Microwave Sensing, Signals and Systems (MS^3)
group

Department of Microelectronics

Faculty of Electrical Engineering, Mathematics and Computer Science

Topics for research MSc projects

Delft - 2020

Note

If you did not find in this booklet a topic that is interesting for you, visit any faculty member of the MS3 group for your interests discussion.

We have much more ideas to research!

Context - Radar is investigated for the classification of human activities and movements, as knowing what activities someone performs, when, where, and how often, can be a powerful indicator of his/her health status, both in terms of physical mobility and cognitive wellbeing.

As for any classification problem, recent techniques developed by the deep learning community are also of great interest to the radar researchers to process the radar data as images (using convolutional networks) or as time series of samples (using some form of recurrent networks).

However, a fundamental issue is that radar data are intrinsically different from optical images, video, audio, or language data. Radar data encode in their pixels and/or samples kinematic information about the targets, their position, their velocity, their bearing. Hence, simply "recycling" networks and algorithms designed for different types of data may not be the winning strategy. The following two MSc projects investigate two interesting outstanding questions out of the many!

Project 1 – ***Good data for free with GANs: too good to be true?***
One of the limitations of using radar data and deep learning for classification is that there are not enough data to train deep and complex neural networks for classification. For example, if we think of human gestures, it is hard to collect experimentally the tens of thousands of samples of different gestures from different people that would be required.

Here is where techniques for data augmentation on radar data, for example transfer learning approaches and *Generative Adversarial Networks (GANs)* can be useful. GANs can be trained to generate synthetic data starting from a small number of experimental data, but are these new data any good? What is the best format of the radar data for this augmentation? And What is the best structure and training approach to have these GANs working well?

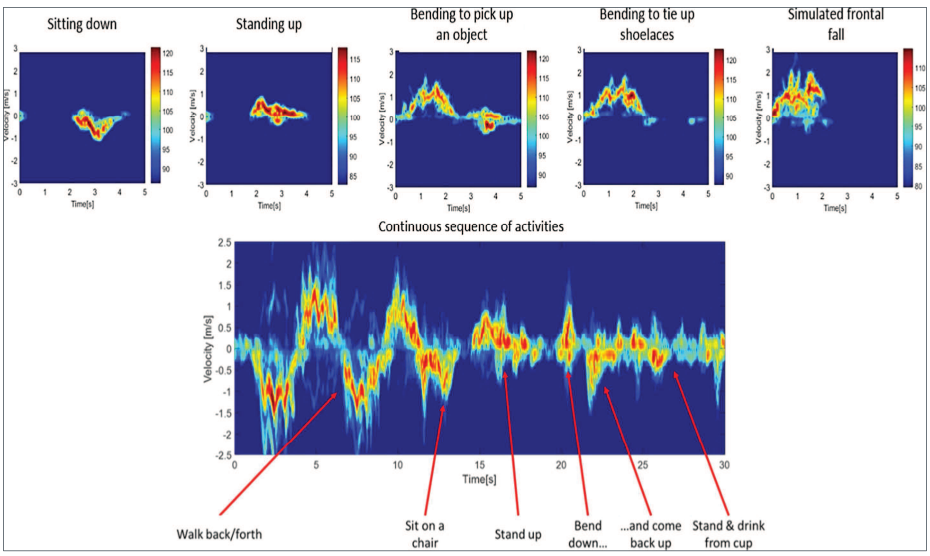
These are some of the research questions to tackle in this project, where we also seek to collaborate with Dr M. Hoogendoorn at VU University Amsterdam, where they investigate GANs for wearables' data.

Project 2 – ***Change of perspective: from images to sequences***
When people move about, they perform activities and movements in a continuous manner: one walks, sits down, stand up, walk somewhere, does something with their hands and so on. Reality is continuous in time and so is the sequence of radar data collected. However, many approaches to analyse radar data for classification take "snapshots" of separate activities (see the spectrograms below).

These are some of the research questions to tackle in this project.

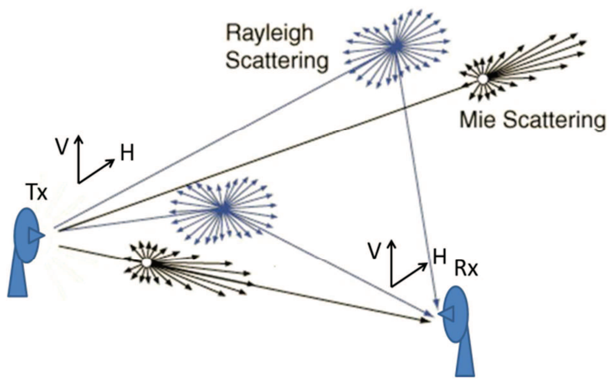
How to process and characterise a continuous sequence of radar data separating and classifying the different activities? Deep learning tools for sequence processing include recurrent neural networks of different kinds (LSTM, GRU), and the recent TCN, but how well do they work with radar data, and is there anything that we can do to make them work better? Is there anything in their architecture or training that we can change to be adapted to radar problems?

Requirements – Radar basics, MATLAB, Python (very desirable), basis of pattern recognition & AI
Contact – Dr Francesco Fioranelli; F.Fioranelli@tudelft.nl; MS3 Group -> http://radar.ewi.tudelft.nl/



Potential benefits of polarimetric Doppler weather radars with the bi-static configuration

The polarimetric capabilities are nova-days widely accepted as "must have" features of the Doppler weather radars. At the same time there are currently an active national and international processes of the development and installation of dense networks of high-resolution meteorological radar network that will improve sensing coverage areas, its space and time-resolution. Currently such networks are developing for the operation as independent monostatic polarimetric Doppler radars with post-processing cross-radar data fusion at the product data level.



From technological and signal processing point of view it is clear that such radar network can produce much more data if radars will be used in bi-static or even multi-static configurations like distributed MIMO sensing system. At the same time it is still not well studied what additional information about cloud and precipitation microphysics can be extracted from bi-static polarimetric Doppler characteristics of sensing signals, how well such characteristics can be measured using classical polarimetric radars architecture. These research topics can be used as initial formulation of the research questions for the MSc research project.

The master thesis project will consist of several parts:

- Bistatic weather radar: possible configurations and related characteristics of bistatic scattering on small water drops (e.g. two horizontally scanning systems within an arbitrary or only forward-scattering sectors, vertical profiler and horizontally scanning systems, etc.)
- Calculation and analysis of the bistatic polarimetric Rayleigh and Mie scattering characteristics of water drops
- Simulation and analysis of polarimetric characteristics for signals that are scattered on ensembles of drops with random sizes
- Simulation and analysis of the relations between precipitation microphysics and traditional polarimetric Doppler weather observables (Zdr, Ldr, Kdp, etc.) in bistatic cases
- Can be proposed any new polarimetric characteristics/observables for the retrieval of precipitation's microphysics and/or meteorological parameters that are based on bi-static radar measurements?

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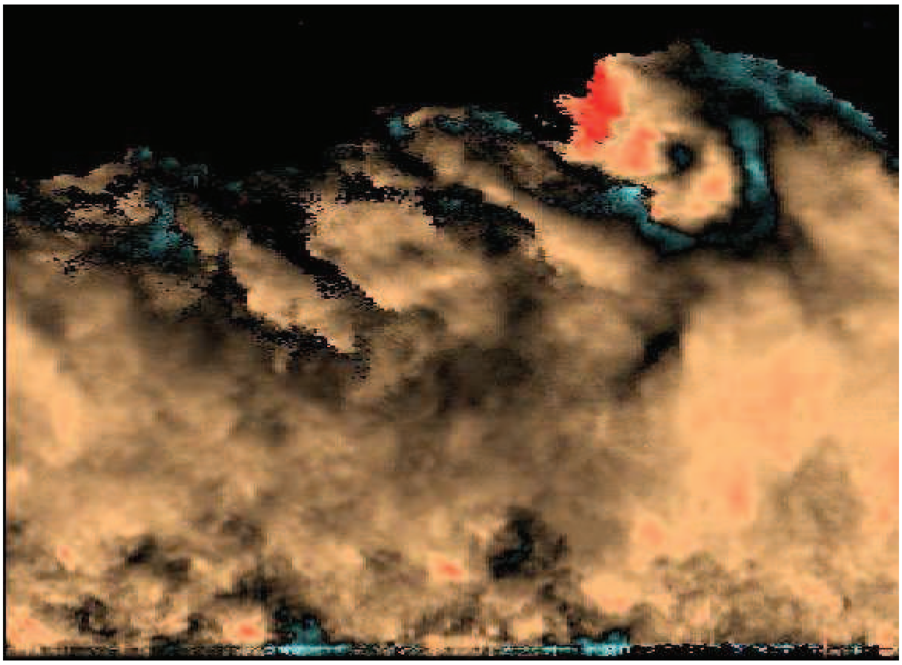

Radar-measured Doppler velocity vertical field above the EEMCS building during a rain event

Classification of Moving Automotive Targets using polarimetric Doppler radar data

Motivation. In many practical applications it is of interest to classify observed objects of interest, also called targets, using features that are measured using a sensor. A typical example is the people classification and identification using video camera sensor. The measured features are compared to features of targets from a database and a decision is made about the class of the observed target.

