knowledge is then passed to Gaussian mixture model (GMM) to facilitate a more rapid sorting process. When changes in the radar within the sorting scenario are detected, it switches back to ADPC. This method allows for rapid sorting of stable data while promptly generating new prior knowledge in response to data changes. Numerical experimental results demonstrate that the proposed method achieves high precision in sorting results while using a lower time cost compared with the prevailing sorting methods.

14:10 – 15:20
Poster Session 4: Imaging
Room: DENVER BALLROOM 5-6
Session Chair: Nathan Goodman

8223: A Split SPICE-TV Super-Resolution Method for Scanning Radar

Jiawei Luo, Yongchao Zhang, Tianzhi Sun, Yin Zhang, Weibo Huo, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

Recently, the sparse iterative covariance fitting estimation (SPICE) method has garnered attention for scanning radar super-resolution imaging. While it offers improved azimuth resolution, a notable drawback is its limited efficacy in reconstructing target contours. In this paper, a Split SPICE total variation (Split SPICE-TV) super-resolution method is proposed to address this problem. First, the scanning radar angular super-resolution problem is transformed into a convex optimization problem, leveraging the sparse covariance fitting criterion alongside TV regularization constraint. Then, the split Bregman method is employed to derive a efficient close-form solution for this problem. Furthermore, the proposed Split SPICE-TV method effectively mitigates the computational complexity of traditional SPICE-TV based on CVX and furnishes a closed-form solution, which is beneficial for practical applications. Simulation results validate the superiority of the proposed method.

8116: Super-Resolution Imaging Method for Forward-Looking Scanning Radar Based on Two-Layer Bayesian Model

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

Forward-looking scanning radar imaging is achieved by inversion of the matrix. However, the antenna measurement matrix pathology amplifies the noise of the inversion process, making direct inverse convolution imaging a pathological issue. Therefore, it is necessary to convert this problem into a benign one. A Bayesian model consisting of two layers is utilized to model the forward-looking super-resolution imaging noise and the target. In the first layer, the noise likelihood model is constructed as a normal distribution, while in the second layer, it is constructed as a gamma prior distribution conjugate to the normal distribution. The likelihood model parameters are updated through autonomous iterations, which can effectively fit the actual scenario noise. This approach allows for the recovery of the target scattering coefficients with good beam sharpening ability, even in situations with low signal-to-noise ratios (SNR). Simulation experiments have demonstrated the effectiveness of the proposed method.

8148: Online Angular Super-Resolution with Total Variation Regularization for Airborne Scanning Radar

Xian Zhao, Deqing Mao, Wenjing Wang, Yongchao Zhang, Yin Zhang, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

Total variation (TV) regularization method has been used in forward imaging of airborne scanning radar. However, the traditional regularization method usually adopts batch processing, which needs to wait for all the echoes to be updated successively and then process line by line, which results in high computational complexity and insufficient real-time performance. To solve this problem, an improved TV regularization method is proposed for online real aperture radar super-resolution. By using the correlation between adjacent echoes, the matrix inversion operation is transformed into the iterative operation of matrix multiplication, and the real-time scanning echoes are used to effectively update the reconstruction results online, and the real-time online update of the target in the forward view area is realized. Compared with the traditional batch processing method, the proposed method significantly reduces the computational complexity without losing the imaging performance, saves the computing time, and is suitable for the fast imaging of scanning radar.

8151: Superresolution Imaging for Real Aperture Radar by Two-Dimensional GP-SOONE Method

Jianan Yan, Yongchao Zhang, Ping Zhang, Wenjing Wang, Jianyu Yang, Yin Zhang, Haiguang Yang
University of Electronic Science and Technology of China, China

Ground-to-air real aperture scanning radar receives range-azimuth-pitch three-dimensional echoes by antenna scanning. However, the angular resolution of real aperture radar, including pitch and azimuth directions, is limited by its aperture size. In this paper, a robust 2D-gradient projection (GP)-sequential order one negative exponential (SOONE) superresolution imaging algorithm is proposed to enhance the 2D angular resolution. First, the echo signal model of the scanning radar is established. Second, a SOONE function is extended as a 2D case to describe the sparse properties of the targets, and the 2D angular superresolution problem is transformed into a constrained optimization problem. Finally, the GP method is adopted to solve the constrained optimization problem, and we use the regularization strategy to enhance the robustness of the algorithm. Our proposed algorithm is competitive with the existing algorithms in terms of discrimination capability and computational efficiency. The effectiveness of the algorithm is verified by comparing with the simulations of other superresolution algorithms.

