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2021 IEEE Radar Conference (RadarConf21)

Tutorials

Contents

Tutorials

The 2021 IEEE Radar Conference featured a wide selection of tutorials from distinguished academics and professionals around the globe.

Overview

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MA-4: Convex Optimization for Adaptive Radar	MP-4: Deep Learning for Radar Systems with MATLAB	FA-4: Micro-Doppler Signatures: Principles, Analysis and applications
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Recent Developments in Maritime Radar Detection [MA-1]

Instructors

- Dr. Luke Rosenberg, Defence Science and Technology Group
- Prof. Simon Watts, University College London

Abstract

Traditional maritime radar is based on non-coherent detection, mainly due to the complexities of implementing coherent detectors in sea clutter. Over the past decade, there has been significant new research into the characterization and modelling of sea clutter and how to improve maritime target detection. The use of models has also led to techniques for predicting the performance of many new radar detection schemes. This tutorial will include a comprehensive coverage of new research in three key areas. The first is sea clutter modelling for both monostatic and active bistatic radar systems. The second area looks at a number of detection schemes, which have been proposed for detection of targets in sea clutter. These include both non-coherent techniques based on constant false alarm rate (CFAR) schemes, coherent single and multichannel techniques and approaches based on time-frequency analysis and sparse signal separation. The final part of the tutorial links these two areas by showing how sea clutter models can be used to determine the expected detection performance of both non-coherent and coherent detection schemes.

Instructor Biographies

Prof. Simon Watts graduated from the University of Oxford in 1971, obtained an MSc and DSc from the University of Birmingham in 1972 and 2013, respectively, and a PhD from the CNAA in 1987. He was deputy Scientific Director and Technical Fellow in Thales UK until 2013 and is a Visiting Professor in the department of Electronic and Electrical Engineering at University College London. He joined Thales (then EMI Electronics) in 1967 and since then has worked on a wide range of radar and EW projects, with a particular research interest in maritime radar and sea clutter. He is author and co-author of over 60 journal and conference papers, a book on sea clutter and several patents. He was chair of the international radar conference RADAR-97 in Edinburgh UK. Professor Watts received the IEE JJ Thomson Premium Award in 1987 and the IEE Mountbatten Premium Award in 1991. He has served as an Associate Editor for Radar for the IEEE Transactions AES and is a member of the Editorial Board of IET Radar, Sonar & Navigation. He was appointed MBE in 1996 for services to the UK defense industry and is a Fellow of the Royal Academy of Engineering, Fellow of the IET, Fellow of the IMA and Fellow of the IEEE.

Dr. Luke Rosenberg received the Bachelor of Electrical and Electronic Engineering in 1999, the Masters in Signal and Information Processing in 2001 and the Ph.D. in 2007, all from the University of Adelaide, Australia. In 2016, he completed the Graduate Program in Scientific Leadership at the University of Melbourne, Australia. He is currently a Discipline Lead for Maritime Airborne Radar in the Defence Science and Technology Group, Australia. His work covers the areas of radar image formation, adaptive filtering, detection theory, and radar and clutter modelling. He is an adjunct Associate Professor at the University of Adelaide, and in 2014 spent 12 months at the U.S. Naval Research Laboratory (NRL) working on algorithms for focusing moving scatterers in synthetic aperture radar imagery. Dr. Rosenberg has jointly received the best paper awards at international radar conferences in 2014 and 2015 and has presented a number of tutorials at the IEEE American (national) and international radar conferences. In 2016, he received the prestigious Defence Science and Technology Achievement Award for Science and Engineering Excellence and in 2017, the NRL ARPAD award with colleagues from the NRL, and in 2018, the IEEE AESS Fred Nathanson award for 'Fundamental Experimental and Theoretical Work in Characterizing Radar Sea Clutter'.

Introduction to Airborne Ground-Moving Target Indicator Radar [MA-2]

Instructor

- Dr. Armin Doerry, Sandia National Laboratories

Abstract

Airborne Ground-Moving Target Indicator (GMTI) is a radar mode that detects and discriminates moving ground targets, such as vehicles and dismounts. This is an important Intelligence, Surveillance, and Reconnaissance (ISR) tool particularly for the military and intelligence communities, but also with application in the civilian and government communities. We will discuss the physical concepts, processing, performance, features, and exploitation modes that make GMTI radar work, and be useful. We will focus on the qualitative significance of the relevant mathematics rather than dry derivations, with liberal use of example GMTI data and other processing products to illustrate the concepts discussed.

The presentation will be given as four distinct modules.

1. Introduction and basic GMTI processing, including basic detection theory. We will focus on airborne pulse-Doppler systems. Basic data models will be developed, and several processing algorithms will be illustrated and compared. These include a simple range-Doppler algorithm, as well as keystone processing enhancements. Also included will be Constant False Alarm Rate (CFAR) target detection.
2. GMTI performance prediction and the radar equation. The radar equation for GMTI will be developed and explored in some detail to illustrate how GMTI operating parameters can be traded for performance. Target statistics will be presented for vehicles and dismounts, including Swerling models. Minimum Detectable Velocity (MDV) will be discussed.

3. Clutter mitigation techniques. Multichannel processing algorithms will be discussed like Displaced Phase Center Antenna (DPCA) techniques, Along-Track Interferometry (ATI), and basic Space-Time Adaptive Processing (STAP). Note that this is not a STAP course, but rather focused on the larger system for which STAP may be an optional component.

4. Ancillary topics. Several ancillary topics will be discussed, including, but not limited to, antenna design requirements, geometric effects, micro-Doppler, target tracking, the scope of moving targets, vibrometry, cross-polarization effects, and VideoSAR with shadow detection/tracking.

Instructor Biography

Dr. Armin Doerry is a Distinguished Member of Technical Staff in the ISR Mission Engineering Department of Sandia National Laboratories. He holds a Ph.D. in Electrical Engineering from the University of New Mexico. He has worked in numerous aspects of airborne ISR and other radar systems' analysis, design, and fabrication since 1987, and continues to do so today. He has taught Radar Signal Processing classes (and related topics) as an adjunct professor at the University of New Mexico, and has taught numerous seminars on SAR, GMTI, and other radar topics to government, military, industry, and academic groups.

Introduction to Automotive Radars [MA-3]

Instructor

- Dr. Igal Bilik, ECE Department, Ben Gurion University of the Negev, Israel

Abstract

Autonomous driving is one of the megatrends in the automotive industry, and a majority of car manufacturers are already introducing various levels of autonomy into commercially available vehicles. The main task of the sensing suite in autonomous vehicles is to provide the most reliable and dense information on the vehicular surroundings. Specifically, it is necessary to acquire information on drivable areas on the road and to port all objects above the road level as obstacles to be avoided. Thus, the sensors need to detect, localize, and classify a variety of typical objects, such as vehicles, pedestrians, poles, and guardrails. Comprehensive and accurate information on vehicle surroundings cannot be achieved by any single practical sensor. Therefore, all autonomous vehicles are typically equipped with multiple sensors of multiple modalities: radars, cameras, and lidars. Lidars are expensive and cameras are sensitive to illumination and weather conditions, have to be mounted behind an optically transparent surface, and do not provide direct range and velocity measurements. On the contrary, radars are robust to adverse weather conditions, are insensitive to lighting variations, provide long and accurate range measurements, and can be packaged behind optically nontransparent fascia. The uniqueness of automotive radar scenarios mandates the formulation and derivation of new signal processing approaches beyond classical military radar concepts. The reformulation of vehicular radar tasks, along with new performance requirements,

provides an opportunity to develop innovative signal processing methods. As a result, Automotive Radars is active field of research in both industry and academia.

This Tutorial will first describe active safety and autonomous driving features and associated sensing challenges. Next it will overview technology trends and state advantages of available sensing modalities and describe automotive radar performance requirements. It will discuss propagation phenomena experienced by typical automotive radar and radar concepts that can address them. Next this tutorial will focus on the radar equation and the radar processing chain: range and Doppler measurement estimation, beamforming, detection, range and angle-of-arrival migration, tracking and clustering. Discussing modern automotive radars, the tutorial will describe MIMO radar methods. Finally, the automotive radar applications and advanced topics, such as interference mitigation, and sensor fusion will be discussed.

Instructor Biography

Igal Bilik received B.Sc., M.Sc., and Ph.D. degrees in electrical and computer engineering from the Ben- Gurion University of the Negev, Beer Sheva, Israel, in 1997, 2003, and 2006, respectively. During 2006– 2008, he was a postdoctoral research associate in the Department of Electrical and Computer Engineering at Duke University, Durham, NC. During 2008-2011, he has been an Assistant Professor in the Department of Electrical and Computer Engineering at the University of Massachusetts, Dartmouth. During 2011-2019, he was a Staff Researcher at GM Advanced Technical Center, Israel, leading automotive radar technology development. Between 2019-2020 he was leading Smart Sensing and Vision Group where he led development of the state-of-art automotive sensing technologies: radar, lidar, vision and sensor fusion. Currently, Dr. Bilik is an Associate Professor in the Department of Electrical and Computer Engineering at the Ben Gurion University of the Negev. Dr. Bilik has more than 170 patent inventions, authored more than 60 peer-reviewed academic publications, received the Best Student Paper Awards at IEEE RADAR 2005 and IEEE RADAR 2006 Conferences, Student Paper Award in the 2006 IEEE 24th Convention of Electrical and Electronics Engineers in Israel, and the GM Product Excellence Recognition in 2017.