The MS3 group has a reconfigurable polarimetric Doppler radar, PARSAX, that can observe cars, ships and aircrafts using different sensing modes dynamically. The group is interested in advancing the state of the art in automatic target classification by exploiting modern polarimetric waveforms and sensor management algorithms for selecting the best sensing parameters for observing and classifying targets.

Problem. For one selected specific class of targets (cars on highway) based on database of real polarimetric observations define subclasses with specific meaningful differences (e.g. in targets type, size, operational characteristics or in values or behaviour of observed polarimetric-Doppler variables) and develop algorithm(s) of radar data processing for reliable classification observed target into one of these subclasses.

Project goal. The goal of the project is to identify which target attributes can contribute to its classification and which radar parameters can be controlled in order to achieve better classification results.

This project involves both experimental (and/or simulations) and theoretical aspects. Important aspects of this project are:

- A literature survey on target classification that describes classification algorithms, target features that can be used and how these features are related to radar parameters that can be controlled;
- Data collection and processing for the creation of a database of moving targets' polarimetric-Doppler characteristic. Developed within the previous MSc project software for multiple moving targets tracking and their polarimetric characteristic extraction has to be used for massive dataset processing and extended database creation.
- Study, select most promising, implement and adapt for use with multi-dimensional polarimetric features existing clustering and classification algorithms.
- Apply these clustering/classification algorithms to database and interpret results in terms of most-informative polarimetric features for automotive targets classification
- (optional) Experimental verification of the proposed algorithm using synchronous video-data.
- Report your findings in a MSc thesis

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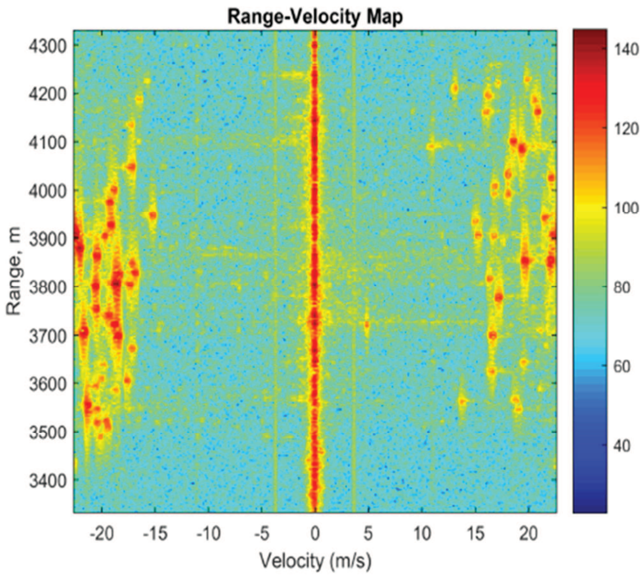
A13 highway



Monopulse angle estimation of range-extended targets

Monopulse radar is widely used to provide accurate angle measurements. In one angular dimension, the monopulse radar transmits energy in a beam and observes the complex returns of a pair of squinted sub-beams steered relatively left and right (for azimuth angle) the expected target location. By comparing the difference and sum of returns from the two beams, an angle of arrival estimation can be formed in one dimension. Monopulse angle estimation provides sub-beam accuracy of the estimation for a single point-like target in a beam, observed at long ranges [1]. However, the estimation accuracy drops significantly when more than one target is observed in the beam, or the target dimension in cross-range is comparable to the cross-range resolution (extended target) [2]. In order to preserve the high accuracy of the angle estimation, the presence of multiple targets in the beam should be declared, and angular estimator has to be modified, taking into account the presence of multiple targets in the beam [3, 4]. These techniques merge information from a few burst with frequency agility to obtain independent realizations of complex targets reflections.

In the high resolution radar mode (sub-meter range resolution), the targets of interest become range-extended. Therefore, target diversity can be gained by merging together information from the adjacent range cells on the target . The fusion of the angle measurements from adjacent range gates on the targets (presented in Fig.1 as formation of histogram), and the decision rule (how many targets are present in the detected range cluster, what is the angular spread of the targets) should be adopted for the high resolution radar settings. The algorithms to be analysed via numerical simulation and real data analysis from automotive radar with sub-meter range resolution (~0.15 m).

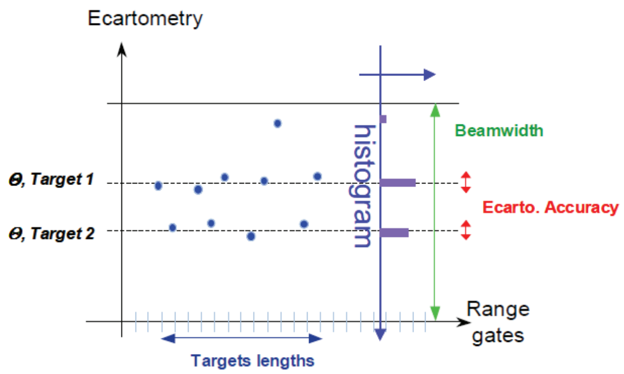


Figure 1. Angle measurments of an extended target

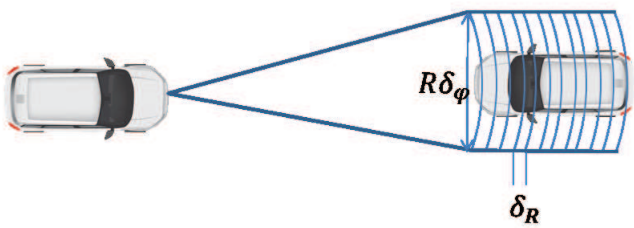


Figure 2. Automotive scenario

The study will include the following sub-tasks:

- Principles of monopulse radars;
- Modelling of extended targets, the effects of the target extend on the angle estimation (glint);
- Simulations of existing techniques for multiple targets detection and angle estimation [3, 4]; performance assessment by numerical simulations;
- Study of the impact of non-ideal antenna characteristics on the detection of target multiplicity;
- Experimental data processing and algorithms verification.

The final report will describe the methodology, description of the proposed/analysed techniques, together with their performance assessment.

References:

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[3] W. D. Blair and M. Brandt-Pearce, “Unresolved rayleigh target detection using monopulse measurements,” IEEE TAES, 1998.
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Dual-polarization multi-frequency radar data processing for moving target detection/tracking/classification

The aim of this project is to develop reliable methods for the cooperative measurements with two operational radars at TU Delft, namely PARSAX and MESEWI. PARSAX is an S-band radar (operating at 3,315 GHz) providing data with up to 1.5 m range resolution and dual-polarization; MEXEWI is an X-band radar (operating at 9,6 GHz) and providing data with up to 0.5 m range resolution and dual-polarization. Currently, these two radars operate independently of each other, while multi-frequency target observation is a strongly desirable tool for many radar applications.

The objective of this study is to develop the procedure for automatic synchronization of radar data in space (2D map) and time (with sub-second accuracy) by observing moving targets of opportunity in the high-resolution mode. Further, techniques for dual-polarization multi-frequency data fusion should be developed, aiming at improved target detection/imaging/tracking/classification by employing polarization and frequency diversity, taking into account mechanical limitations of the systems (two radars have different maximum rotation speed). The developed techniques should be tested on the data records in experimental scenarios.

Figure 1. PARSAX radar (in front) and MESEWI radar (at the back)

The study will include the following sub-tasks:

- Revision of radar data processing, including range/Doppler, polarization, angular processing, targets detection and tracking;
- Data-based compensation for spatial and time difference of the radars;
- Study and development of new techniques for joint target detection/imaging/tracking/classification in multi-frequency radar
- Experimental data processing and algorithms validation.

The final report will describe the methodology, description of the proposed/analyzed techniques, together with their performance assessment.