8171: Millimeter Wave Radar Azimuth Super-Resolution Method Based on Multi-Frame Reconstruction

Shuaidi Liu, Yongchao Zhang, Zhenyu Sun, Deqing Mao, Yulin Huang, Jianyu Yang
University of Electronic Science and Technology of China, China

Aiming at the problem of low azimuth resolution in traditional millimeter wave radar real-beam imagery, an azimuth super-resolution method based on multi-frame reconstruction is proposed. First, utilizing complementary information between multiple frames, the convex set constraint is constructed by the projection onto convex set (POCS) method. Then, projection correction is performed on high-resolution echo data estimation using azimuth residuals and other constraints between multiple frames, ultimately achieving azimuth super-resolution imaging. On the basis of existing single-frame super-resolution methods, this method fully utilizes the complementary information in multi-frame echo data, and can achieve higher azimuth resolution. We use a real-data set to verify the effectiveness of the proposed method.

14:10 – 15:20
Poster Session 4: Passive and Distributed Radar
Room: DENVER BALLROOM 5-6
Session Chair: Diego Cristallini

8061: Remote Oscillator Characterisation Method for Netted Radar Systems

Ferran Valdes Crespi{2}, Santiago Pérez Pérez{1}, Matthias Weiß{1}, Peter Knott{1}
{1}Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany; {2}Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR / RWTH Aachen, Germany

A method to characterise a remote local oscillator from a radar transmitter of choice is described. It is achieved by sampling with an USRP a transmitted signal at selected time intervals. With the intention to save processing resources, after a first coarse estimation of the transmitted signal periodicity, recursively smaller sampling windows at selected time intervals are used. The developed algorithm updates a selection window and choses within the sampled period the most likely time of arrival, with a comparison to the previous measurements. The proposed method saves processing time while allowing a real-time oscillator characterisation to be remotely carried-out. Sampling occurs at selected time intervals and allows to interleave the characterisation function with other radar modes of operation. At the expense of a lower oscillator characterisation accuracy when compared to characterise the remote oscillator with laboratory equipment, the source remote oscillator may be characterised within a shorter period of time after n successful measurement.

8245: Cost-Efficiency Analysis of Distributed Radar Coverage

Thomas Thoresen{2}, Hans Jonas Fossum Moen{2}, Alexander Wold{2}, Idar Norheim-Næss{1}
{1}Norwegian Defence Research Establishment, Norway; {2}University of Oslo, Norway

Research in distributed radar systems has gained a lot of traction over the last two decades. There are many benefits using distributed radar systems, like the increase in detection coverage or filling gaps in a surveillance area. However, no research paper has explicitly analyzed the scalability of distributed radar coverage and its direct impact on radar system design. First, the paper derives analytical bounds on how the gain in distributed radar coverage scales in terms of range, area, and volume compared to a single radar case. Then, a numerical calculation example is used to analyze the cost efficiency of various distributed radar configurations. The cost efficiency analysis compares different prices of power amplifiers as the primary driver for unit cost. The analysis compares system cost and gain in coverage for the different distributed radar configurations. In the numerical calculation example, it is demonstrated that a distributed radar system with 15 W output power has the potential to increase the coverage by 3.8 times in range, 2.3 times in area and 1.5 times in volume compared to the 100 W single case radar of similar cost.

8322: Radar Network Optimization Under Communication Cost Constraint

Yanhao Wang, Lei Wang, Yimin Liu
Tsinghua University, China

We consider the network optimization problem of target localization in a distributed MIMO radar system under communication cost constraint. Limited by the communication cost, it is impossible to combine all the radar nodes in the network for signal-level data fusion. However, performing full parameter-level data fusion leads to significant localization performance degradation. We group the radar nodes into clusters to perform joint signal-level and parameter-level data fusion. Within a cluster, the radar nodes send received signals to the sub-FCs for signal-level processing. Then the localization results from each cluster are sent to a FC to perform parameter-level data fusion. The aim is to find an optimal networking topology, that satisfies the constraints of communication cost while maximizing the localization accuracy of the radar network. A greedy algorithm with shrinkage constraint is proposed to obtain an approximate optimal solution of the network topology. Simulation results show that the proposed joint signal-level and parameter-level data fusion scheme provides better localization performance than pure signal-level fusion.