Convex Optimization for Adaptive Radar [MA-4]

Instructors

- Prof. Vishal Monga, The Pennsylvania State University
- Dr. Muralidhar Rangaswamy, Air Force Research Laboratory

Abstract

The main theme of the tutorial is to motivate, describe and illustrate the application of convex optimization principles for radar signal processing. The scope of the tutorial is to introduce a variety of optimization problems for adaptive radar processing, including disturbance covariance matrix estimation and waveform and receive filter design, encountered by real-world systems under challenging practical constraints. Incorporating the aforementioned constraints into an optimization framework often results in ill-posed problems where no unique solutions are available and no globally optimal solutions are guaranteed. The central thrust of the tutorial is to introduce novel optimization approaches to solve estimation, detection and waveform design problems core to modern radar signal processing that are complicated by a plethora of real-world effects arising from systems and environmental considerations. A key example of a resource constraint in this context is limited number of homogenous training samples for estimating statistics such as disturbance and clutter covariance. Phenomenology based constraints involve understanding and exploiting clutter rank in covariance estimation. On the other hand, hardware limitations force the inclusion of constant modulus constraint in waveform design. The tutorial will extensively employ the theory of convex and non-linear optimization, convex analysis, and approximation to expand on recent exciting progress in convex optimization for radar systems.

The tutorial is organized into three parts. The first part reviews modern radar STAP and motivates the need for algorithmic approaches rooted in constrained convex optimization. The second part focuses on the estimation of disturbance/clutter covariance: incorporating physically inspired constraints. Furthermore, we devote attention to imperfect knowledge of these constraints caused by a plethora of real world effects such as antenna errors, mutual coupling, internal clutter motion, and aircraft crabbing. Ameliorating solutions for these perturbations are also discussed in some detail. The third part delves into waveform optimization problems under constant modulus and similarity constraints. Also studied is waveform design that guarantees desirable beam patterns for MIMO radar and finally, the problem of waveform design under spectral interference constraints. Many new analytical results are introduced based on recently published work: some that generalize and extend known past work, and others that involve new optimization approaches altogether. For each practical radar problem considered, extensive experimental results will be shown illustrating the suitability of aforementioned optimization techniques for real-world conditions.

Instructor Biographies

Prof. Vishal Monga has been on the Electrical Engineering faculty at Penn State since Fall 2009, where he is currently a tenured Professor. From Oct 2005-July 2009 he was an imaging scientist with Xerox Research Labs. He has also been a visiting researcher at Microsoft Research in Redmond, WA and a visiting faculty at the University of Rochester. Prior to that, he received his PhD EE from the department of Electrical and Computer Engineering at the University of Texas, Austin. Prof. Monga's research has been recognized via the US National Science Foundation CAREER award. For his educational efforts, Dr. Monga received the 2016 Joel and Ruth Spira Teaching Excellence award. He has served on the editorial boards of the IEEE Transactions on Image Processing, IEEE Transactions on Circuits and Systems for Video Technology and the IEEE Signal Processing Letters. Dr. Monga is a Senior Member of the IEEE.

Dr. Muralidhar Rangaswamy received the B.E. degree in Electronics Engineering from Bangalore University, Bangalore, India in 1985 and the M.S. and Ph.D. degrees in Electrical Engineering from Syracuse University, Syracuse, NY, in 1992. He is presently employed as the Senior Advisor for Radar Research at the RF Exploitation Branch within the Sensors Directorate of the Air Force Research Laboratory (AFRL). Prior to this he has held industrial and academic appointments. He received the IEEE Warren White Radar Award in 2013, and the 2005 IEEE-AESS Fred Nathanson memorial outstanding young radar engineer award. He was elected as a Fellow of the IEEE in January 2006. Dr. Rangaswamy is a technical editor (Associate Editor-in-Chief) for the IEEE Transactions on Aerospace and Electronic Systems and was the technical program chair for the 2014 IEEE Radar Conference in Cincinnati, OH. Recently, he received the 2019 IEEE Dayton Section Fritz Russ memorial award for his contributions to cognitive radar signal processing, modeling and simulation, and architectures. He also received the 2019 Technical Cooperation Program ISTAR Basic Research Award.

Radar Tracking: A Long-Standing Cooperation Between Industry and Academia [MA-5]

Instructors

- Dr. Alfonso Farina Selex-ES (retired)
- Dr. Giorgio Battistelli, Dipartimento di Ingegneria dell'Informazione, Università di Firenze, Italy
- Dr. Luigi Chisci, Dipartimento di Ingegneria dell'Informazione, Università di Firenze, Italy

Abstract

The tutorial will describe the intertwined R&D activities, along several decades, between academia and industry in conceiving and implementing - on live radar systems - tracking algorithms for targets in civilian as well as defense and security applications.

We trace back from the alpha-beta adaptive filter to modern random set filters passing thru Kalman algorithm (in its many embodiments), Multiple Model filters, Multiple Hypothesis Tracking, Joint Probabilistic Data Association, Particle filter for nonlinear non Gaussian models. Fusion from heterogeneous collocated as well as non-collocated sensor data are also mentioned. Applications to land, naval and airborne sensors are considered. Active as well as passive radar experiences are overviewed. The description will be a balanced look to both mathematical aspects as well as practical implementation issues including mitigation of real life system limitations.

The aim is to show the long experience of fruitful cross-disciplinary cooperation between industry and universities especially in the field of signal and data processing in radar, where the advantage is that learning goes both ways in these relationships! It is shown that refined mathematical algorithms conceived by this cooperation can indeed either influence or even live in real systems. The tutorial will also provide a comprehensive overview of tools and methodologies for the design and evaluation of modern radar tracking systems.

Instructor Biographies

Alfonso Farina (Fellow of EURASIP, FIEEE, FIET, FREng) received the degree in Electronic Engineering from the University of Rome (IT) in 1973. In 1974, he joined Selenia, then Selex ES, where he became Director of the Analysis of Integrated Systems Unit and subsequently Director of Engineering of the Large Business Systems Division. In 2012, he was Senior VP and Chief Technology Officer of the company, reporting directly to the President. From 2013 to 2014, he was senior advisor to the CTO. He retired in October 2014. From 1979 to 1985, he was also professor of "Radar Techniques" at the University of Naples (IT). He is the author of more than 600 peer-reviewed technical publications and of books and monographs (published worldwide), some of them also translated into Russian and Chinese. Some of the most significant awards he's received include: (2004) Leader of the team that won the First Prize of the first edition of the Finmeccanica Award for Innovation Technology, out of more than 330 submitted projects by the Companies of Finmeccanica Group; (2005) International Fellow of the Royal Academy of Engineering, U.K., and the fellowship was presented to him by HRH Prince Philip, the Duke of Edinburgh; (2010) IEEE Dennis J. Picard Medal for Radar Technologies and Applications for "Continuous, Innovative, Theoretical, and Practical Contributions to Radar Systems and Adaptive Signal Processing Techniques"; (2012) Oscar Masi award for the AULOS® "green" radar by the Italian Industrial Research Association (AIRI); (2014) IET Achievement Medal for "Outstanding contributions to radar system design, signal, data and image processing, and data fusion". He is a Visiting Professor at UCL, Dept. of Electronics, and Cranfield University.

Giorgio Battistelli received the degree in electronic engineering and the Ph.D. degree in robotics from the University of Genoa, Genoa, Italy, in 2000 and 2004, respectively. From 2004 to 2006, he was a Research Associate with the Dipartimento di Informatica, Sistemistica e Telematica, University of Genoa. Since 2006 he has been with the University of Florence, Florence, Italy, where he is currently a Full Professor of automatic control with the Dipartimento di Ingegneria dell'Informazione. His current research interests include adaptive and learning systems, real-time control reconfiguration, linear and nonlinear estimation, hybrid systems, sensor networks, data fusion. Dr. Battistelli was a member of the editorial boards of the IFAC Journal Engineering Applications of Artificial Intelligence and of the IEEE Transactions on Neural Networks and Learning Systems. He is currently an Associate Editor of the IFAC Journal Nonlinear Analysis: Hybrid Systems, and a member of the conference editorial boards of IEEE Control Systems Society and the European Control Association.

Luigi Chisci received the degree in electrical engineering in 1984 from the University of Florence and the Ph.D. in systems engineering in 1989 from the University of Bologna. He is full professor at University of Florence. His educational and research career have been in the area of control and systems engineering. His research interests have spanned over: adaptive control and signal processing, algorithms and architectures for real-time control and signal processing, recursive identification, filtering and estimation, predictive control. His current interests concern networked estimation, multitarget multisensor tracking and distributed data fusion. He has coauthored over 180 papers of which about 80 on international journals. His research group has a long-standing collaboration with Alfonso Farina's group at Finmeccanica starting from 1994 on several topics including adaptive signal processing, stochastic filtering, multitarget multisensor tracking and data fusion.

