April 2013 to March 2014

UDRC Annual Report

Mike Davies, Yvan Petillot, Janet Forbes

Edinburgh Consortium,

Joint Research Institute of Signal

Image Processing

Contents

University Defence Research Collaboration

The University Defence Research Collaboration (UDRC) in Signal Processing is delivered in partnership with Dstl, the University of Edinburgh and Heriot-Watt University (Edinburgh Consortium) and Loughborough University, University of Surrey, University of Strathclyde and Cardiff University (LSSC Consortium). This work is funded by the MOD and EPSRC.

Objectives

The key objectives are to:

- Develop novel signal acquisition and processing techniques to address the needs of the MOD.
- Develop the theory of networked sensor integration to enable future competitive advantage
- Apply methods in real and simulated data demonstrating effectiveness of the algorithms

Vision

To develop an ambitious programme of research which will enhance and build upon existing sensor technologies in defence and will provide integrated multi-sensor systems while simultaneously limiting the data overload and maximising data relevance within the network through data acquisition, processing and sensor management.

Staff and Students

The Edinburgh Consortium comprises signal processing experts from the University of Edinburgh and Heriot-Watt University and is one of the two Consortiums funded for the second phase of the University Defence Research Collaboration (UDRC).

The Joint Research Institute of Signal and Image Processing is a partnership between these two universities and incorporates the activities of the three research groups:

Institute for Digital Communications (IDCOM), University of Edinburgh.

Vision Image and Signal Processing Laboratory (VISP), Heriot-Watt University.

Oceans Systems Laboratory (OSL), Heriot-Watt University

Academic Staff

Prof Mike Davies
Prof Yvan Petillot
Prof Bernie Mulgrew
Prof John Thompson
Prof Andy Wallace
Dr Neil Robertson
Dr Daniel Clark
Dr James Hopgood
Dr Mathini Sellathurai

Research Associates

Dr Mehrdad Yaghoobi
Dr Murat Uney
Dr Yan Pailhas
Dr Rolf Baxter
Dr Emmanuel Delande
Dr Calum Blair
Shaun Kelly

Research Students

Di Wu
Puneet Chhabra
Jose Franco
Saurav Sthapit

Project Management

Janet Forbes
Madeleine McBeath
Audrey Tainsh

Director's Report

Director, Professor Mike Davies

This is our first annual report and encompasses the progress, highlights and the future focus of the research within the Edinburgh Consortium for the University Defence Research Collaboration (UDRC) on signal processing for a networked battlespace. The first year of UDRC has seen the establishment of an exciting and challenging research programme with the creation of a team with diverse expertise in the field of signal processing. I hope you enjoy reading about our successes.

Research focuses on 6 fundamental areas within this field and each research area is led by a senior academic and supported by other academics, research associates and PhD students. The research is divided into the following areas and sub areas:

WP 1 Sparse Representation and Compressed Sensing

- WP 1.1 Efficient subNyquist sampling schemes
- WP 1.2 Compressive imaging with sensor constraints
- WP 1.3 Compressed Sensing, beyond imaging

WP 2 Distributed multi-sensor processing

- WP 2.1 Fusion and Registration
- WP2.2 Distributed Decentralised Detection

WP 3 Unified Detection, Localization, and Classification (DLC) in complex environments

- WP 3.1 Estimating targets in scenarios with spatio-temporally correlated clutter
- WP 3.2 Physical Modelling for DLC
- WP 3.3 Man-made object detection

WP 4 Context-driven Behaviour Monitoring & Anomaly Detection

- WP 4.1 Detecting anomalous behaviour in audio-video sensor networks
- WP 4.2 Mobile vehicle monitoring, resource allocation and situational awareness

WP 5 Network enabled sensor management

- WP 5.1 Hierarchical sensor management for target tracking
- WP 5.2 Computationally tractable solutions
- WP 5.3 Multi-objective sensor management

WP 6 Efficient Computation of Complex Signal Processing Algorithms

- WP 6.1 Efficient parallelization of Sensing Processing
- WP 6.2 Implementation of Distributed Signal Processing Algorithms
- WP 6.3 Algorithm/computation resource management

This year, the Edinburgh Consortiium have published 14 papers with a further 14 papers submitted. Research has advanced well over the first year.

Notable are the leading research positions established in the areas such as Sub-nyquist sampling where research into low complexity and efficient fractional delays through delay compensated TF transforms has offered some novel ideas.