8329: Phase Center Agile Array: A New Bistatic Radar Scheme for Encrypted Sensing

Ziheng Zheng, Lei Wang, Yihan Su, Yimin Liu
Tsinghua University, China

Bistatic radar has received much interest due to its advantages over monostatic radar such as capabilities of anti-stealth and anti-jamming. In conventional bistatic radar systems, by using the direct signal from the transmit station as reference, any receiver is able to perform radar functionalities such as detection and estimation. However, in some situations where dedicated transmitter is used such as military application, it is unacceptable for the transmitted signal to be utilized by enemy receivers. In this paper, we propose Phase Center Agile Array: a physical layer encryption scheme for bistatic radars and corresponding target detection method so that the signal from the transmitter can only be utilized by the desired receivers. The effectiveness and the properties of the encryption scheme are demonstrated via simulation results.

8244: Parameter Estimation Method for LFM Direct Wave Signals Under Multi-Domain Aliasing Condition with Passive Radar

Jiangyun Deng, Zhi Sun, Haonan Zhang, Xiaolong Li, Guolong Cui, Xiaobo Yang
University of Electronic Science and Technology of China, China

Accurate parameter estimation of external radiation source signal is the premise of effective detection for passive radar. However, due to the increasingly complex electromagnetic environment, the multi-domain aliasing situation may appear for the received LFM direct wave signals, making the parameter estimation performance degradation. To solve the above problems, this paper proposes an aliasing removal algorithm based on analytic signal construction-blind source separation (ASC-BSS). Specifically, the analytical expression for the aliasing direct wave signals at different Fractional Fourier transform (FrFT) orders are derived at first. Then, the ASC is applied to construct the pseudo-channel signal and then the BSS is utilized to realize aliasing removal in FrFT domain. Finally, the pulse modulated parameters (including pulse width, center frequency and frequency modulation rate) can be estimated. Simulation experiments show that the validity of the proposed method.

8257: Efficient Multi-Target Localization Through Geometric Data Filtering in Passive Multistatic Radar Systems

David Melon Fuksman, Nahuel Almeira, Octavio Cabrera Morrone
Raxar Srl, Argentina

We introduce a novel technique for increasing the efficiency of localization algorithms in multistatic passive radar systems. Our method consists of filtering out data falling out of the space of feasible bistatic range measurements using easy-to-implement geometric constraints. In single-target scenarios, this strategy successfully eliminates faulty measurements without compromising the localization accuracy. In multi-target scenarios, it provides a substantial speedup increasing with the number of targets for our chosen localization algorithm, still without sacrificing localization accuracy. This makes the filtering method particularly advantageous for real-time applications with a high number of simultaneously observed targets.

8012: Simulation of the Longitude Error Due to Signal Propagation in a Passive Emitter Tracking Geolocation Algorithm

Marcello Asciolla{2}, Witold Dyszynski{1}, Francesco Dell'Olio{2}
{1}MetaSensing S.r.l., Italy; {2}Polytechnic University of Bari, Italy

The aim of this study is the simulation of the contribution of the position error due to signal propagation in a geolocation algorithm, which is the estimation of the position of a target in geographic coordinates. The analysis considers an emitter placed on the surface of the Earth and a passive receiver mounted on a satellite in LEO (Low Earth Orbit) which is able to perform AoA (Angle of Arrival) measurements. The adopted approach involves the analysis of the origin of the position errors through the study of the relative geometry between the satellite and the target, considering both their relative movements and the time delay in a single AoA measurement. The focus is on the longitude component of the position error and its numerical simulation and a strategy of error compensation is derived. Two alternative algorithms of simulation are also presented and simulated. Finally, the fitting of simulated data in form of first degree and second degree polynomial models are presented and discussed.