Analytic Combinatorics for Multi-Object Tracking [MA-6]

Instructors

- Roy L. Streit, Metron Inc.
- R. Blair Angle, Metron Inc.
- Dr. Murat Efe, Ankara University

Abstract

Exact solutions of many multitarget tracking problems have high computational complexity and are impractical for all but the smallest of problems. Practical implementations entail approximation. There is a bewildering variety of established trackers available, and practicing engineers and/or researchers often study them almost in isolation of each other without fully understanding what these trackers are about and how they are inter-related. One reason for this is that they have different combinatorial problems which are approached by explicitly enumerating the feasible solutions. The enumeration is usually a highly detailed, hard to understand accounting scheme specific to the filter, and the details cloud understanding the filter and make it hard to compare different filters. On the other hand, the analytic combinatorics approach presented in this tutorial avoids the heavy accounting burden and provides a solid tool to work with, namely the mixed derivative of multivariate calculus, which all engineers easily understand.

This tutorial is designed to facilitate understanding of the classical theory of Analytic Combinatorics (AC) and how to apply it to problems in multi-object tracking. AC is an economical technique for encoding combinatorial problems—without information loss—into the derivatives of a generating function (GF). Exact Bayesian filters derived from the GF avoid the heavy accounting burden required by traditional enumeration methods. Although AC is an established mathematical field, it is not widely known in either the academic engineering community or the practicing data fusion/ tracking community. This tutorial lays the groundwork for understanding the AC method, starting with the GF for the classical Bayes-Markov filter. From this cornerstone, we derive many established filters (e.g., PDA, JPDA, JIPDA, PHD, CPHD, MultiBernoulli, MHT) with simplicity, economy, and insight. We also show how to use the saddle point method (method of stationary phase) to find low complexity approximations of probability distributions and summary statistics.

Instructor Biographies

Roy Streit Senior Scientist, Metron, Reston, Virginia, and Professor (Adjunct) of Electrical and Computer Engineering, University of Massachusetts– Dartmouth. IEEE Fellow. IEEE AESS Board of Governors, 2016-18. President, ISIF, 2012. Research interests include multi-target tracking, multi- sensor data fusion, medical imaging, signal processing, pharmacovigilance, and business analytics. Author, Poisson Point Processes, Springer, 2010 (Chinese translation, Science Press, 2013). Co-author, Bayesian Multiple Target Tracking, 2nd Edition, Artech, 2014. Seven US patents. He is the co-author of the book entitled Analytic Combinatorics for Multiple Object Tracking, Springer, scheduled to be published in December 2020.

Blair Angle is a senior research scientist at Metron, Inc. Since joining Metron in 2008, he has worked as the technical lead on a variety of projects involving mathematical and statistical modeling, machine learning, tracking, simulation, signal processing, and software development. During his tenure at Metron, he has written or co-written several proposals for DARPA, ONR, etc. which have led to new Metron funding and research. His current research involves multiple-object tracking, with a focus on applying analytic combinatorial (AC) methods to data association problems. Along with Dr. Roy Streit, he recently developed and implemented a working version of the Multisensor JiFi (JPDA intensity Filter), a multisensor, multiobject tracking filter for extended objects. He is the co-author of the book entitled Analytic Combinatorics for Multiple Object Tracking, Springer, scheduled to be published in December 2020.

Murat Efe is a full Professor and Head of the Electrical and Electronics Engineering Department at Ankara University. He has publisher numerous papers in refereed journals, conferences, and seminars on target tracking/data fusion. He is an Associate Editor for IEEE Transactions on Aerospace and Electronic Systems and was one of the lecturers for the NATO-CSO Lecture Series entitled “Radar and SAR Systems for Airborne and Space-based Surveillance and Reconnaissance” between 2013-2017 where a total of 13 countries, namely Italy, UK, France, Spain, Germany, Romania, US, Canada, Portugal, Lithuania, Bulgaria, Poland and Australia were visited for these lectures. Dr. Efe is a technical consultant to a number of defense companies on tracking and fusion related projects. Also, he served on the executive board of the Electrical, Electronics and Informatics Research Group of the Scientific and Technological Research Council of Turkey. Dr. Efe has been an elected member of Board of Directors of ISIF since 2014 where his term ends in 2023. He is the co-author of the book entitled Analytic Combinatorics for Multiple Object Tracking, Springer, scheduled to be published in December 2020.

Passive Radar – From Target Detection to Imaging [MP-1]

Instructors

- Dr. Mateusz Malanowski, Warsaw University of Technology
- Dr. Piotr Samczyński, Warsaw University of Technology
- Dr. Krzysztof Kulpa, Warsaw University of Technology

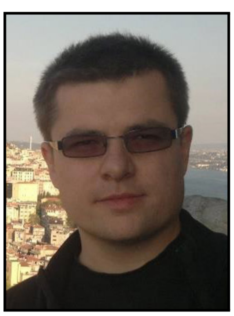
Abstract

The topic of the tutorial is multistatic passive radar for target detection and imaging. In the first part of the tutorial the basics of passive radar will be presented. These include a review of possible illuminators of opportunity (e.g. FM radio, digital television, cellular telephony), and features of different signals from the point of view or radar detection. The bi/multi-static geometry will be presented, and passive radar equation will be analyzed.

The second part will be focused on detection and tracking of airborne targets using passive radar. A typical signal processing chain, consisting of clutter filtering, crossambiguity function calculation, detection, bistatic tracking and Cartesian tracking, will be described. Selected results and applications will be shown. The third part will be devoted to target imaging using passive radar. This will be focused on ISAR (Inverse Synthetic Aperture Radar) mode, where images of targets are created.

The last part of the tutorial will outline possible future applications of passive radar. These include passive radar on moving platforms, e.g. airborne or seaborne. Terrain mapping in the SAR (Synthetic Aperture Radar) mode will be presented as one of the possible applications of passive radar on a moving platform. At the end, the concept of Deployable Multiband Passive/Active Radar will be presented, in which a combination of active and passive radars is used.

Instructor Biographies



Prof. Mateusz Malanowski received his M.Sc., Ph.D. and D.Sc. degrees in Electrical Engineering from the Warsaw University of Technology, Warsaw, Poland, in 2004, 2009 and 2013 respectively. He was a Research Scientist with FGAN (Forschungsgesellschaft fuer Angewandte Naturwissenschaften), Germany, and an Engineer with Orpal, Poland. Currently, he is an Associate Professor at the Warsaw University of Technology. Prof. Malanowski is the author/coauthor of over 180 scientific papers. He is also an author of “Signal Processing for Passive Bistatic Radar” book, published by Artech House. His research interests are radar signal processing, target tracking, passive coherent location, synthetic aperture radar and noise radar. For the last 14 years he has been involved in numerous national and international projects, focusing on passive radar, synthetic aperture radar and noise radar. He has been a member of several NATO Science and Technology Organization groups. Prof. Malanowski is currently managing a project, whose aim is to develop first Polish, and one of the first in the world, operational military (TRL9) passive radar system. Prof. Malanowski is a IEEE Senior Member and a member of Institution of Engineering and Technology (IET) and European Microwave Association (EuMA).

Prof. Piotr Samczynski received his B.Sc. and M.Sc. degrees in electronics and Ph.D. and D.Sc. degrees in telecommunications, all from the Warsaw University of Technology (WUT), Warsaw, Poland in 2004, 2005, 2010 and 2013 respectively. Since 2018, he has been the Associate Professor at the WUT; and since 2014 – a member of the WUT's Faculty of Electronics and Information Technology Council. Prior to this, he was Assistant Profesor at WUT (2018-2010), a research assistant at the Przemyslowy Instytut Telekomunikacji S.A. (PIT S.A.) (2010-2005) and the head of PIT's Radar Signal Processing Department (2010-2009). Prof. Samczynski's research interests are in the areas of radar signal processing, passive radar, synthetic aperture radar and digital signal processing. He is the author of over 200 scientific papers. Prof. Samczynski was involved in several projects for the European Research Agency (EDA), Polish National Centre for Research and Development (NCBiR) and Polish Ministry of Science and Higher Education (MiNSW), including the projects on SAR, ISAR and passive radars. Since 2009 he has been a member of several research task groups under the NATO Science and Technology Organization, where he supports the research work in the fields of radar signal processing, modern passive and active radars architectures and noise radars. Since 2018 he is a Chair of NATO SET-258 research task group (RTG) on Deployable Multiband Passive/Active Radar (DMPAR) deployment and assessment in military scenarios. Prof. Samczynski is an IEEE member since 2003, and IEEE Senior member since 2016. He is a member of IEEE AES, SP, and GRS Societies and since March 2017 Prof. Samczynski is a Chair of the Polish Chapter of the IEEE Signal Processing Society. He received IEEE Fred Nathanson Memorial Award for outstanding contribution to the field of passive radar imaging, including systems design, experimentation and algorithm development in 2017.