Our distributed multi-sensor processing work has moved on considerably to provide improved scalability and has overcome issues of resource limitations such as communication bandwidth and power.

Current research focus in underwater sonar systems and in particular Multiple Input Multiple Output (MIMO) systems has developed new algorithms which enhance the capabilities and performances of current MIMO systems.

Fundamentally our work on audio-video tracking has focused on the development of new probabilistic behaviourial recognition models that have led to a number of publications.

Novel algorithms for multiple target tracking has been developed in a closed-loop sensor management context.

Recently, work has focused on efficient implementations of Gaussian Processes to support classification with confidence, i.e. associating a confidence value to the output of binary classifiers with applications to automatic target recognition in Sonar.

Many of these work packages are interlinked and their assemblage gives an excellent opportunity for researchers to collaborate. Research partnership success can be seen within WP3 and WP5 where collaborative work has enabled the design of a harbour surveillance scenario utilising work from the MIMO simulator and multi-object trackers. Also an alliance in WP2 and WP5 has produced original work on regional variance in the expected number of targets.

In addition to this research, we are delivering a coordination role across both Consortia involving the development and maintenance of a dedicated website, organisation of an annual conference, planning and strategy meetings, themed meetings, knowledge transfer meetings and an annual summer school.

The development of strong industry links with the researchers is a major objective of the UDRC. This early collaboration will ensure that the research is usefully integrated into the defence sector's challenges allowing for the future commercial development of these research outputs. A key issue in the first year has been to establish an effective management structure and the proximity of the two Universities is a great advantage for this. Regular research meetings and a reading group have been established which allows for communication and collaboration within the groups of researchers.

The first year of the UDRC has been exciting, productive and rewarding and the Strategic Advisory Group has played an essential role in providing direction and guidance.

Mike Davies, UDRC Director
April 2014

Research Highlights

Sparse Representations and Compressed Sensing

Designing a framework for sub-Nyquist sampling of wideband Radio Frequency (RF) signals. The immediate application of the proposed framework is Radar Electronic Support Measures (ESM) receivers. A patent has been filed and a paper has been accepted for the ICASSP2014 conference.

Development of super-resolution sensing and imaging for sparse sensing and imaging. This application is focused on super-resolution multi-dimensional SAR imaging, i.e. 3D SAR and GMTI.

A novel autofocus SAR imaging using the sparsity nature of the point targets. The results of this new framework are published in the IEEE Transactions on Aerospace and Electronic Systems in April 2014.

Distributed multi-sensor processing

Proposed a cooperative sensor self-localisation algorithm for fusion networks. Each sensor finds its location in a network coordinate system using only the information already exchanged for distributed fusion and local measurements from non-cooperative targets and without any need to transmit these measurements to other sensor platforms. An article covering the preliminary results has been accepted at the IEEE Statistical Signal Processing Workshop 2014.

Proposed a centralised sensor localisation algorithm which features scalability with the number of sensors. We demonstrated that this algorithm can perform target tracking for bearings only sensors. Preliminary results have been submitted to Sensor Signal Processing for Defence 2014 (SSPD).

Production of a UDRC technical report on “multi-sensor calibration for fusion networks” which covers the details of the parameter likelihoods based on target measurements and probabilistic models that allows scalable and/or distributed calibration. This report also features a maritime surveillance EO/camera registration example using on board GPS of cooperating vehicles. Parts of this report will be submitted to technical journals in the field.

Implementation of belief propagation libraries for Gauss Markov Random Fields and non-parametric distributions employing particle representations. Released initially for UDRC use and soon will be released under General Public Licence (GPL).

Unified Detection, Localization and Classification

A theoretical study of sonar MIMO systems where the capabilities of such systems including automatic target recognition and super-resolution for MIMO images are highlighted. A new metric based on MIMO intra-views distance correlation was developed providing guidelines of how to build efficient sonar MIMO systems.

A realistic MIMO simulator including realistic 3D environment, bistatic reverberation based on physical models and multi-paths, has been developed. The output of the simulator allowed us to work in a dynamic environment and linked directly with new multi-objects trackers developed in the research area of networked enables sensor management.

The academic output of the MIMO study is; one paper submitted to the Journal of Oceanic Engineering, two invited papers to the Underwater Acoustics Conference and one paper submitted to SSPD.