15:20 – 17:00
Multistatic & Distributed
Room: DENVER BALLROOM 4
Session Chairs: Mateusz Malanowski and Matthew Ritchie

8248: Target Shape Reconstruction from Multi-Perspective Shadows in Drone-Borne SAR Systems

Ilaria Nasso{1}, Fabrizio Santi{1}, Debora Pastina{1}, Ali Bekar{2}, Michail Antoniou{2}, Christopher Gilliam{2}
{1}Sapienza Università di Roma, Italy; {2}University of Birmingham, United Kingdom

This paper explores the potentials of multi-perspective shadow features in drone-borne SAR images for the reconstruction of targets' shapes. By exploiting target shadows from multiple viewing angles, a comprehensive understanding of targets' morphology can be obtained. This holds substantial promise in potentially deriving three-dimensional measurements encompassing length, width, and height of the targeted objects. The proposed methodology adopts a decentralized approach, involving the extraction and subsequent combination of information from shadowed areas within individual images. This approach is validated through application to experimental data acquired by means of a 24 GHz INRAS radar-equipped drone-borne SAR system. The outcomes show the capability of diverse illumination angles in capturing distinct characteristics of targets, thereby enabling the extraction of the 3D shapes of man-made objects spanning varying dimensional classes.

8032: Bistatic SAR Flight Demonstration Using Agile Frequency Waveforms to Achieve Orthogonal Sidelobe Axes

John Summerfield, Leif Harcke, Brandon Conder, Eric Steinbach
Sandia National Laboratories, United States

Bistatic synthetic aperture radar (SAR) transfer functions have skewed passband regions when traditional waveforms are used. The impulse responses that correspond to these skewed shapes have sidelobes distributed along sets of nonorthogonal axes. Many SAR applications require orthogonal sidelobe axes. Inscribing a rectangular shape within a skewed passband archives orthogonal axes by sacrificing resolution. Alternatively changing the waveform's frequency from pulse to pulse can manipulate the shape of the passband forcing the axes to be orthogonal. This agile frequency waveform method was proven with a bistatic SAR demonstration using an airborne transmitter and a stationary receiver. The transmitter and receiver had a bistatic angle of 35 degrees between them relative to the image scene. Using standard waveforms, the sidelobe axes were measured to be 74.6 degrees apart. The ideal separation is 90 degrees. Using agile frequency waveforms sidelobe axes were measured to be 88.5 degrees apart.

8272: Adaptive Beamforming Applied to Coherent MIMO Radar-Over-Fiber Systems

Salvatore Maresca{2}, Malik Muhammad Haris Amir{5}, Filippo Scotti{3}, Mirco Scaffardi{3}, Paolo Ghelfi{1}, Antonella Bogoni{4}, Antonio Malacarne{1}

{1}CNIT, Italy; {2}IEIIT, Consiglio Nazionale delle Ricerche, Italy; {3}PNTLab, CNIT, Italy; {4}PNTLab, CNIT, Scuola Superiore Sant'Anna, Italy; {5}Scuola Superiore Sant'Anna, Italy

In this paper, adaptive beamforming (ABF) tech- niques are applied to a coherent multiple-input multiple-output (MIMO) radar-over-fiber (RaoF) network for precise target localization. In the proposed system, a common central unit transmits and receives radio-frequency signals through optical standard single-mode fiber (SSMF) links, to/from remoted radar transmitters and receivers placed along a linear baseline. Electro- optical conversion is achieved through direct modulation of low-cost, power-effective, and high-speed vertical-cavity surface- emitting lasers (VCSELs). Among the available MIMO-ABF techniques, both data- independent and data-dependent approaches are taken into account. In particular, one estimation technique per family is analyzed (i.e., data-independent, data-dependent without array steering vector errors and data-dependent with array steering vector errors), i.e., respectively the least-squares estimator, the Capon and the robust Capon beamforming techniques. The advantages and disadvantages of these techniques are illustrated through their application to experimental X-band data acquired with a MIMO RaoF system in a controlled scenario.

8169: Bandwidth, Carrier Frequency, and Waveform Optimization for Sensing and Communications in a Distributed Radar Network

Batu Chalise{2}, Benjamin Kirk{1}, Kenneth Ranney{1}

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

We propose joint radar and communications bandwidth and carrier frequency allocation (BWCFA), and radar waveform optimization for a distributed radar network. Considering that target related information acquired by all nodes can be equally important for obtaining global performance, maximization of the minimum of the signal-to-clutter and noise ratios (SCNRs) under constraints on minimum range resolution and communications capacity, and the available system bandwidth, is proposed. Considering that each node allocates contiguous and non-overlapping bandwidths for its radar and communications operations and SCNR is a monotonically decreasing function of bandwidth and carrier frequency, and utilizing explicit relations between bandwidth and carrier frequencies, we solve the joint optimization problem in two steps. The radar waveforms are first optimized, and then the resulting objective function is utilized for solving BWCFA with geometric programming. Computer simulations show that the proposed waveform optimization and BWCFA (WO-BWCFA) outperforms random waveform with BWCFA (RW-BWCFA) and waveform optimization with equal bandwidth allocation (WO-EBWA) algorithms.