Prof. Krzysztof Kulpa received his M. Sc., Ph.D. and D.Sc. degrees from the Warsaw University of Technology (WUT) in 1982, 1987 and 2009 respectively. Since 1990 he is with Institute of Electronic Systems (WUT), working on Radar Technology, including SAR, ISAR, passive and noise radars. Since 2011 he is of Scientific Director of the Defense and Security Research Center at WUT. In 2014 he obtained the title of State Professor. He has had more than 250 published papers, and recently had his book "Signal Processing in Noise Waveform Radar" published by Artech House Publishers. In his professional life he has always combined teaching, theoretical research and applications. He has been involved in several application projects and worked for the Polish radar industry for 15 years.

Advanced Inverse Synthetic Aperture Radar Imaging [MP-2]

Instructor

- Dr. Marco Martorella, University of Pisa and Radar and Surveillance Systems Laboratory

Abstract

Inverse Synthetic Aperture Radar (ISAR) is a technique used for reconstructing radar images of moving targets. Often, modern high-resolution radars implicitly offer the system requirements needed for implementing ISAR imaging. ISAR images can be obtained by means of a signal processing that can be enabled both on and off-line by using dedicated image formation algorithms. Automatic Target Recognition (ATR) systems are often based on the use of radar images because they provide a 2D electromagnetic map of the target reflectivity. Therefore, classification features that contain spatial information can be extracted and used to increase the performance of classifiers. The understanding of ISAR image formation is crucial for optimising ATR systems that are based on such images. This tutorial will start with an introduction of ISAR imaging and will then focus on a number of advanced ISAR techniques and applications, including but not limited to Passive ISAR (P-ISAR), Polarimetric ISAR (Pol-ISAR), Compressed-Sensing-Based ISAR (CS-ISAR) and Three-dimensional ISAR (3D-ISAR).

Instructor Biography

Marco Martorella received his Laurea degree (Bachelor+Masters) in Telecommunication Engineering in 1999 (cum laude) and his PhD in Remote Sensing in 2003, both at the University of Pisa. He is now an Associate Professor at the Department of Information Engineering of the University of Pisa and an external Professor at the University of Cape Town where he lectures within the Masters in Radar and Electronic Defence. Prof. Martorella is also Director of the CNIT's National Radar and Surveillance Systems Laboratory. He is author of more than 200 international journal and conference papers, three books and 17 book chapters. He has presented several tutorials at international radar conferences, has lectured at NATO Lecture Series and organised international journal special issues on radar imaging topics. He is a Fellow of the IEEE, a member of the IET Radar Sonar and Navigation Editorial Board and a member of AFCEA. He is also a member of the IEEE AES Radar Systems Panel, a member of the NATO SET Panel, where he sits as co-chair of the Radio Frequency Technology Focus Group, and a member of the EDA Radar Captech. He has chaired several NATO research activities, including three Research Task Groups, one Exploratory Team and two Specialist Meetings. He has been recipient of the 2008 Italy-Australia Award for young researchers, the 2010 Best Reviewer for the IEEE GRSL, the IEEE 2013 Fred Nathanson Memorial Radar Award, the 2016 Outstanding Information Research Foundation Book publication award for the book Radar Imaging for Maritime Observation and the 2017 NATO Set Panel Excellence Award. He is a co-founder of ECHOES, a radar systems-related spin-off company. His research interests are mainly in the field of radar, with specific focus on radar imaging, multichannel radar and space situational awareness.

Digital Array Radar [MP-3]

Instructors

- Dr. Caleb Fulton, University of Oklahoma
- Kenneth W. O'Haver, Johns Hopkins Applied Physics Laboratory
- Dr. Salvador H. Talisa, Johns Hopkins Applied Physics Laboratory
- Dr. Mark Yeary, University of Oklahoma

Abstract

With continuing advances in RF Integrated Circuits, digital data transport, and digital signal processing technologies, digital arrays are beginning to enter the mainstream of radar system development. Digital arrays offer new capabilities for radar, including large numbers of independent simultaneous receive beams and unprecedented levels of flexibility and re-configurability.

This tutorial will be devoted to the emerging technology of digital phased arrays and their applications to advanced radar systems. The tutorial will include a history of digital phased array development and of work completed on recent testbeds and small-scale demonstrators. It will also help provide the audience with an understanding and awareness of

- Differences between analog and digital architectures for arrays
- The need for, and methods by which to achieve, dynamic range scaling and calibration
- Challenges encountered when performing calibration
- The opportunities, applications and future trends for CSWAP reduction
- Application of dual/arbitrary polarization processing
- The role of digital arrays in weather radar and satellite communications
- Expected benefits from modern and next generation digital-array systems including:
  - Enhanced dynamic range
  - Full MIMO capability
  - Arbitrary, and even ubiquitous, formation of multiple simultaneous receive beams
  - Array scalability and modularity
  - System longevity through standardization
- Current development efforts towards larger-scale demonstrators and testbeds
- The associated beamforming, adaptive algorithms, etc., enabled by these new systems

Instructor Biographies

Dr. Caleb Fulton (S'05-M'11-S'16) received his B.S. and Ph.D. in ECE from Purdue University in West Lafayette, IN, in 2006 and 2011, respectively, and is now an Associate Professor in ECE at the University of Oklahoma's Advanced Radar Research Center in Norman, OK. His work focuses on antenna design, digital phased array calibration and compensation for transceiver errors, calibration for high-quality polarimetric radar measurements, integration of low-complexity transceivers and high-power GaN devices, and advanced digital beamforming design considerations. He is currently involved in a number of digital phased array research and development efforts for a variety of applications. He received the Purdue University Eaton Alumni Award for Design Excellence In 2009 for his work on the Army Digital Array Radar (DAR) Project. He also received the Meritorious Paper Award for a summary of these efforts at the 2010 Government Microcircuit Applications and Critical Technologies Conference. More recently, he received a 2015 DARPA Young Faculty Award for his ongoing digital phased array research. Dr. Fulton is a member of the IEEE Antennas and Propagation, Aerospace and Electronic Systems, and Microwave Theory and Techniques Societies, and serves on the Education Committee of the latter.

Kenneth W. O'Haver is a member of the Principal Professional Staff and Chief Scientist of the Sensor and Communications Systems Branch at The Johns Hopkins University Applied Physics Laboratory. His recent work has focused on digital array technology development for advanced radar and other applications. He has extensive experience on the development of phased array technologies and systems for a variety of applications including radar, electronic warfare, and communications systems. Mr. O'Haver holds a B.S. in Electrical Engineering from Virginia Polytechnic Institute and State University and an M.S. in Electrical Engineering from the Johns Hopkins University. He has authored and co-authored more than 20 articles.

Salvador H. Talisa is a member of the Principal Professional Staff and Chief Scientist of the Radar and Electronic Warfare Systems Development Group at The Johns Hopkins University Applied Physics Laboratory. His recent work is focused on advanced radar systems and technology and digital arrays, including the radar performance impact of distributed receivers and exciters. He has conducted research on microwave magnetic, magneto-optic and microwave superconducting devices and materials at the Westinghouse (later Northrop Grumman) Science and Technology Center in Pittsburgh and was a program and business development manager for radar receiver and exciter technology at Northrop Grumman Electronic Systems. Dr. Talisa is a Life Senior Member of the IEEE and holds a Telecommunications Engineering degree from the Polytechnic University of Catalonia in Barcelona, Spain, and M.Sc. and Ph.D. degrees in (Electrical) Engineering from Brown University. He has authored and co-authored more than 60 articles and was awarded 7 patents.

Dr. Mark Yeary graduated with his Ph.D. in Electrical Engineering from Texas A&M University in 1999. He is a founding member of Advanced Radar Research Center (ARRC) at the University of Oklahoma (OU) in Norman, OK and was named a Hudson-Torchmark Presidential Professor in 2011. His research interests are in the areas of digital signal processing (DSP) as applied to customized DSP systems, and instrumentation for radar systems with an emphasis on hardware prototype development. He has authored or co-authored 250+ conference papers, conference abstracts and journal papers in these areas. From 2003 to 2016, he was heavily involved in the SPY-1A phased array project at the National Weather Radar Testbed (NWRT) in Norman, OK when this radar was operational. He was a performer on the DARPA ACT program with the Rockwell-Collins team, 2013-2017. He is currently a teammate on the ARRC's S-band all-digital mobile phased array radar program known as Horus. Dr. Yeary was General Co-Chair of the 2018 IEEE Radar Conference held in Oklahoma City. He is a licensed Professional Engineer (PE) and IEEE Fellow.

Deep Learning Applications for Radar Systems with MATLAB [MP-4]

Instructors

- Rob Graessle, MathWorks, Inc.
- Rick Gentile, MathWorks, Inc.
- Dr. Honglei Chen, MathWorks, Inc.

Abstract

Modulation identification and target classification are important functions for intelligent RF receivers. These functions have numerous applications in cognitive radar, software-defined radio, and efficient spectrum management. Machine Learning and Deep Learning techniques can be used in these applications to successfully classify radar data.