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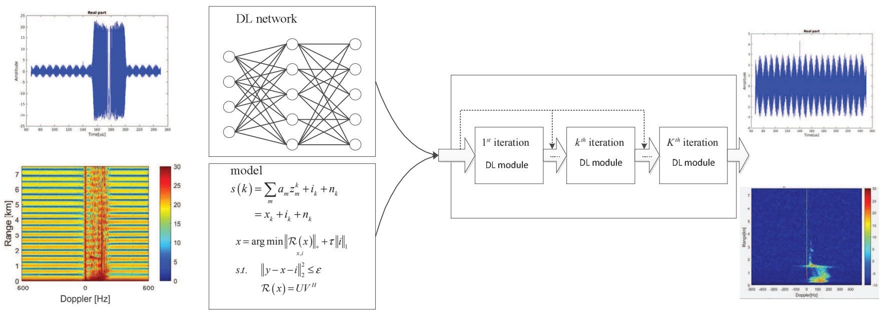
Model-driven Deep Learning for Interference Mitigation in FMCW Radars

Deep learning (DL) is a type of big data-driven approaches and has be extensively used for data regression and classification as well as signal processing. Generally, huge amount of data are required to train a convolutional neural network (CNN) (or its variants) which aims to extract the key features/an adequate representation for a particular application by optimizing a loss function. The CNN is typically treated as a “black box”, which makes it uninterpretable. and its architecture is usually designed and optimized based on the experience or the trial and error approach. The performance of the resultant CNN heavily depends on its architecture, and the quality and quantity of the training data. On the other hand, in traditional signal processing fields, researchers establish numerous models using the “prior” physical principles behind a phenomenon or the domain knowledge of an application. Based on the models, various signal processing algorithms are developed, which then could be easily and conveniently used to process the fed data. However, the performance of the model-based algorithms is largely determined by the fact how faithfully the fed data are generated according to the model utilized for the derivation; otherwise, it leads to the so-called “misspecification degradation”. To address the disadvantages of DL scheme and the model-based methods, a new research direction is the model-driven deep learning, which attempts to improve the interpretability and significantly reduce the volume of the data set need for training by introducing the model.

Model-driven deep learning is a general research topic. In the literature, a few optimization algorithm inspired model-driven deep learning approaches have been reported for inverse problems, for instance, Magnetic Resonance Imaging (MRI) and Computer Tomography (CT) image reconstruction[1][2][3][4]. However, the model-driven deep learning for radar signal processing is almost a void. In this thesis, interference mitigation will be studied by exploring the possible model-driving deep learning approaches. Specifically, autoregressive model or summation of exponential components are used to model the beat frequency of FMCW signals while the interference can be of an arbitrary form[4]. An Alternating Direction Method of Multipliers (ADMM)-based interference mitigation approach has been developed in [4], where multiple hyper-parameters should be selected properly. In principle, by exploring the idea developed in [1]-[4], the ADMM-based interference mitigation approach could be unfolded as a deep neural network and the hyper-parameters involved in each iteration can be optimized through data-assisted training; thus, it results in a model-driven deep learning approach to interference mitigation and improves the performance of the traditional iterative ADMM-based interference mitigation approach. The task of this thesis can be divided as follows.



- Synthesize a dataset for FMCW beat signals with various interferences at different signal to noise ratio with MATLAB.
- Design a proper deep (convolutional) neural network frame inspired by, for instance, ADMM-based interference mitigation approach;
- Implement the deep network in Python, train the network with the synthetic data by using the DL solvers, and tune the network with the real data.
- Test the interference mitigation performance of the deep network with both synthetic data and real data
- Possible extensions of the developed approach to other applications.

Reference

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Enhancing MIMO Array Imaging Quality: Sidelobe and Grating Lobe Suppression via Nonlinear Apodization

Multiple-Input-Multiple-Output (MIMO) array exploits spatial diversity of transmit and receive antennas for high-resolution imaging, which significantly reduces the number of antennas for the array-based imaging systems. Generally, in such systems, at least one sparse antenna array is used as transmitter (or receiver), which would cause grating lobes in the related antenna array radiation pattern. Although the transmit and receive antenna arrays in a MIMO system can be elaborately designed with various array design techniques in attempts to eliminate the grating lobes in the radiation pattern of the corresponding virtual aperture, the achievable sidelobe and grating lobe levels of the resultant MIMO array are not always low enough due to some practical constraints (for instance, number of antennas, cost, space, etc.), especially for short-range applications. The high side/grating lobe level reduces the contrast of a target's impulse response, masks the weak target at the sidelobe region of a strong targets and reduces the dynamic range of the focused image. To suppress the side and grating lobes, amplitude tapering is a widely used technique for antenna array design; however, it would broaden the main lobe of the antenna array radiation pattern and thus decrease the cross-range resolution of the system. On the other hand, Ultra-wideband (UWB) technique can be integrated with MIMO array technique to achieve very low sidelobe/grating lobe level. However, without the motivation for high down-range resolution, the UWB technique may be not an economical solution for side/grating lobe control.

Spatially variant apodization (SVA) is a technique initially proposed for sidelobe control in SAR imagery [1, 2]. It exploits the cosine-on-pedestal functions to suppress the sidelobes of the impulse response of targets but without influence their spatial resolutions. The SVA imposes an adaptive weighting to different targets (i.e., pixels) in space and could completely suppress the unwanted sidelobes. For MIMO array imaging, the wavenumber domain spectrum of each target is also spatially variant. Thus, from this perspective, the SVA could be potentially used to substantially suppress the side/grating lobes for MIMO array imaging. But, different from the SAR imaging with a synthetic (at least quasi-) linear array, the wavenumber spectra resulting from both transmit and receive antenna arrays have to be taken into account. In this thesis, it aims to develop SVA technique for side/grating lobe suppression in MIMO array imaging. The task of this thesis can be described in detail as follows.

(1) Investigate the SVA technique for sidelobe control.
(2) Develop the SVA technique to suppress side/grating lobes for MIMO array imaging.
(3) Implement the SVA technique for MIMO array imaging, and verify and compare its performance with other existing techniques through numerical simulations;
(4) Validate the side/grating lobe suppression performance of the developed SVA with experimental data.
(5) Extend the developed SVA to other possible applications.
(6) Try to prepare a paper to publish the results if possible.

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Reference

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Contactless Vital Signs Monitoring via Radar Sensing for Sleep Applications

MS3 Research Group**, TU Delft, in contact with Remote Sensing Department, **Philips Research Eindhoven

CONTEXT: Despite sleep apnea being one of the most common sleep disorders, it often remains undiagnosed, or even unnoticed, due to both unawareness of its symptoms and the flaws and complexity of current diagnostic methodologies. Radar is a promising technology to monitor a sub-set of the diagnostic parameters contactless, including respiration and heart rate. A reliable contactless alternative would not only improve patient comfort, but it could also make sleep monitoring applicable outside the clinic in home environments.

There are three types of apnea: central, obstructive and mixed. During central apnea the brain fails to signal the muscles to breathe, leading to an absence of both respiratory effort and (air) flow. Obstructive sleep apnea (OSA, 80 percent of all cases) is the most common type of sleep apnea where the effort is still present but there is no flow because of the collapse of the upper airway, preventing air inflow.
During an OSA event, the respiratory movements of the chest and abdomen often change from in-phase to counter-phase, as visualized in Fig. 1. In order to detect and classify such events, it is important that the radar can monitor the movements of the chest and abdomen independently and continuously, as state of the art medical devices can do.

Besides sleep apnea, features extracted from respiration and heart rate have shown their promise in the classification of sleep stages. Therefore, radar also has its potential as a contactless sleep monitor. As the information is predominantly present in the variability of the signals, beat-to-beat/breath-to-breath accuracy rather than average heart/breathing rate is required.

ASSIGNMENTS:

- Investigate how chest and abdominal movements can be monitored independently in a sleep setting using radar(s) where the patients can be in either supine, side or prone position. Here the radar measurements should be compared to the signals measured by the respiratory inductance plethysmography (RIP) bands attached to the chest and abdomen.
- Investigate the feasibility of radar-based heart rate monitoring with beat-to-beat accuracy for sleep apnea detection and sleep stage classification. To assess the accuracy, the radar-based measurement should be compared to the ground-truth ECG.

This initial investigation should aim at demonstrating feasibility in healthy subjects ("proof-of-concept") in a simulated sleep environment. Experiments on actual patients are beyond the scope of this assignment.

The student is expected to perform a combination of experimental and signal processing work, contributing to the design and validation of a setup to collect relevant radar data, as well as the development of signal processing algorithms that can provide the required details of thorax/abdomen movements and breath-to-breath / heart beat-to-beat accuracy.

Once a reliable and effective framework for radar-based monitoring is established, the combination of information from the radar sensors and cameras in a multimodal fusion framework can also be considered within the scope of this project, combining the expertise of the MS3 group at TUD in radar processing and Philips' expertise on image processing. In first instance, the camera could provide an estimate of the position and orientation of the subject to enhance the performance of the radar estimation (localization of the area of maximum movement, adaptation of the signal processing depending on the person's position).

The student is expected to spend the majority of his time at TU Delft using the facilities of the MS3 research group, but attending periodic meetings involving the team at Philips Research Eindhoven. A placement at the Philips facilities in Eindhoven can also be considered in due course, depending on progress and needs within the project workload.