8271: Distributed PMCW Radar Network in Presence of Phase Noise

Jialun Kou{3}, Marc Bauduin{1}, André Bourdoux{1}, Sofie Pollin{2}

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

In Frequency Modulated Continuous Waveform (FMCW) radar systems, the phase noise from the Phase-Locked Loop (PLL) can increase the noise floor in the range-Doppler map. The adverse effects of phase noise on close targets can be mitigated if the transmitter (Tx) and receiver (Rx) employ the same chirp, a phenomenon known as the range correlation effect. In the context of a multi-static radar network, sharing the chirp between distant radars becomes challenging. Each radar generates its own chirp, leading to uncorrelated phase noise. Consequently, the system performance cannot benefit from the range correlation effect. In this paper, we propose an alternative approach to exploit waveform design for reducing sensitivity to phase noise. Previous studies show that selecting a suitable code sequence for a Phase Modulated Continuous Waveform (PMCW) radar can reduce the impact of uncorrelated phase noise in the range dimension. In this paper, we demonstrate how to leverage this property to exploit both the mono- and multi-static signals of each radar in the network without having to share the carrier frequency signal.

15:20 – 17:00
SAR/ISAR Imaging & Exploitation
Room: DENVER BALLROOM 3
Session Chairs: Faruk Uysal and Marco Martorella

8033: Synthetic Aperture Radar Flight Path Optimization for Resolution and Coverage

Naomi Owens-Fahrner{1}, Scott Altrichter{3}, Margaret Cheney{2}

{1}BAE Systems, Inc., United States; {2}Colorado State University, United States; {3}Northrop Grumman, United States

In Synthetic Aperture Radar (SAR), addressing image resolution and scene coverage involves strategies like frequency and geometric diversity. Increasing system bandwidth for resolution improvement is often constrained by fixed frequency bands. Geometric diversity, achieved by non-straight flight paths and steering radar antennas, is explored for scene coverage. The paper introduces a hybrid SAR mode blending stripmap and spotlight SAR modes. To analyze the resolution-coverage trade-off, a mathematical tool called the Data-Collection Manifold (DCM) is developed. The DCM shapes an objective function guiding optimal flight paths by adjusting heading, pitch, and antenna steering. This approach offers a balance between resolution and coverage, demonstrated through simulations outperforming traditional SAR modes. The study lays the groundwork for flexible flight paths in SAR scenarios.

8193: Design of Convolutional Neural Networks for Classification of Ships from ISAR Images

Saraansh Agarwal{2}, Swetha Sathish{2}, Dyana A{1}, Nethravathi K.A{2}
{1}Electronics and Radar Development Establishment Lab, Defence Research & Development Organisation, India; {2}R.V. College of Engineering, India

Automatic recognition of ships is crucial in military applications for maritime surveillance. Transfer learning with pre-trained CNN using VGG16 model is used for classification of ships from ISAR images. In this work, we design and propose an optimized VGG16 network model with reduced number of layers and number of filters for classification of ships from ISAR images. The model is robust and has led to better convergence with an improved classification performance and simplification of the network. The number of layers are drastically reduced and the number of filters are designed using clustering technique. The design of this simplified architecture is discussed in this paper. The proposed model is compared with VGG16 based model with transfer learning and has shown better performance. The dataset consists of electromagnetically simulated targets at different azimuth and elevation angles. Also, a real time scenario depicting the oscillatory motion was also used to generate ISAR images. The proposed CNN has shown good performance for this scenario as well. This study shows that CNN with reduced number of layers and filters is effective for ship classification from ISAR Images.