In this tutorial, we will demonstrate a range of different techniques to:

1. Collect data from off-the-shelf radars and software-defined radios to train and test classifiers
2. Label I/Q data collected from radar hardware
3. Synthesize data to train Deep Learning and Machine Learning networks for a range of radar and wireless communications systems
4. Explore radar signals in the spectral and time-frequency domains
5. Perform pre-processing and feature extraction for machine learning and deep learning applications
6. Input data and features into networks and configure network architectures for the best performance
7. Interface to deep learning networks outside MATLAB

We will use real world examples to demonstrate these techniques including:

1. Radar RCS identification
2. Radar/comms waveform modulation ID
3. Micro-Doppler signatures for target identification (for example, pedestrians, bicycles, aircraft with rotating blades)
4. RF Fingerprinting
5. Anomaly detection for tracking and sensor fusion applications
6. Synthetic Aperture Radar (SAR) Attendees will learn:
7. How to make data set trade-offs between machine learning and deep learning workflows
8. Implement efficient ways to work with 1D and 2D (time-frequency) signals
9. Extract features that can be used to improve classification results
10. Validate designs with over-the-air signals from software-defined radios (SDR) and radars.

A pdf version of the slides, all of the tutorial examples, along with a temporary license, will be provided for attendees to explore the concepts covered in this tutorial.

Instructor Biographies

Rob Graessle is a Senior Applications Engineer at MathWorks focused on wireless communications, radar systems, and software-defined radio. He previously worked for the Air Force Research Laboratory, Sensors Directorate, and holds a B.S. and M.S. from Miami University.

Rick Gentile focuses on Phased Array, Signal Processing, and Sensor Fusion applications at MathWorks. Prior to joining MathWorks, Rick was a Radar Systems Engineer at MITRE and MIT Lincoln Laboratory, where he worked on the development of many large radar systems. Rick also was a DSP Applications Engineer at Analog Devices where he led embedded processor and system level architecture definitions for high performance signal processing systems, including automotive driver assist systems. Rick co-authored the text "Embedded Media Processing". He received a B.S. in Electrical and Computer Engineering from the University of Massachusetts, Amherst and an M.S. in Electrical and Computer Engineering from Northeastern University, where his focus areas of study included Microwave Engineering, Communications and Signal Processing.

Honglei Chen is a Principal Engineer at MathWorks, Inc. where he leads the development of phased array system simulation. He received his Bachelor of Science from Beijing Institute of Technology and his MS and PhD, both in Electrical Engineering, from the University of Massachusetts, Dartmouth.

Efficient Spectral Access for Radar and Communications [MP-5]

Instructors

- Dr. Cenk Sahin, Sensors Directorate, Air Force Research Laboratory
- Dr. Patrick McCormick, Sensors Directorate, Air Force Research Laboratory
- Dr. Justin Metcalf, University of Oklahoma

Abstract

The electromagnetic spectrum (EMS) is a precious resource that connects and protects our societies across the globe. However, the spectrum has become increasingly congested with no end in sight. 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 (DoF): time, frequency, space, coding and polarization. Technologies for efficient radar-communications spectral access can be grouped into two broad categories: co-design and coexistence. Coexistence is where radar and communications systems must share a set band while a co-designed radar/communications system uses a single, flexible RF aperture to time-multiplex or emit dual-function waveforms.

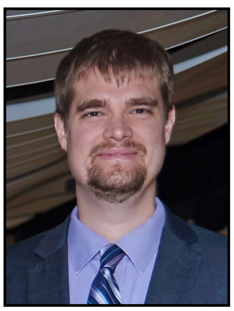
Successful co-existence and co-design of radar and communication systems both rely on fundamental understanding of the design goals, constraints, and performance metrics of both types of systems, which are not related to each other in a mathematically tractable fashion. Therefore, this tutorial will 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. Implications of hardware constraints on these techniques will be illustrated. To narrow the focus radar detection will be the primary radar application.

We hope this tutorial will provide a strong foundation to introduce both experienced and novice practitioners of both radar and communications research into the area of efficient spectrum access. The congested spectrum is our new reality, and future RF engineers will have to understand and operate within this reality.

Instructor Biographies

Dr. Cenk Sahin received his B.S. degree in electrical and computer engineering from the University of Missouri – Kansas City, MO in 2008, and his M.S. and Ph.D. degrees both in electrical engineering, from the University of Kansas, Lawrence, KS, in 2012 and 2015, respectively. He received the Richard K. & Wilma S. Moore PhD Dissertation Award given to the best PhD dissertation in the Department of Electrical Engineering & Computer Science, University of Kansas. For his PhD work he characterized channel coding and latency performance (coding and queueing delay, and achievable data throughput) of various practical modulation schemes over wireless fading channels. In 2016 Cenk Sahin was awarded the prestigious National Research Council (NRC) Postdoctoral Research Fellowship. As an NRC fellow at AFRL (2016-2018) he developed a family of spectrally-efficient constant-modulus radar-embedded communications waveforms. Since 2018 he has been with the RF Technology Branch at the Sensors Directorate, Air Force Research Laboratory, WPAFB, OH where he has been leading the design, development, and testing of spectrum-sharing methods for radar and communications, radar-embedded communication waveforms, and signal processing techniques for dual-function systems. He is the author of 5 journal papers, 6 (1 issued, 5 pending) patents (5 in the area of dual-function system design), 22 peer-reviewed conference papers and 2 book chapters.

Dr. Patrick M. McCormick received his BS in Mechanical Engineering (May 2008), his BS in Electrical Engineering (May 2013) and his Ph.D. in Electrical Engineering from the University of Kansas (May 2018). In August of 2018 he began his current position with the Air Force Research Laboratory (AFRL) Sensors Directorate as a Research Electronics Engineer at Wright-Patterson Air Force Base in Ohio researching dual-function radar and communications co-design. Dr. McCormick has over 40 peer-reviewed publications including 5 journal, 35 conference, and 4 book chapters as well as 4 patents (pending) in the area of waveform design and implementation. He has made significant contributions to radar waveform design, adaptive receive signal processing, and new forms of waveform diversity and radar/communication spectrum sharing. He has either led or supported 18 open-air and 9 benchtop experiments to evaluate new radar emission structures and/or new receive processing schemes. Dr. McCormick has received numerous awards and honors including the 2018 Robert T. Hill Best Dissertation Award; PhD EE with honors in May 2018; University of Kansas Electrical Engineering and Computer Science Department Nominee for Outstanding Doctoral Researcher; 1st Place in the 2018 IEEE Radar Conference Student Paper Competition; and 3rd place in the 2016 IEEE Radar Conference Student Paper Competition.



Dr. Justin Metcalf received his BS in Computer Engineering from Kansas State University in 2006. 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 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 2020 DARPA Young Faculty Award and is a member of the Radar Systems Panel. He has published 47 peer-reviewed publications, including 38 conference papers, 6 journal papers, and 3 book chapters, as well as a patent and 5 pending patent applications 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 11 years.

Virtual RF Environments to Support Advanced Radar Mode Development [FA-1]

Instructors

- Dr. Joseph Guerci, Information Systems Laboratories, Inc.
- Dr. Brian Watson, Information Systems Laboratories, Inc.
- Dr. Sandeep Gogineni, Information Systems Laboratories, Inc.
- Dr. Radu Visina, Information Systems Laboratories, Inc.
- Dr. Hoan Nguyen, Information Systems Laboratories, Inc.

Abstract

In an increasingly crowded spectral environment, radar and RF systems have evolved to adaptively and cooperatively exploit the limited spectrum. Cognitive systems that Sense, Learn, and Adapt (SLA) using conventional processing or by leveraging artificial intelligence are becoming more common. These systems continuously estimate the RF channel and adjust their emissions to extract the most information from the limited available spectrum. It is difficult to predict the behavior of these systems during design and laboratory testing as their behavior depends on the particular RF environment. It is nearly impossible to test RF systems in operational or contested environments whose behavior depends dynamically on the RF spectrum.

Part I of this tutorial is an overview of high-fidelity Modeling and Simulation (M&S) with a focus on particular applications including Cognitive Radar, Deep Learning, and Cognitive Radar Schedulers. M&S is a key enabler of intelligent RF systems. For instance, antagonist tactics (e.g., cell site simulation, jamming, spoofing) are constantly changing. Flight tests are extremely expensive and difficult to schedule and do not accurately replicate contested environments. In the future, engineers will increasingly rely on sophisticated M&S tools for RF system design.

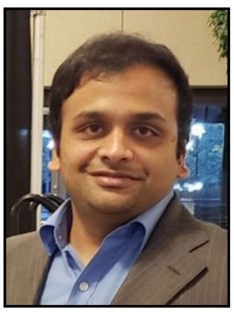
In Part II, high-fidelity M&S techniques are described in detail including the traditional covariance-based modeling of radar clutter channels, Green's function modeling of radar clutter channels, and real-time Hardware-in-the-Loop (HWIL) testing to emulate complex environments for radar and communication systems.

In Part III, four real-world examples of high-fidelity M&S techniques are presented entitled: Urban Tracking, Cognitive Radar, Deep Learning for RF Data, and Cognitive Radar Schedulers. These examples encompass M&S for generation of the expected radar returns for complex environments, the SLA paradigm including channel estimation and optimal waveform design, generation of annotated I&Q training data for deep learning, and the optimal control and management of multiple sensors with multiple modes.