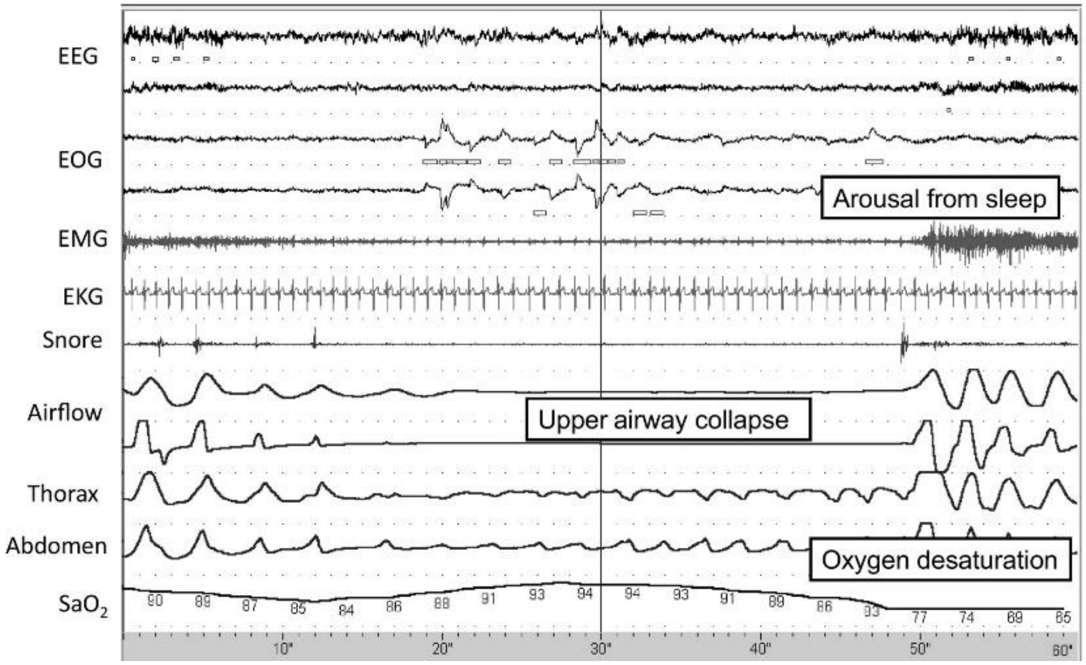

Figure 1. *During an obstructive apneic event, the respiratory-induced thoracic and abdominal movements change from in-phase to counter-phase. Can a comparable level of details in characterizing the movements of chest/abdomen be obtained with the usage of contactless radar sensing?*

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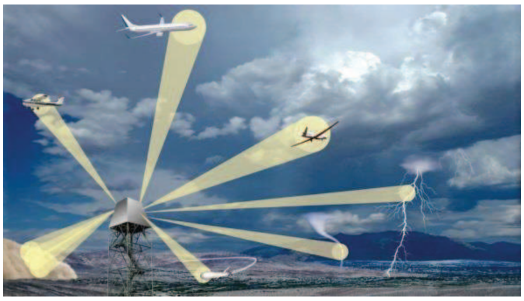
Investigating the convergence of algorithms for Radar Resource Management

Due to improvements in hardware and software, radar systems are getting more and more degrees of freedom. Some examples are the rise of phased-array antennas, digital beamforming (DBF) and digital waveform generation. This led to so-called multi-function radar (MFR) systems. In the past, a radar was usually used in a single mode and multiple radar tasks often needed to be performed successively or by separate radar systems. Nowadays, MFRs are able to execute many functions jointly and practically in parallel, especially due to the possibility of very quick changes in the direction of the beam by the use of phased-array antennas.

A big problem for the control of MFR systems is that its resources, especially the sensor time, are limited. Therefore it is common for a radar to work in some kind of overload situation where it cannot give all objects the same amount of attention. Due to the fact that MFRs are supposed to handle many different tasks in parallel, those limited resources have to be distributed to the different tasks according to their importance. Radar Resource Management (RRM) is usually not a simple scheduling problem, because the length of the tasks can be adjusted according to the importance of a target.



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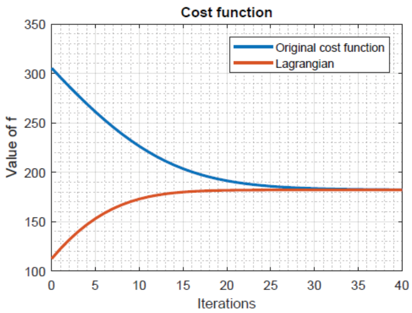

Our approach is the combination of a constrained Partially Observable Markov Decision Process (POMDP) and Lagrangian relaxation. The POMDP framework will be used to implement a non-myopic RRM, which means that future time steps are going to be taken into account when a decision is made about the next best action. By applying Lagrangian relaxation, the optimization problem can be simplified by including the constraints into the objective function and decoupling the overall problem into smaller optimization problems, one per task.

In order to find an optimal solution with Lagrangian relaxation, iterative algorithms need to be used that recursively find the optimum for the Lagrange multipliers. Some possible algorithms are for instance the subgradient method, the Nesterov accelerated gradient descent or the proximal algorithm.

The project will consist of several parts:

- Understand the background of RRM and study some possible approaches [1][2][3].
- Study certain aspects of convex optimization theory and Lagrangian relaxation [4][5].
- Review different iterative methods to solve constrained convex optimization problems [6][7].
- Apply the found methods on Lagrangian relaxation in a typical RRM framework (for instance assigning sensor time to different targets in a tracking scenario).
- Investigate the influences of different input values for the algorithms (for example the initial guess or the step size) and how multiple algorithms can be combined for improved performance.

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Radar resource management for autonomous cars in i-CAVE project

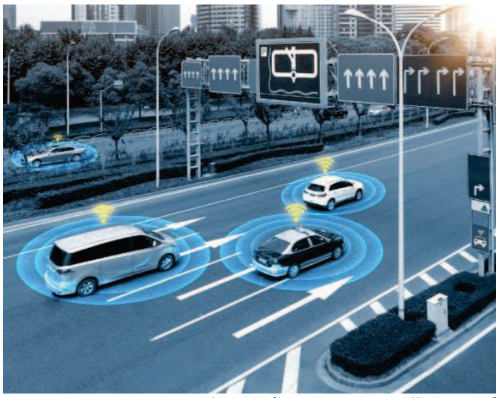


Figure 1: Autonomous driving (source: www.allion.com).

Self-driving cars are a very popular research topic in academia and industry at the moment, because it is anticipated that they will revolutionize individual traffic and increase safety and efficiency on the road. Apart from the big traditional car companies, also others are working on solutions for autonomous driving like Google (Waymo), Uber and Tesla [1]. This shows that self-driving cars need novel and innovative solutions in order to become reliable enough for everyday use.

Radars are very important sensors for autonomous cars, because they work in almost every weather condition, contrary to cameras and lidars, for instance [2]. They therefore form an essential part of future traffic solutions.

Within the i-CAVE project (Integrated Cooperative Automated Vehicles) [3], we want to use the automotive radar to transmit sensing as well as communication signals in between of autonomous vehicles. Therefore, radar communication (RadCom) is considered to be another radar task (like detecting, tracking or classification for example) for the task scheduler. Radar resource management (RRM) is going to be applied to find the optimal schedule of all radar tasks in order to minimize the situation uncertainty for all vehicles involved. The radar systems of all cars are being taken into account within a single optimization problem. In order to avoid interference, a time division of the tasks is the most promising approach (see figure 2).

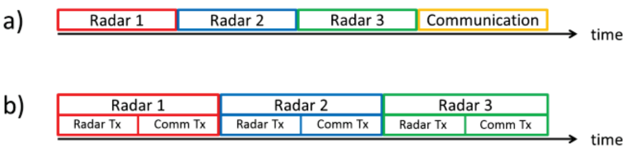


Figure 2: Possible time division scheme of radar tasks in i-CAVE.

An RRM optimization algorithm has already been developed in theory. The main task of this thesis project is to analyze relevant automotive scenarios where such an algorithm can be applied to reduce situation uncertainty. This also involves the development of a cost or reward function that takes into account all necessary important parameters of the radar tasks, as well as the traffic situation.

The master thesis project will consist of several parts:

- Preparing a literature review of basic radar resource management techniques, as well as basic optimization theory [4], [5], [6], [7]. It might be useful to have a look at current RadCom solutions as well [8].
- Investigating common traffic situations. What are the relevant scenarios where RRM could decrease the situation uncertainty and help avoid interference of automotive radars [9]?
- Defining one (or more) traffic situations that are going to be investigated in detail. What are the important parameters that need to be taken into account (related to the radar, the traffic or the vehicles)?
- Defining of a cost or reward function that assigns a value to each radar task based on the current and future situation. Relevant optimization theory needs to be taken into account for this (convexity of the cost function, for example).
- Implementing of a simulation that shows how the solution approach deals with the chosen situations compared to simpler ad-hoc approaches.

Contact: Max Ian Schöpe (m.i.schope@tudelft.nl)

References:

[1] David Welch and Elisabeth Behrmann, "Who's Winning the Self-Driving Car Race?", *Bloomberg*, 7 May 2018. [Online]. Available: https://www.bloomberg.com/news/features/2018-05-07/who-s-winning-the-self-driving-car-race [Accessed 10 December 2019].