8233: Local DEM Compensation for Along-Track SAR Formations

Naomi Petrushevsky, Andrea Monti Guarnieri, Marco Manzoni
Politecnico di Milano, Italy

Along-track formations of small satellites are of great interest for future Synthetic Aperture Radar (SAR) systems since they can image at high resolution over wide swaths. Each sensor operates with reduced pulse-repetition-frequency (PRF), which causes significant azimuth ambiguities. However, these ambiguities can be removed by a well-known multichannel recombination that is effective only if the cross-track (XT) baseline between sensors is kept negligible. This work proposes a post-processing approach to mitigate the residual ambiguities caused by small XT baselines based on the knowledge of the scene's Digital Elevation Model (DEM). The method has been validated with simulated data, considering a realistic distributed scene.

8274: Uncertainty-Aware SAR ATR: Defending Against Adversarial Attacks via Bayesian Neural Networks

Tian Ye{2}, Rajgopal Kannan{1}, Viktor Prasanna{2}, Carl Busart{1}
{1}DEVCOM Army Research Laboratory, United States; {2}University of Southern California, United States

Adversarial attacks have shown the vulnerability of image classifiers based on machine learning in SAR ATR systems. An adversarial attack can fool SAR image classifiers by perturbing the input SAR images. Hence, it is critical to develop robust SAR ATR that can detect possible adversarial attacks and alerts human decision-makers about the attacks. In this paper, we propose an uncertainty-aware SAR ATR based on Bayesian Neural Networks (BNNs). Specifically, we leverage the capability of BNN to perform image classification with quantified uncertainty to measure the confidence for each input SAR image. Based on the uncertainty, our approach alerts when the input SAR image is likely to be adversarial. For adversarial SAR images, we also generate visual explanations to show the concrete regions in the SAR image where the adversarial scatterers may occur. This provides human with the evidence of adversarial attacks and assists them in making further decisions. Experiments on the MSTAR dataset show that our approach can identify over 80% adversarial SAR images with less than 20% false alarms, and our visual explanations can identify up to over 90% scatterers in an adversarial SAR image.

8315: Single-Channel Super-Resolution SAR-GMTI via Atomic Norm Minimization

Bariscan Yonel, Birsen Yazici, Sean Thammakhoune
Rensselaer Polytechnic Institute, United States

Synthetic aperture radar imaging algorithms are designed to image stationary scatterers. A moving target is mis-positioned and results in artifacts in reconstructed images. In this paper, we present a novel approach to ground-moving target imaging (GMTI) using single-channel SAR data based on atomic norm minimization (ANM), which is capable of localizing targets with sub-resolution cell precision. We use ANM to decompose the received SAR data into the echoes received from each scatterer in the scene, which facilitates processing them individually and isolating velocity-related phase variations by cross-correlations across the slow-time samples. We use these estimates for motion compensation and form the SAR image. Motion parameters are then numerically estimated without a pre-specified grid. We demonstrate the off-grid, sub-resolution cell localization capability of our ANM-based method in the SAR-GMTI setting by numerical simulations.

15:20 – 17:00
Machine Learning for Radar Applications
Room: DENVER BALLROOM 2-1
Session Chairs: Kumar Vijay Mishra and Emre Ertin

8145: Multiple Target Recognition Within SAR Scene Achieved Using YOLO and Explanability Investigated Using Gradient-Free Visualisation

Chandana Panati, Simon Wagner, Stefan Brüggenwirth
Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany

Detecting multiple targets of interest within a Synthetic Aperture Radar (SAR) scene is the most commonly addressed problem in Automatic Target Recognition (ATR). Since there are not many SAR scenes with multiple ground targets against a simple background, SAR scenes are first simulated using the SARBake algorithm. Compared to other methods, this paper uses the most popular You Only Look Once (YOLO) method, which is known for its speed and accuracy. The YOLOv3 network with transfer learning is used as a reference, followed by different versions of YOLOv5 (s,m,l) and the YOLOv7. The networks are compared to find the one with the best performance and minimum computation time. The YOLOV5 with the fewest trainable parameters compared to the other models, performs well in terms of Mean Average Precision (mAP) and Recall for multiple ground target detections. In addition, all targets from 10 classes at different locations within the test SAR scene are detected and classified with an Intersection over Union (IoU) and a confidence score greater than 0.80. Later, the predictions made by the YOLOv5s on unseen test scenes are visualised using a gradient-free method called Score-CAM.