Instructor Biographies

J. R. Guerci has 30 years of experience in advanced technology research and development in government, industrial, and academic settings including the US Defense Advanced Research Projects Agency (DARPA) as Director of the Special Projects Office (SPO) where he led the inception, research, development, execution, and ultimately transition of next generation multidisciplinary defense technologies. In addition to authoring over 100 peer reviewed articles in next generation sensor systems, he is the author of Space-Time Adaptive Processing for Radar, 2nd Ed., and Cognitive Radar: The Knowledge-Aided Fully Adaptive Approach, (Artech House). In 2020 he received the IEEE Dennis J. Picard Medal for contributions to advanced radar technology. He is currently President and CEO of Information Systems Laboratories, Inc.

Brian Watson is the Chief Technology Officer for Information Systems Laboratories with over 25 years of experience. He worked for the Navy and Air Force as an electronics engineer in support of DOD programs including the Tomahawk Weapons System and F-111 aircraft. The topic of his thesis was magnetic and acoustic measurements on low-dimensional magnetic materials. The primary purpose was to understand the quantum mechanical mechanism governing high temperature superconductivity. He designed and built a 9 Tesla nuclear magnetic resonance system that can operate at temperatures near 1 Kelvin. He was the winner of the University of Florida Tom Scott Memorial Award for distinction in experimental physics. Dr. Watson has experience with Labview programming, analog RF electronics design, PCB design and layout, high-speed data acquisition systems, matching networks, and low-noise electronics. Dr. Watson was the PI for ONR and DARPA programs that investigated neural network architectures in collaboration with the Salk Institute and the University of California at San Diego. In that role, he designed asynchronous recurrent neural networks for high-speed parallel data processing. More recently, he has developed deep learning neural networks for SIGINT and ELINT applications. He is the co-author of Non-Line-of-Sight Radar (Artech House).



Sandeep Gogineni is a Research Scientist for Information Systems Laboratories with over 12 years of experience working on radar and wireless communications systems. He has worked for 6 years as an on-site contractor for Air Force Research Laboratory (AFRL), developing novel signal processing algorithms and performance analysis for passive radar systems. He received the IEEE Dayton Section Aerospace and Electronics Systems Society Award for these contributions to passive radar signal processing. Prior to his time at AFRL, during his graduate studies at Washington University in St. Louis, Dr. Gogineni developed optimal waveform design techniques for adaptive MIMO radar systems and demonstrated improved target detection and estimation performance. At ISL, Dr. Gogineni has been working on channel estimation algorithms and optimal probing strategies for MIMO radar systems in the context of Cognitive Fully Adaptive Radar (CoFAR). Additionally, Dr. Gogineni and his colleagues at ISL have demonstrated the feasibility of using neural networks and artificial intelligence techniques to solve extremely challenging radio frequency (RF) sensing problems. His expertise includes statistical signal processing, detection and estimation theory, deep learning, artificial intelligence, performance analysis, and optimization techniques with applications to active and passive RF sensing systems.

Hoan K Nguyen is a Principal Research Scientist at ISL and a principle investigator (PI) and co-PI on several AFRL and NAVAIR-sponsored cognitive radar and cognitive fully adaptive radar (CoFAR) scheduler projects. She has over 15 years of experience providing direct analytic support to multiple three-star flag officers in the U.S. military. Hoan served as a special staff to the Commander, Naval Air Forces, Commanding General, III MEF, Commander, U.S. Third Fleet, U.S. Army Rapid Equipping Force, and the Combined Joint Task Force Paladin. In her roles, Hoan deployed with the staff to Afghanistan, Nepal, and the Philippines, for real world operations and embarked on multiple Naval platforms, such as aircraft carriers, amphibious ships, and MV-22, just to name a few. She also led a wide range of studies to include the development of new training readiness metrics, operational assessment metrics, mishaps analysis, combat power analysis, OPLAN feasibility analysis, and emerging technologies assessments. Dr. Nguyen has published over a dozen peer-reviewed papers and several dozen CNA research papers. Her current research interests include optimization methods, radar scheduling algorithms, and signal processing.

Radu Visina received the PhD in Electrical Engineering from the University of Connecticut in 2019 and has over 15 years of experience in the electrical, systems, and software engineering disciplines. Before pursuing graduate studies, Dr. Visina designed and developed high-performance, high-precision control systems and supporting software for the sensor calibration as well as power systems industries. Passion and curiosity in these fields moved him to academia, where he studied and contributed to systems engineering with a focus on radar target tracking. Dr. Visina has since made significant contributions in the field and maintains expertise in the challenging sub-fields of nonlinear estimation & feedback control, maneuvering/multiple model target tracking, nonlinear information fusion (including track-to-track fusion), Bayesian decision theory, and urban target tracking using non-line-of-sight radar measurement extractions. Dr. Visina's current position at ISL is Technical Lead Research Engineer, developing real-time RF simulation tools and knowledge-aided target tracking techniques.

Deep Learning for Radio Frequency Automatic Target Recognition (ATR) [FA-2]

Instructors

- Dr. Uttam K. Majumder, Air Force Research Lab
- Dr. Erik P. Blasch, Air Force Office of Scientific Research
- Prof. David A. Garren, Naval Postgraduate School

Abstract

The focus of this course will be recent research results, technical challenges, and directions of deep learning (DL) based object classification using radio frequency data (i.e., Synthetic Aperture Radar (SAR) data, RF communication signals data). First, we will present ATR theory from the perspective of robust and reliable performance evaluation. We also discuss RF ATR research in the past (i.e., template-based approach) conducted under DARPA MSTAR (Moving and Stationary Target Acquisition and Recognition) program. Second, we will provide an overview of various machine learning (ML) theories applied to RF data and present important deep learning architectures/models. Third, we will demonstrate implementations and performance analysis (confusion matrix analysis, t-SNE plot, etc.) of DL-based ATR on SAR data. Finally, we will highlight advanced/specialized machine learning techniques such as transfer learning (TL), few-shot learning (FSL), adversarial machine learning (AML), and out of distribution (OOD) /open set problems applied to solving challenging ATR problems. Software/tools to be used include Python/PyTorch, Google colaboratory GPUs, Amazon's Web Service (AWS) cloud computing, and/or TensorFlow. Datasets to be used include AFRL public released MSTAR, CVDome, and SAMPLE datasets, North Eastern University RF signals data, and ship detection datasets. Overall contents of this course will be our recently published (July 2020, Artech House) textbook "Deep Learning for Radar and Communications ATR". We have presentation slides ready for the attendees.

Instructor Biographies

Uttam K. Majumder, Ph.D., is a senior electronics engineer with the Air Force Research Laboratory (AFRL). He earned Ph.D. in electrical engineering from Purdue University, M.S. in electrical engineering from Air Force Institute of Technology, an MBA from Wright State University, and a B.S. in computer science from the City College of New York, CUNY. His research interests include artificial intelligence / machine learning (AI/ML), synthetic aperture radar (SAR) algorithms development for surveillance applications, radar waveforms design, and high performance computing for SAR based automatic target recognition (ATR). Dr. Majumder is a co-author of the book ”Deep Learning for Radar and Communications Automatic Target Recognition”. He is an IEEE AESS Distinguish Lecturer for the research area, “Deep Learning for RF Target Classification”. He delivered SAR Signal and Image Processing and RF ATR tutorials at several IEEE and SPIE conferences, symposiums, invited venues, and academic institutions. Dr. Majumder is a senior member of IEEE.

Erik P. Blasch, Ph.D., is a program officer with the Air Force Research Laboratory. He received his B.S. in Mech. Eng. from the Massachusetts Institute of Technology and Ph.D. in Electrical Eng. from Wright State University in addition to numerous Master’s Degrees in Mech. Eng., Ind. Eng., Elect. Eng., Medicine, Military Studies, Economics, and Business. Additionally, his assignments include Colonel (ret) in the USAF reserves, adjunct associate professor, and president of professional societies. His areas of research include information-fusion performance evaluation, image fusion, and human-machine integration; compiling over 900 papers, 30 patents, and 7 books. He is an Associate Fellow of AIAA, Fellow of SPIE, and Fellow of IEEE.

David A. Garren, Ph.D., has been a Professor in the Electrical and Computer Engineering Department at the Naval Postgraduate School (NPS) since 2012. He received the B.S. degree from Roanoke College in 1986, the Ph.D. degree from William & Mary in 1991, and was awarded an Office of Naval Research (ONR) Postdoctoral Fellowship at the Naval Research Laboratory (NRL) from 1991 through 1993. From 1994 through 2012, he held engineering positions at two Fortune-500 defense companies, which culminated in being awarded the titles of both Technical Fellow and Assistant Vice President. Professor Garren is a co-author of the book Deep Learning for Radar and Communications Automatic Target Recognition and has authored or co-authored 20 refereed journal papers and over 50 conference publications. He holds 7 U.S. Patents and is a Senior Member of the IEEE. In addition, he is an Associate Editor for the IEEE Transactions on Aerospace and Electronic Engineering.