[2] VIA Technologies, Inc., "Which Sensors are Best for Autonomous Vehicles? Cameras, Radar or Lidar?", 16 September 2019. [Online]. Available: https://www.viatech.com/en/2019/09/which-sensors-are-best-for-autonomous-vehicles-cameras-radar-or-lidar/?cn-reloaded=1 [Accessed 10 December 2019].

[3] i-CAVE project, "Project website". [Online]. Available: https://i-cave.nl/ [Accessed 10 December 2019].

[4] S. Boyd and L. Vandenberghe, "Convex Optimization", Cambridge University Press, 2004.

[5] P. Moo and Z. Ding, "Adaptive Radar Resource Management", London: Academic Press, 2015.

[6] A. O. Hero and D. Cochran, "Sensor Management: Past, Present, and Future", in IEEE Sensors Journal, vol. 11, no. 12, pp. 3064-3075, Dec. 2011. doi: 10.1109/JSEN.2011.2167964.

[7] Max Ian Schöpe, Hans Driessen and Alexander Yarovoy, "Optimal Balancing of Multi-Function Radar Budget for Multi-Target Tracking Using Lagrangian Relaxation", Proceedings of 22nd International Conference on Information Fusion (FUSION), Ottawa, 2019.

[8] F. Lampel, R. F. Tigrek, A. Alvarado and F. M. J. Willems, "A Performance Enhancement Technique for a Joint FMCW RadCom System", *16th European Radar Conference (EuRAD)*, PARIS, France, 2019, pp. 169-172.

[9] MOSARIM project, "Study report on relevant scenarios and applications and requirements specification", 2010. [Online]. Available: https://cordis.europa.eu/docs/projects/cnect/1/248231/080/deliverables/001-MOSARIMDeliverableD121V11.pdf [Accessed 10December 2019].

Phase Coded FMCW Automotive Radar

Millimeter-wave radar has become one of the key sensors in any modern Advanced Driver Assistant System (ADAS) to enhance autonomous driving. However, present automotive radar sensors suffer from radar-to-radar interference between multiple cars due to sharing limited spectrum. The mutual interference between automotive radars degrades performance of victim radar and increases the chance of miss detection and false detection. In order to mitigate the mutual interference, Phase Coded Frequency Modulated Continuous Waveform (PC-FMCW) concept was initially studied by using Binary Phase Shift Keying (BPSK). In the framework of this project, different phase coding techniques will be studied to generate phase codes of PC-FMCW.

The main goals of the project:

- Understand of radar systems and waveform design.
- Study the working principle of phase coding and its application on interference mitigation.
- Investigate different phase coding and implement it to existing PC-FMCW radar.
- Compare performance of developed new method with current solution.

Requirements

Radar Basics and MATLAB simulation experience

Contact: Utku Kumbul (u.kumbul@tudelft.nl) Microwave Sensing, Signals and Systems

A few more possible topics for the MSc projects (initial directions for detail discussions)

The researchers of the MS3 group are working within the wide area of radar sensors technology, signal and data processing and interpretation for variety of applications. To give you an impression what can be the research topics for your MSc project within the MS3 group, an example of the extendable list of a few hot titles is presented below.

Electromagnetics and Antenna Systems design

- Full-Polarimetric MIMO Antenna Array at 77-81GHz for automotive radar applications
- 10cm*10cm 25GHz Waveguide-slot Array for a Nanosatellites
- The influence of composite paints substances on signals scattering at 77-81GHz automotive radars frequency band.

Technological problems of modern radars

- Multi-static measurements in distributed L-band radar network: handling noise , RF coherency and modulation synchronization of distributed nodes
- Integration and synchronization of the Texas Instrument (TI) and/or NXP automotive MIMO radars with video camera and GPS

Radar Signal and Data Processing

- Ground Penetration Radar (GPR) Imaging of Sewage Pipes Partly Filled with Sand
- Measurements of Moving Targets using multichannel ASTAP MS3/TUD radar system
- Improvement of radars synchronization in distributed network using observations the same moving targets
- Automotive MIMO radars self-diagnostics and instant calibration using statistical processing of targets of opportunity.

If you are interested in one of listed topics or even in some more general or specific research directions, you can contact Prof. DSc. Alexander Yarovoy (a.yarovoy@tudelft.nl, HB21.100) for further discussions.

THALES

www.thalesgroup.com

Classification with radar using Deep Learning techniques

Deep Learning is a type of machine learning that attempts to model high level abstractions in data. In recent years, remarkable achievements using Deep Learning architectures have been reached in the fields of speech and image recognition, text analysis, autonomous driving, etc.

In this assignment, you will apply Deep Learning techniques on radar data with the goal of classifying different (moving) objects using synthetic data and/or measurement data from an experimental radar.

Some prior experience with machine learning is favorable.

Total length of the project is preferably >3 months.

Affinity: Machine Learning, Python, Tensorflow/Keras, MATLAB

https://thales.wd3.myworkdayjobs.com/Careers/job/Delft/Stage--Afstudeeropdracht---WO---Elektrotechniek--Natuurkunde--Informatica--Wiskunde-Classification-with-radar-using-Deep-Learning-techniques_R0050802

Information-based Processing in Radar and Communications with Compressive Sensing, Information Geometry and Machine Deep Learning

Thales NL proposes an internship project whose aim is to investigate applicability of the information-based processing with emphasis on practical issues in signal processing (SP). Simulated data are to be used to demonstrate the applicability in realistic cases.

Proposed project planning:

- selecting a practical issue and its SP application(s) of interest,
- studying CS, IG and MDL, and information-specific (radar) measurements and their SP,
- (theoretically) investigating practical links between CS- IG-MDL and the application;
- implementing the CS- IG-MDL analysis for particular measurements in MATLAB,
- testing and evaluating the CS- IG-MDL applicability with simulated data, and
- reporting the CS- IG-MDL applicability in the (radar/comms) SP in a report.

Affinity: Strong background in stochastic signal processing and geometry; Experience in MATLAB or Python;

https://jobs.thalesgroup.com/job/delft/stage-afstudeeropdracht-wo-elektrotechniek-toegepaste-wiskunde-technische-natuurkunde-information-b/1766/9442822

Metasurfaces for Compressive Sensing on Radar Antenna Array Systems

Data acquisition based on Compressive Sensing (CS) has shown enormous potentialities in terms of reduction of system complexity and costs, without compromising performances. CS allows working with a reduced number of measurements under the conditions that the sensing results are sparse and the sensing is incoherent. It has been recently proved at Thales NL in [1] that among the different schemes to implement CS, the one where the operation of compression is performed before the signal is processed by the receiving modules, therefore directly at antenna level, can achieve much better performances in terms of Signal-to-Noise ratio. In order to do that, it is necessary to realize a Metasurface Random Phase Mask that can add at each array antenna element a random phase and combine the different element contributions into a single signal. Different combinations with different phase settings would form the set of signals for CS. Metasurfaces [2] have attracted an enormous attention of the scientific community in the last decade, and they have been proved to be a breakthrough technology in several applications. TNO and TU/e have jointly developed a considerable know-how on the design and application of metasurfaces over a very wide frequency spectrum: from microwaves up to optical frequencies.

[1] R. Pribić, G. Leeus, C. Tzotzadinis, “Signal-to-Noise-Ratio Analysis of Compressive Data Acquisition”, 2018 IEEE Workshop on Statistical Signal Processing (SSP).
[2] Theory and Phenomena of Metamaterials; Metamaterials Handbook; Applications of Metamaterials; edited by F. Capolino, CRC Press, 2009.

Project Description

Thales NL, TU/e and TNO propose an MSc-degree graduation project which will take 6 to 9 months whose goal is to design a metasurface for CS in phased arrays and demonstrate the concept with the realization of a hardware demonstrator of a metasurface antenna array with M outputs and with N outputs as the reference, M<N. Following a literature study of the current state-of-the-art of metasurface theory and design and a proper understanding of the CS sensing techniques in radar arrays, the student will perform the design of M metasurfaces and will combine them with an antenna array of N elements, based on the requirements derived in collaboration with the research partners.

Project organisation

The graduation project will be performed within the Center for Wireless Technologies (CWT/e, EM group) at TU/e in close collaboration with Thales NL and TNO. The student is expected to perform the project at TU/e (Electromagnetics Group) in Eindhoven or at the TNO premises in Delft, with regular visits to the Thales NL premises, in Delft. Equipment, support and a budget for experiments are available.

Affinity

- Strong background in antenna design, electromagnetics and signal processing;
- Experience in MATLAB or Python;
- Good verbal and written communication skills in English

https://jobs.thalesgroup.com/job/delft/afstudeeropdracht-wo-elektrotechniek-toegepaste-wiskunde-technische-natuurkunde-metasurfaces-for-co/1766/9929182

Target tracking and classification based on kinematic information using recurrent neural networks.