8247: Multi-Perspective SAR to 3D Translation Using Generative AI

Michael Newey, James Kuczynski, Rebecca Laher, Michael Chan, Alexandru Vasile
MIT Lincoln Laboratory, United States

This work explores the use of generative adversarial networks (GAN) for multi-look SAR to 3D conversion. We extend 2D-to-2D image translation techniques such as CycleGAN to convert SAR imagery to 3D, taking advantage of existing LiDAR data to provide the 3D information for model training. We use collected X-band radar data from the MITLL ARTB sensor, LiDAR from the MITLL AOSTB sensor and USGS public data in our experiments. We evaluate GAN-based translation performance on large sub-urban scenes as well as on small chips centered on ground vehicles. We evaluate the performance of the algorithms with different number and extents of synthetic aperture radar look angles. Finally, for the case of under- or non-represented cases in training data, we introduce a novel inverted simulation augmentation training-and-test procedure for target classification.

8258: STAP-Informed Neural Network for Radar Moving Target Indicator

Dalton Vega, Michael Newey, David Barrett, Alan Axelrod, Anu Myne, Allan Wollaber
MIT Lincoln Laboratory, United States

As machine learning (ML) approaches advance the state-of-the-art for radar clutter removal, their network architectures leave valuable domain understanding unexploited, and there remains a dearth of radar datasets to train models, compare algorithms, and report progress. We present a neural network architecture that leverages knowledge of radar image formation via locally stenciled IQ input data and custom activation functions to produce Space-Time Adaptive Processing (STAP)-like weights for rapid clutter removal in Ground Moving Target Indicator problems. We also present a training and validation radar dataset to stress-test STAP-based techniques with novel ML approaches. The dataset consists of multichannel data under three clutter conditions, each having over 2000 range-Doppler chips for training and evaluation. This simulated dataset includes variable numbers of injected, moving, point targets with a range of scattering cross sections both inside and outside of an obfuscating, heterogeneous clutter ridge. In general, our knowledge-integrated, convolutional architecture outperforms STAP on all simulated datasets by a significant margin.

8303: Application of Generative Machine Learning for Adaptive Detection with Limited Sample Support

Alexander J. Stringer{3}, Timothy Sharp{2}, Geoffrey Dolinger{3}, Steven Howell{2}, Joseph Karch{2}, Justin Metcalf{1}, Adam Bowersox{2}

{1}Advanced Radar Research Center, University of Oklahoma, United States; {2}US Air Force/AFSC/SW/76 SWEG, United States; {3}US Air Force/AFSC/SW/76 SWEG, OC-ALC, University of Oklahoma, United States

This paper presents a method to directly generate inverse covariance matrices from correlated noise using generative machine learning techniques. This method uses convolution-based neural network structures to both infer correlation characteristics from noise and generate an appropriate inverse covariance matrix. Frobenius distance measurements were used to determine accuracy and consistency of the generated matrices. The goal of this work is to prove out a concept for adaptive filtering in detection with limited support samples. As such, proof of concept testing was performed to determine the feasibility of integrating this method with the well-known GLRT algorithm. The testing demonstrated that the proposed method successfully generated the desired matrices and could be used to improve performance of detection algorithms with limited sample support. However, substantial work remains to improve this approach and determine how well it generalizes.

8281: See Further Than CFAR: A Data-Driven Radar Detector Trained by LiDAR

Ignacio Roldan{2}, Andras Palffy{2}, Julian F. P. Kooij{2}, Dariu M. Gavrila{2}, Francesco Fioranelli{1}, Alexander Yarovoy{1}

{1}Microwave Sensing Signal & Systems MS3 Group, Technische Universiteit Delft, Netherlands; {2}Technische Universiteit Delft, Netherlands

In this paper, we address the limitations of traditional constant false alarm rate (CFAR) target detectors in automotive radars, particularly in complex urban environments with multiple objects that appear as extended targets. We propose a data-driven radar target detector exploiting a highly efficient 2D CNN backbone inspired by the computer vision domain. Our approach is distinguished by a unique cross-sensor supervision pipeline, enabling it to learn exclusively from unlabeled synchronized radar and lidar data, thus eliminating the need for costly manual object annotations. Using a novel large-scale, real-life multi-sensor dataset recorded in various driving scenarios, we demonstrate that the proposed detector generates dense, lidar-like point clouds, achieving a lower Chamfer distance to the reference lidar point clouds than CFAR detectors. Overall, it significantly outperforms CFAR baselines in both detection accuracy and false alarm rate.

17:00 – 17:30
Closing
Room: DENVER BALLROOM 4

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