Multi-function Radar Resources Management [FA-3]

Instructor

- Dr. Alexander Charlish, Fraunhofer FKIE

Abstract

Electronically steered array technology combined with the capability to generate diverse waveforms significantly increases the ability of a radar to execute multiple functions. Such multifunction radar systems are capable of executing numerous tasks by multiplexing in time and angle. However, automated management techniques are required as fully controlling the available degrees of freedom is beyond the capability of a human operator. These management techniques are emerging as key performance factors for the next generation of multifunction radar systems. This tutorial introduces the topic of radar resources management. The core components of a radar manager will be described, and it will be shown how the components interact with each other and the radar signal processing. It will be shown how a radar can prioritize specific tasks, optimize the execution of radar tasks and divide constrained resources between tasks. Simulation examples will be used to demonstrate key concepts, such as adaptive tracking. The tutorial will also provide a perspective on how aspects such as cognitive radar, multifunction RF systems, multi-sensor management and machine learning impact on radar resources management.

The tutorial will follow the following schedule:

1. Resources management motivation
2. Review of background knowledge
3. Radar resource management architectures
4. Radar functions
5. Measurement scheduling
6. Task management
7. Priority assignment
8. Related topics

Instructor Biography

Alexander Charlish obtained his M.Eng. degree from the University of Nottingham and received his Ph.D. degree from University College London on the topic of multifunction radar resources management. In 2011, he joined the Sensor Data and Information Fusion (SDF) Department at the Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE), where he now leads the Sensor and Resources Management Group. In this role, he leads a group of scientists conducting research on intelligent sensing with a focus on cognitive radar and resources management for sensor systems. Additionally, he is a visiting lecturer at RWTH Aachen University, where he teaches estimation and detection theory, as well as estimation, information fusion and machine learning. He is currently serving as an Associate Editor for Radar Systems for IEEE Transactions on Aerospace and Electronic Systems, and as Subject Editor for Radar, Sonar and Navigation for IET Electronic Letters. He is an elected member of IEEE AESS Radar Systems Panel and is currently serving as vice-chair of the panel. He is also active in the NATO community, where he currently co-chairs the Cognitive Radar Research Task Group. In 2019, he received the NATO SET Panel Excellence Award, and in 2020, he received the NATO SET Panel Early Career Award.

Micro-Doppler Signatures: Principles, Analysis and Applications [FA-4]

Instructors

- Dr. Carmine Clemente, University of Strathclyde
- Dr. Francesco Fioranelli, Delft University of Technology

Abstract

The micro-Doppler analysis is the study of the time varying Doppler effect from multiple scattering centers with different dynamics. Over the past few years the potentials of micro-Doppler signature analysis has been demonstrated in areas such as enhanced target detection, characterization and tracking. The advantage of micro-Doppler resides in the distinctive Doppler modulations from different targets components that allow unique features to be obtained. These can be the basis of the development of algorithms for automatic target classification, that can increasingly leverage on advances in the field of deep learning. This topic is highly relevant to the conference as micro-Doppler can play a significative role in modern radar systems in both civilian and defense applications. For instance, thanks to the enhancement in computational capabilities, the exploitation of micro-Doppler analysis is possible in a plethora of applications such as condition monitoring, urban surveillance, healthcare, automotive and manufacturing.

Contents Outline:

- Introduction: the introduction to the basic Doppler principle, definition of the micro-Doppler phenomenon, sampling, demodulation and data representation.
- Time-Frequency Analysis: Wide-band and Narrowband Spectrogram, Gabor Uncertainty principle and Energy distributions.
- Canonical Cases- Rigid Bodies: Basic principles of kinematic motion of rigid bodies. Micro-Doppler from vibrating, rotating and helicopters.
- Non-Rigid Bodies: Modelling and simulation approaches, human gait and trotting of a German shepherd.
- Signature Extraction Techniques: Extraction of the micro-Doppler from clutter and from the main body return.
- Algorithms for Feature Extraction for Micro-Doppler Based ATR: Target recognition based on micro-Doppler. Principles of feature extraction and example of features extraction techniques applied to micro-Doppler.
- Advanced emerging applications and techniques: Micro-Doppler for UAV classification, m-D Based ballistic threats discrimination, micro-Doppler in Industry 4.0 and Aggrotech, hand gesture recognition and vital sign monitoring, deep learning approaches for micro-Doppler applications.

Instructor Biographies

Dr. Carmine Clemente is Senior Lecturer and Chancellor's Fellow in Sensors Systems and Asset Management at the Department of Electronic and Electrical Engineering at the University of Strathclyde, Glasgow, UK since 2016. He obtained his PhD in Signal Processing from the University of Strathclyde in 2012. He received the Laurea cum laude (BSc) and Laurea Specialistica cum laude (MSc) degrees in Telecommunications Engineering from Universita' degli Studi del Sannio, Benevento, Italy, in 2006 and 2009, respectively. Dr Clemente research interests lie on advanced radar signal processing algorithms, MIMO radars, passive radar systems and micro-Doppler analysis, extraction and classification. He published over 100 papers in journals and proceedings and he was co-recipient of the best student paper competition at the IEEE Radar conference 2015, and best paper at the Sensor Signal Processing for Defence Conference 2017.

Dr. Francesco Fioranelli is an Assistant Professor at TU Delft, the Netherlands, in the MS3 (Microwave Sensing Signals and Systems) research group. Between April 2016 and October 2019, he was a Lecturer at the School of Engineering, University of Glasgow. He received his Laurea cum laude (BEng) and Laurea Specialistica cum laude (MEng) degrees in telecommunication engineering from the Università Politecnica delle Marche, Ancona, Italy, in 2007 and 2010, respectively. He then obtained his PhD in through-wall radar imaging from Durham University, UK, in February 2014, and was a Research Associate on multistatic radar at University College London with Prof Hugh Griffiths from 2014 to March 2016. Dr Fioranelli has extensive expertise on the development and characterization of multistatic radar systems, and micro-Doppler radar signatures analysis for different applications. He has authored over 85 publications between book chapters, journal, and conferences, edited the recent book on "Micro-Doppler Radar and Its Applications" published by IET-Scitech, and received three best paper awards

Terahertz and Sub-Terahertz Automotive Radar: Emerging Technologies and Challenges [FA-5]

Instructors

1. Dr. Kumar Vijay Mishra, United States Army Research Laboratory
2. Dr. Bhavani Shankar M. R., University of Luxembourg
3. Dr. Marina Gashinova, University of Birmingham
4. Dr. Fatemeh Norouzian, University of Birmingham

Abstract

We are witnessing an autonomy race to get the first fully self-driving car on the road. The radar community has emerged at the forefront of fulfilling the promise of a self-driving car. As the automotive community inches closer to accomplishing this goal, more and newer problems get identified. This cycle is leading to the emergence of new technologies in automotive radar. As a result, current sophisticated automotive radars have much less in common with the radars developed just a few years ago.

In this context, there is a gradual push to sense the automotive environment not only at the millimeter-wave (mmWave) or sub-Terahertz band but also Terahertz (THz) frequencies. The high bandwidths available when using low-THz frequencies make it possible to distinguish between more closely spaced features in the reflected signal. At the same time, waves in this band are not susceptible to complete obscuration by road dirt or precipitation, as infrared and optical systems would be. The mm-Wave and low THz bands also offer opportunities to combine sensing and communications. The joint-sensing-communications approaches do not easily extend to multiple-input multiple-output (MIMO) configurations and novel methods have been introduced in this context.

There has also been a quantum leap in automotive imaging techniques including synthetic aperture radar (SAR) processing for identifying objects from a moving vehicle. Many signal processing algorithms e.g. STAP earlier applied to only conventional radars are now increasingly re-interpreted and adapted for automotive radars. The displaced sensors and sensor-fusion are witnessing new developments in the context of automotive radar imaging. This tutorial will highlight the challenges and opportunities in these new technologies covering the mm-Wave and THz sensing and phenomenology, imaging systems, automotive SAR, interference mitigation, joint radar-communications, and the role of MIMO array processing in automotive radars.