In the framework of target classification using kinematic information, targets' states available during the tracking phase represent the main information available. Besides existing tracking techniques, new approaches based on machine learning techniques are acquiring more and more attention. Specifically neural networks have shown to have large potential in dealing with complex problems associated with tracking and classification. Especially specific neural networks have the capability to preserve relevant information that is contained in a sequence of data. The goal of the assignment consists in the definition and assessment of target tracking and classification techniques based on neural networks, especially for those cases that are particularly challenging for model-based approaches.

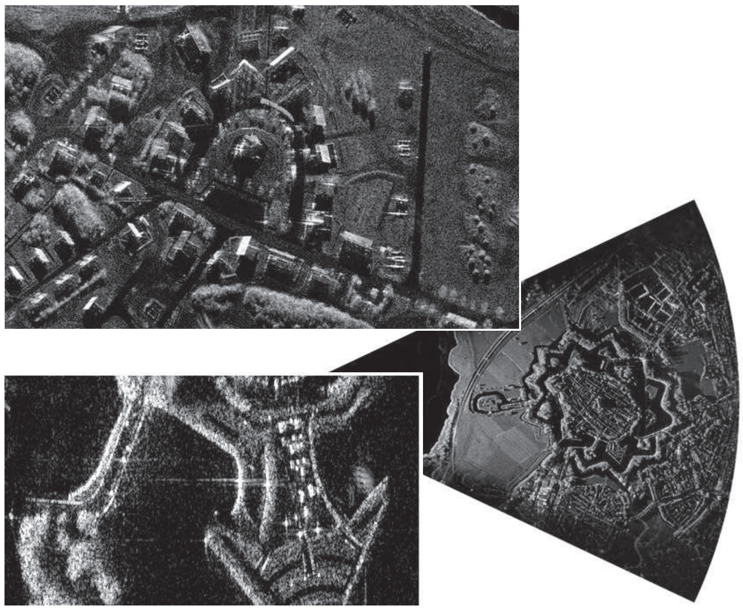
Cross-modal techniques with deep neural networks for robust sensor fusion.

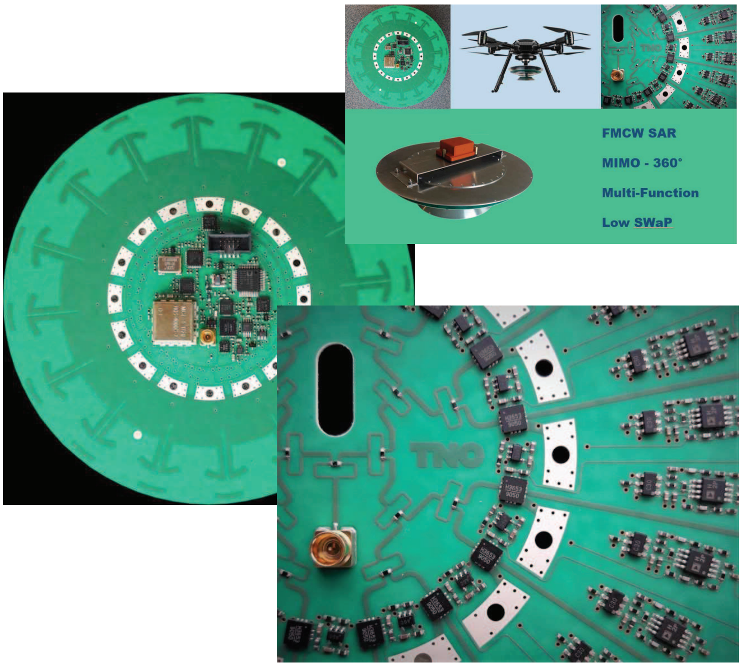
Deep learning techniques have been already introduced to achieve an efficient sensor fusion in order to enhance functionalities like target tracking and classification. From a different perspective, the availability of multiple simultaneous information captured by different sensors, might provide an improved robustness of the overall systems, especially in the case of failure of one of the sensing nodes, or whether the captured measurements of one of the sensors do not contain relevant information to accurately perform the desired functionality. The objective of the assignment consists in the definition of cross-modal techniques based on deep neural networks, specifically focusing on the enhancement of the robustness of system consisting on a camera and a radar, for the problem of human-gait classification.

Contact: Lorenzo Cifola (lorenzo.cifola@nl.thalesgroup.com)

Agile Radar System for Drones

Synthetic aperture radar (SAR) is a high-resolution radar imaging technique used in airborne and spaceborne radars. TNO has developed a miniaturised SAR system that is circular in design, weighs only 800 grams and can be mounted on a small drone. This digital 32-channel radar system is a unique system that is at the very forefront of drone radar developments. Its inherent flexibility allows for many novel and innovative radar modes to be conceived and demonstrated. Thus advanced signal processing techniques for various new detection and imaging modes need to be developed and implemented, including image processing tools for new types of radar imagery such as wide-angle multi-aspect image sets. In addition, suitable motion compensation and navigation methods have to be developed and tested. Depending on your interests, the work may also include application of compressive sensing or machine learning techniques.





Possible research topics include:

- assessment of new radar operating modes
- advanced radar imaging, 360° imaging
- compensation of motion in signal processing
- advanced processing like compressive sensing or machine learning
- accurate navigation methods
- inverse synthetic aperture radar (ISAR)
- interferometric SAR (InSAR)

TNO innovation for life

Contact: Jacco de Wit, TNO Department of Radar Technology
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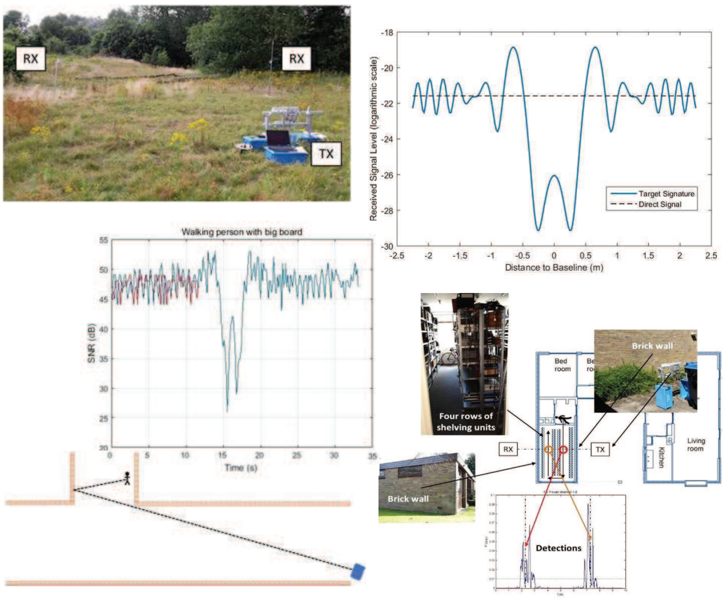
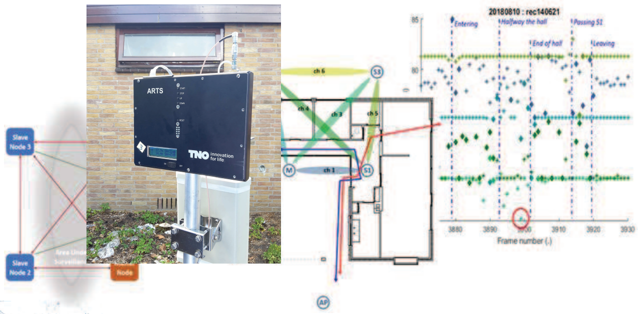
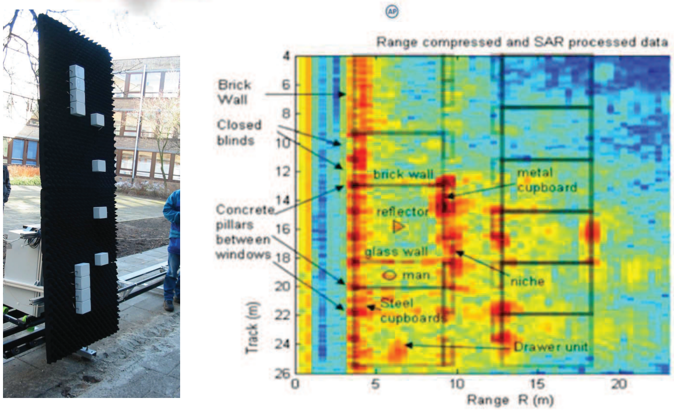
Urban and Through-Wall Radar Surveillance

In the urban environment radar observations are obstructed by buildings, fences and other obstacles. Due to these obstacles a large part of the area under observation may be shielded from the radar and false detections may occur due to multipath. Innovative signal processing methods are needed to enhance the radar observations. One line of investigation in this area is the exploitation of multipath reflections. Another line of investigation is the deployment of a network of active and passive radar sensors observing the area from different sides, for instance exploiting the forward scattering radar principle.



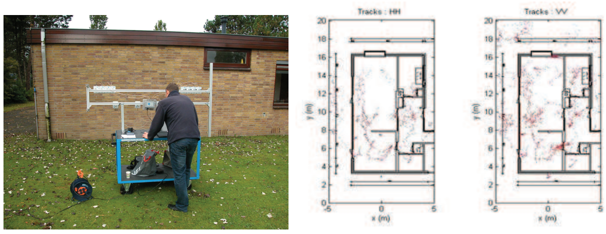




In the urban environment, covert surveillance of building interiors is also an important asset. Through-wall radars are being developed which focus on obtaining building lay-outs and/or on the detection of people inside a building. A new approach to detect people inside a building is forward scattering. TNO has developed several radars for through-wall sensing. Measured data sets of both forward scatter and backscatter radar data are readily available. These data can be used to develop and optimise a tracker (i.e., a data fusion engine to track people over time) or design a novel tracker concept that combines different types of observations. The goal is to track moving people inside a building using active and passive radar technology.

Possible research topics include:

- multistatic tracking, data fusion
- “around the corner” radar
- through-wall radar
- forward scatter radar
- multipath exploitation



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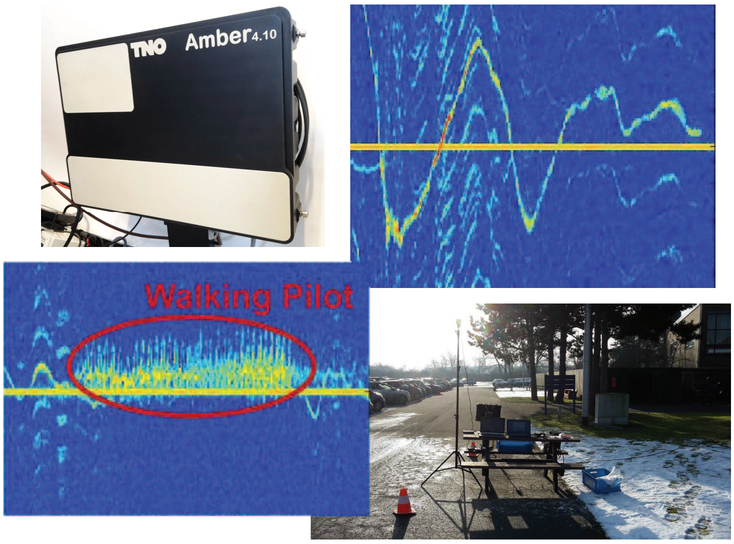
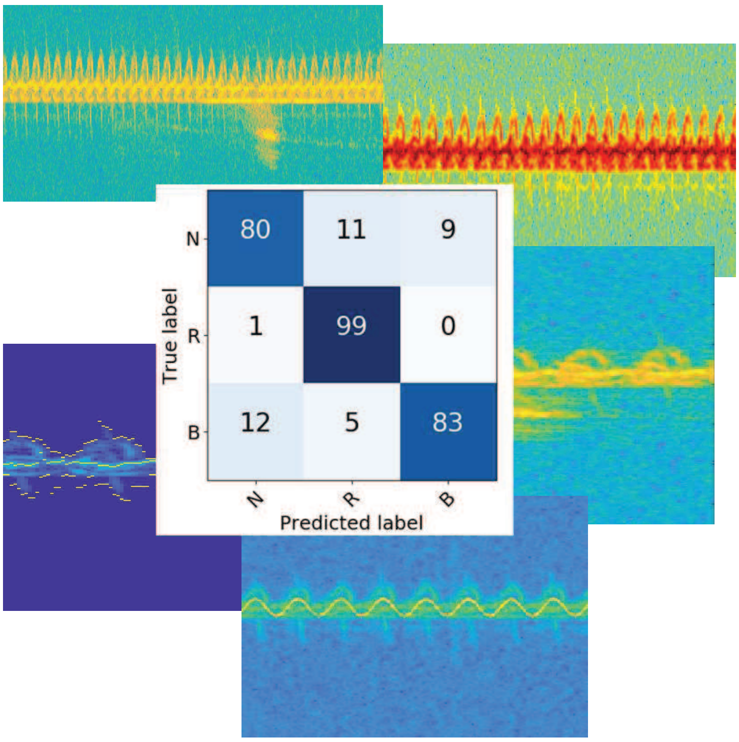
Classification of Radar Micro-Doppler Signatures

The radar micro-Doppler signature of an object is determined by parts rotating or moving in addition to the motion of the object as a whole, think for example of a rotating aircraft propeller. Radar micro-Doppler signatures are specific for different types of objects and can therefore be used for object classification. One example is the micro-Doppler characterisation of human motion. The way of walking, the torso motion and the swinging of the arms (or not) of a person may indicate whether that person is carrying a heavy item or backpack.

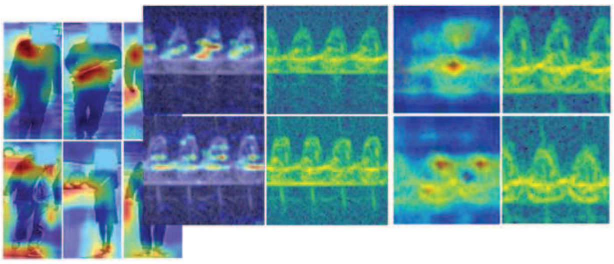




The goal of this task is to develop and test innovative micro-Doppler feature extraction and classification methods. One line of research is the development of tangible, physically meaningful features. The robustness and distinctiveness of these features can be tested using for instance a support vector machine classifier. Another line of research is the application of neural networks for classification. This line of investigation includes visualization and explanation techniques to gain insight in the actual operation of a neural network by highlighting the activation areas within the radar micro-Doppler signatures. Representative data sets of walking people and drones are available. This task may also include conducting additional measurements to test your results.

Possible research topics include:

- Machine learning for classification
    - multimodal learning
    - visualisation and explanation
    - domain adaptation
- Feature extraction



TNO innovation for life

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MSc Thesis in Microwave Sensing, Signals and Systems (MS3)

Urban-specific clutter mitigation for weather radar

Background & Research question

Being reflected by surrounded rain drops, the microwave signal from ground-based weather radars may provide maps of rainfall rate. Compared to the granular measurement obtained by rain gauges, the radar covers a much larger spatial area which is paramount for many applications in meteorology, flood, and climate change monitoring.

However, such radar images can suffer from unwanted, non-atmospheric echoes called 'clutter' that hampers the quality of the retrieved rainfall information. This is particularly true in urban environment where heavy clutter is generated from multiple sources, such as large buildings, windmills, but also interferences from telecommunication systems.

The Rijnmond radar, an advanced weather X-band radar system, is soon going to be deployed in the very centre of a city, in Rotterdam. Thanks to its advanced capabilities, it will map rainfall at very high resolution in order to better manage urban water at street-level and improve our understanding of urban climatology. **The question is whether the clutter in the radar image can be mitigated without removing the information from the rainfall.**

Master topic

Research has been carried out at TU-Delft on clutter filtering using spectral (Doppler) and polarimetric radar measurements. The proposed methodology, spectral polarimetry, can be enhanced with image processing techniques at low radar elevation angles and in the case of radio frequency interference. It was applied on study cases. **The proposed master topic aims at investigating the impact of an urban environment on this promising enhanced methodology**. The master thesis topic is part of the EU funded program ATTRACT (**2019-2020**), under the project: Enhanced Urban Rain Surveillance Systems for Smart city Solutions (EU-RainS4).

Supervision

Organized in collaboration between TU Delft GRS department (CITG) and MS3 (EWI), and co-supervised by SkyEcho, a young startup company working on rainfall estimation and smart city solutions.