- Part I: Introduction to Automotive THz and Sub-THz Sensing (55 mins)
  - Characteristics of THz and mm-Wave channels
  - THz electronics technology for communications and sensing
  - Radar signal attenuation at low-THz for automotive scenarios
  - Radar cross-section of pedestrians at low-THz
- Part II: THz Automotive Radar (55 mins)
  - Elements of THz radar design and capabilities
  - THz imaging in the context of automotive radar
  - Algorithms for image formation and processing (segmentation and classification)
  - Beamforming for THz imagery (SAR, DBS, phased array)
- Part III: Automotive MIMO Radar and MIMO Communications (55 mins)
  - Fundamentals of mm-Wave MIMO radar and MIMO communications
  - MRMC scenarios and architectures
  - Interference in automotive radar
  - Automotive displaced MIMO sensor imaging
  - STAP processing for automotive applications
- Part IV: Automotive MRMC Co-existence and Co-design (55 mins)
  - Monostatic radar with new MRMC waveforms
  - Bi-static MRMC with new and existing waveforms (PMCW, OFDMA, and 802.11ad)
  - MI-based design of automotive MRMC
  - Communications and radar sensor-fusion
  - Hardware prototype design and evaluation

Instructor Biographies

Dr. Kumar Vijay Mishra obtained Ph.D. in electrical engineering and M.S. in mathematics from The University of Iowa in 2015, and M.S. in electrical engineering from Colorado State University in 2012, while working on NASA's Global Precipitation Mission Ground Validation (GPM-GV) weather radars. He received his B. Tech. summa cum laude (Gold Medal, Honors) in electronics and communication engineering from the National Institute of Technology, Hamirpur (NITH), India in 2003. He is currently National Academies of Sciences, Engineering and Medicine (NASEM) Harry Diamond Distinguished Fellow at United States Army Research Laboratory (ARL), Adelphi; technical adviser to Singapore-based automotive radar start-up Hertzwell; and honorary Research Fellow at SnT - Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg. He is the recipient of the Royal Meteorological Society Quarterly Journal Editor's Prize (2017), Viterbi Postdoctoral Fellowship (2015, 2016), Lady Davis Postdoctoral Fellowship (2017), Technion EE Excellent Undergraduate Adviser Award (2017), DRDO LRDE Scientist of the Year Award (2006), NITH Director's Gold Medal (2003), and NITH Best Student Award (2003). He has been Associate Editor (Radar Systems) of IEEE Transactions on Aerospace and Electronic Systems since 2020. His research interests include signal processing, remote sensing, electromagnetics, communications, and deep learning.

Dr. M. R. Bhavani Shankar received Masters and Ph. D in Electrical Communication Engineering from the Indian Institute of Science, Bangalore in 2000 and 2007 respectively. He was a Post Doc at the ACCESS Linnaeus Centre, Signal Processing Lab, Royal Institute of Technology (KTH), Sweden from 2007 to September 2009. He joined SnT in October 2009 as a Research Associate and is currently a Research Scientist at SnT. He was with Beceem Communications, Bangalore from 2006 to 2007 as a Staff Design Engineer working on Physical Layer algorithms for WiMAX compliant chipsets. He was a visiting student at the Communication Theory Group, ETH Zurich, headed by Prof. Helmut Bölcskei during 2004. Prior to joining Ph. D, he worked on Audio Coding algorithms in Sasken Communications, Bangalore as a Design Engineer from 2000 to 2001. His research interests include Design and Optimization of MIMO Communication Systems, Radar and Array Processing, polynomial signal processing, Satellite communication systems, Resource Allocation, Game Theory, and Fast Algorithms for Structured Matrices. He is currently on the Executive Committee of the IEEE Benelux joint chapter on communications and vehicular technology, member of the EURASIP Special Area Team (SAT) on Theoretical and Methodological Trends in Signal Processing and serves as handling editor for Elsevier Signal Processing. He was a co-recipient of the 2014 Distinguished Contributions to Satellite Communications Award, from the Satellite and Space Communications Technical Committee of the IEEE Communications Society. He has co-organized special sessions in ICASSP (2017, 18), SPAWC (2015, 16) and EUSIPCO (2015, 16).

Prof. Marina Gashinova received an M. Math degree from Saint-Petersburg State University, Saint Petersburg, Russia, in 1991, and a Ph.D. degree in physics and mathematics from Saint-Petersburg Electrotechnical University, Saint Petersburg, Russia, in 2003. In 2006, she joined the Microwave Integrated System Laboratory, University of Birmingham, Birmingham, U.K., as a Research Fellow. She is currently a Professor of Radar and RF Sensors and leads a number of collaborative projects with academic and industrial partners, coordinating research on active and passive radar systems with a particular focus on sensing and imaging for situational awareness of autonomous platforms and sub-THz radar.

Dr. Fatemeh Norouzian received B.Eng from Amirkabir University of Technology, Iran, with First-Class Honours and M.Eng in Electronic and Communication Engineering from the University of Birmingham, UK, in 2008 and 2010, respectively. She was awarded a PhD degree at University of Birmingham in January 2015 for developing a methodology to design high-efficiency power amplifiers for Cognitive Radio Communication systems. Since then she is with the Microwave Integrated Systems Laboratory as a research scientist, working within two main streams of research – short-range automotive sensing and THz sensing. Her principal research interests are in microwave and radar technologies, signal processing, fundamental EM theory, with a current focus on THz radar sensing, automotive sensing, modelling and characterization of signal propagation through diverse media, automotive radar signal processing for simulation of co-existence scenarios of autonomous platforms.

Bistatic and Multistatic Radar Imaging [FA-6]

Instructors

- Dr. Marco Martorella, University of Pisa
- Dr. Brian Rigling, Wright State University

Abstract

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.

Interest in bistatic and multistatic radar systems has been steadily increasing in the recent years, including those that also provide imaging capabilities. A NATO task group, namely the SET-250, on "Multidimensional radar imaging" is currently active that aims at demonstrating increased imaging capabilities of multi-static and multi-channel radar imaging systems. Also, the increased number of multi-bistatic passive radar imaging systems that are under study and development produce extra ground for multistatic radar imaging. The tutorial proposed addresses basics of bistatic and multistatic radar imaging and introduces the current state of the art and research activities in this field. The IEEE Radar conference is the optimal venue for proposing this timely subject.

1. Introduction to bistatic and multistatic radar
   (a) Brief history
   (b) Bistatic and multistatic radar geometry Figures of merit and iso-contours
2. Bistatic Synthetic Aperture Radar
   (a) Bistatic SAR geometry
   (b) Bistatic SAR signal modelling
   (c) Bistatic SAR imaging
   (d) Bistatic scattering phenomenology
3. Multistatic Synthetic Aperture Radar
   (a) Multistatic SAR geometries
   (b) Multistatic SAR imaging
   (c) Three-dimensional imaging
   (d) Challenges to multistatic visualization
4. Bistatic Inverse Synthetic Aperture Radar (B-ISAR)
   (a) B-ISAR geometry
   (b) B-ISAR signal modelling
   (c) Bistatically Equivalent Monostatic Theorem
   (d) B-ISAR image formation
   (e) B-ISAR applications: Emulated B-ISAR, Passive ISAR
5. Multistatic ISAR (M-ISAR)
   (a) M-ISAR geometry
   (b) Coherent vs Incoherent Multistatic ISAR
   (c) Coherent M-ISAR: 3D-InISAR and STAP-ISAR
   (d) Incoherent M-ISAR: Multi-perspective ISAR imaging and Image fusion

Instructor Biographies

Marco Martorella received his Laurea degree (Bachelor+Masters) in Telecommunication Engineering in 1999 (cum laude) and his PhD in Remote Sensing in 2003, both at the University of Pisa. He is now an Associate Professor at the Department of Information Engineering of the University of Pisa and an external Professor at the University of Cape Town where he lectures within the Masters in Radar and Electronic Defence. Prof. Martorella is also Director of the CNIT's National Radar and Surveillance Systems Laboratory. He is author of more than 200 international journal and conference papers, three books and 17 book chapters. He has presented several tutorials at international radar conferences, has lectured at NATO Lecture Series and organised international journal special issues on radar imaging topics. He is a Fellow of the IEEE, a member of the IET Radar Sonar and Navigation Editorial Board and a member of AFCEA. He is also a member of the IEEE AES Radar Systems Panel, a member of the NATO SET Panel, where he sits as co-chair of the Radio Frequency Technology Focus Group, and a member of the EDA Radar Captech. He has chaired several NATO research activities, including three Research Task Groups, one Exploratory Team and two Specialist Meetings. He has been recipient of the 2008 Italy-Australia Award for young researchers, the 2010 Best Reviewer for the IEEE GRSL, the IEEE 2013 Fred Nathanson Memorial Radar Award, the 2016 Outstanding Information Research Foundation Book publication award for the book Radar Imaging for Maritime Observation and the 2017 NATO Set Panel Excellence Award. He is a co-founder of ECHOES, a radar systems-related spin-off company. His research interests are mainly in the field of radar, with specific focus on radar imaging, multichannel radar and space situational awareness.

Brian Rigling received the B.S. degree in physics-computer science from the University of Dayton in 1998 and received the M.S. and Ph.D. degrees in electrical engineering from The Ohio State University in 2000 and 2003, respectively. From 2000 to 2004 he was a radar systems engineer for Northrop Grumman Electronic Systems in Baltimore, Maryland. Since July 2004, Dr. Rigling has been with the Department of Electrical Engineering, Wright State University, and was promoted to associate professor in 2009, professor in 2013, department chair in 2014, and Dean of Engineering & Computer Science in 2018. For 2010, he was employed at Science Applications International Corporation as a Chief Scientist while on leave from Wright State University. He has authored chapters for 4 textbooks and has authored more than 110 conference and journal papers. In 2007, Dr. Rigling authored the chapter on Bistatic Synthetic Aperture Radar for the book Advances in Bistatic Radar, edited by Nicholas Willis and Hugh Griffiths. Dr. Rigling served on the IEEE Radar Systems Panel 2009-2018, and has been an associate editor for IEEE Transactions on Image Processing. He was the General Chair for the 2014 IEEE Radar Conference, was awarded the 2015 IEEE Fred Nathanson Memorial Radar Award, and was elevated to IEEE Fellow in 2018.