Requirement and Experience gain

The work doesn't require any real-time processing. Matlab or Python coding is sufficient. The main gain is to apply weather radar signal processing research in real environment with a direct contact with a industrial sector for city climate adaptation applications. **If successful, the student will have the opportunity to present his work in an international conference with high network potential.**

Contact information

Christine Unal (c.m.h.unal@tudelft.nl, CITG HG2.18) – lead supervisor
Prof. Alexander Yarovoy (A.Yarovoy@tudelft.nl, EWI) - Professor
Dr. A. Oude Nijhuis (albertoudenijhuis@sky-echo.eu, SkyEcho, Rotterdam) – co-supervisor

TU Delft
Delft University of Technology

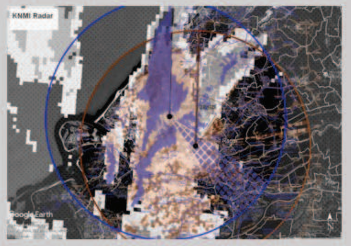
Sky ECHO HD weather experts

ATTRACT

MASTER TOPICS

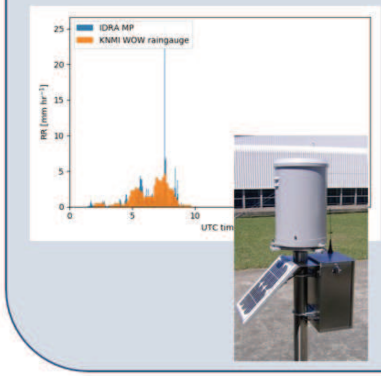
The main goal of these topics is to help SkyECHO optimize hyperlocal High Definition rainfall data in the Rotterdam area (improve coverage, quality, forecast)

TOPIC 1: Improving HD Rainfall rate coverage using X-band radar data fusion



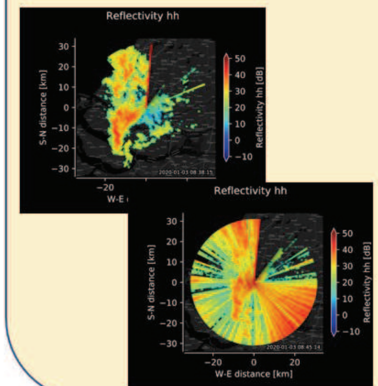
- **Challenge:**
X-band rainfall radars provide high resolution but very limited spatial coverage which can not monitor big cities.
- **Research questions:**
How to combine data from different radar/elevations/scans together taking into account biases/errors/sensitivity/difference of calibration?

TOPIC 2: Rijnmond rainfall data evaluation using multiple sensor approach



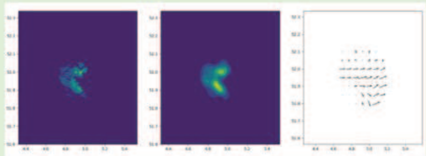
- **Challenge:**
Evaluating the quality your rainfall output is key to ensure the good use of the data for hydrological purpose.
- **Research questions:**
How to best compare and what needs to be taken into consideration? how to take into account the difference of observation scales, sensor calibration? Problem of attenuation? Comparison will be performed between radars and using rainguages

TOPIC 3: Automatic gain control algorithm development to better monitor HD rain



- **Challenge:**
At X-band, heavy rainfall can saturate the received signal, strongly affecting the rainfall rate output quality
- **Research questions:**
When the radar receiver saturating and what threshold to take? How to modulate the power in real-time

TOPIC 4: Evaluation of X-band radar based nowcasting algorithm (short-term forecast)



- **Challenge:**
Characterize the rainfall cells structures to estimate the advection is a challenging step of the forecast that needs to be investigated at X-band
- **Type of tasks:**
How to balance speed and accuracy in radar nowcasts? What are the predictable scales? and what algorithms are best suited for high-resolution real-time radar forecasts?

MASTER TOPIC EVENT – SkyECHO

Contact person: Yann Dufournet – y.dufournet@sky-echo.eu

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Radar Detection of respiratory and heart beat for old, sick and disabled people in Home Care situation.

Data analyses and trigger threshold points are collected in an app and trigger several output devices like nurse call, telephone dialler etc. when exceeding set point parameters of heartbeat and respiratory. App should be developed and hardware could be used from TNO earlier developments in radar detection.

Detection of Dementia-related behaviour like falling, localisation and walking away out of home or the care institute.

Fall detection and localisation out doors are of great importance. As falling is one of the most life threatening situations in elderly care this is a subject of importance in these thesis. Through external localisation by GPS we create an intra- and extramural alarm communication solution. Walking away from home is to be detected through intramural Induction through an antenna. So the unit can also be used for institutes.

Airborne passive RADAR design

Context

In collaboration with Selfly BV the TU D is involved in the development of radar based avionics systems, which eventually will allow aircraft to fly in low visibility conditions. By detecting and processing radar signals the aircraft should be able to determine and track the location of obstacles (both airborne and on the ground) giving the aircraft enough information to navigate as well as detect other aircraft.

Such a future system can also be based on a bistatic principle using airborne illuminators. This will be the focus of your assignment.

SOCATA TB-10 with radar antenna

MSc Assignment

Design a bistatic, airborne sense and avoid system for low size, weight, power and cost (low-SWaPc) airborne drones which swarm under the control of a mothership system. The mothership which is used to control the drone swarm will be used as illuminator (transmitter) for surveillance signal. The swarm nodes will work in passive configuration to detect and avoid incoming air traffic by exploiting the surveillance signal illuminated by mothership.

Your design will be tested both in ground trials as well as airborne flight tests.

For more information contact:

Ir. R.N.H.W. van Gent rvgent@selfly.nl

The location: Haus Humboldtstein

Details

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Contents

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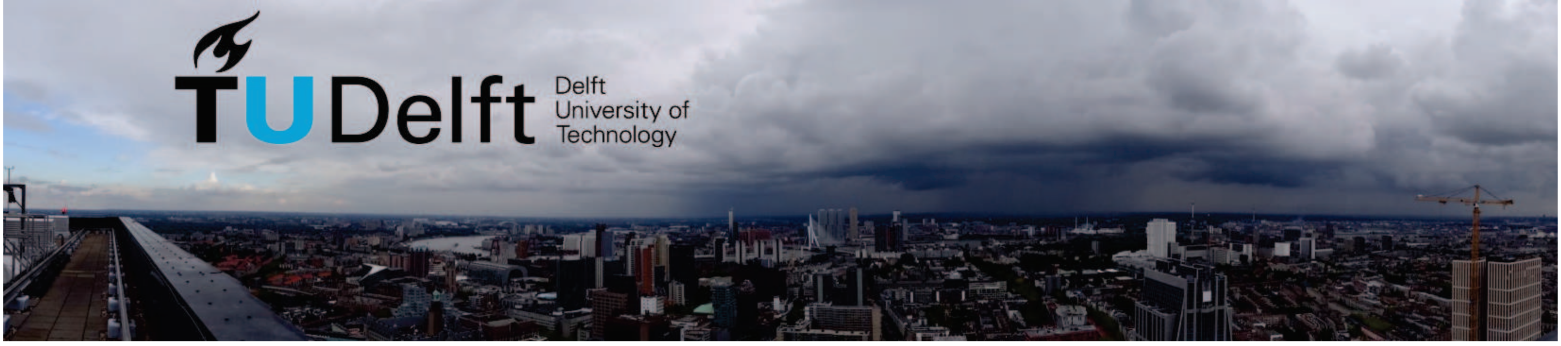
The main focus of the International Summer School on Radar/SAR lies particularly in imparting the knowledge of the physical fundamentals and technologies of modern Radar/SAR systems and the necessary signal processing steps. Special emphasis is put on imaging radar. Considered systems and applications are regarded under dual use aspects.

The exacting challenging lectures and workshops feature crucial topics, such as:

- Radar fundamentals and statistical signal processing
- Overview of different radar systems in the area of remote sensing
- Radar imaging (synthetic aperture radar / SAR)
- Moving target indication
- Interferometric SAR
- Radar Polarimetric
- Bi-/multistatic and passive radar/SAR systems
- Waveform design
- Antennas and scattering
- Special aspects for radar front-ends
- Special radar techniques: Terahertz imaging, ultra wideband (UWB) radar, ground penetrating radar (GPR)
- Compressive sensing
- Cognitive radar



Microwave Sensing, Signals and Systems (MS3) Group

INVITES YOU TO JOIN

THE MS3 MASTER EVENT

Come to learn about our group and current Master Thesis Projects

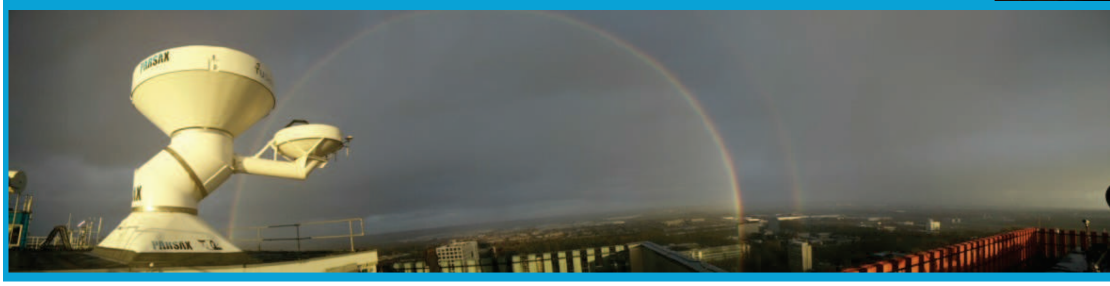
January 8th , 2020

Event Program

15:45 – 18:30

- Start & Welcome
  (Snijderszaal (HB 01.010)
- Introduction of the MS3 group
- Short presentation of companies
  (NXP, TNO, THALES , etc.)
- Free interactions for Master
  Project opportunities

17:30 Social Time & Pizza



MS3
Microwave Sensing
Signals & Systems