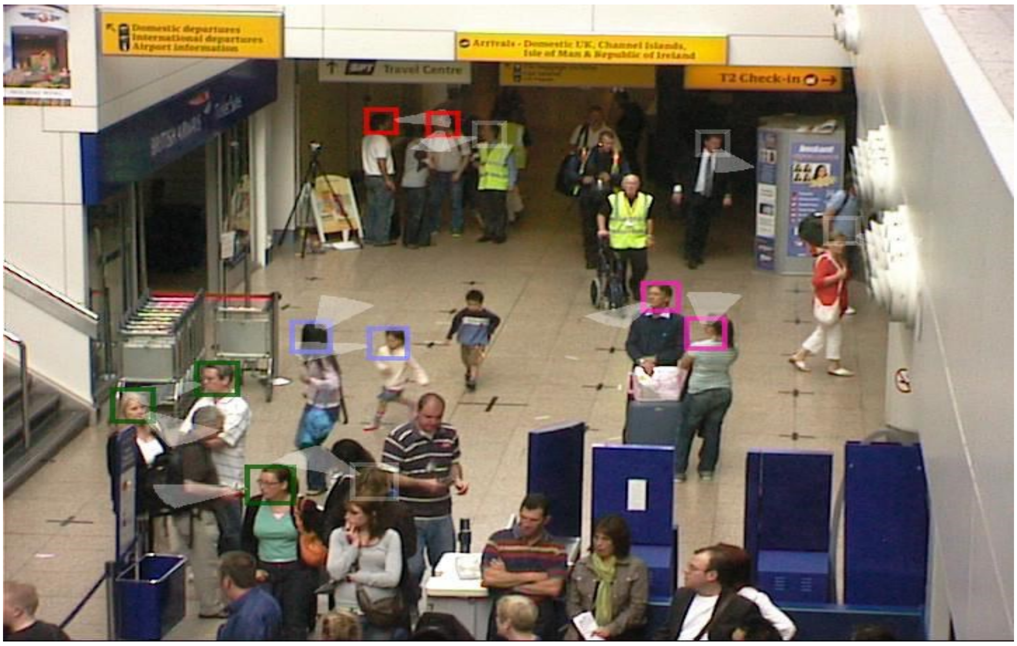


Figure 1. Groups detected via gaze and point features: work from Context Driven Behaviour Monitoring and Anomaly Detection

Context Driven Behaviour Monitoring and Anomaly Detection

Joint audio-video tracking work was accepted for publication at ICASSP 2014. This research proposes a novel method to automatically detect and localise the dominant speaker in a scene using audio-video canonical correlation analysis.

Work with Roke Manor Research on anomaly detection in crowded scenes was published in Pattern Recognition Letters. This work develops new features for automatically partitioning signals derived from video into contextual zones for improved anomaly detection in a challenging “big data” problem.

“Human Behaviour Recognition in Data-Scarce Domains” was submitted to Pattern Recognition, and proposes a novel algorithm for probabilistic behaviour recognition and anomaly detection in domains where annotated training data is unavailable and shows that our algorithm out performs the state-of-the-art in several aspects, including its robustness to distributed sensor-network latency.

Signal level audio-video tracking of people in indoor spaces has been completed and submitted to the IEEE Journal of Selected Topics in Signal Processing, special issue on Signal Processing for Situational Awareness from Networked Sensors and Social Media, on the recommendation of the lead guest editor.

Novel work on the machine learning of target context - social, spatial and temporal has demonstrated that subtle anomalies enacted by people in surveillance may be detected by use of "gazing" patterns in the scene (as well as more basic features), Figure 1. We are working on developing "intentional priors" which aggregate spatial and temporal priors over multiple features. This work seeks to unify the "contextual" and "pattern-of-life" into basic target tracking. Outputs also include paper submissions to SSPD.

Network Enabled Sensor Management

Development of a novel information-based tool for the description of a target population using the higher-order regional statistics. This is applied to multi-object filters and helps the operator assess situational awareness, with a level of confidence, in any region of the surveillance space. It was implemented for two well-established multi-object filters in the tracking community, the Probability Hypothesis Density (PHD) and the Cardinalized PHD filters. These novel results are the topic of a journal article in IEEE Transactions in Signal Processing (TSP), recently accepted.

Design and implementation (Matlab with embedded C) of the Independent Stochastic Population (ISP) filter, drawn from the novel multi-object framework that is in development. It provides a near-optimal solution to the multi-object Bayesian estimation problem with independent targets. This filter is the topic of a journal article in preparation, for a submission in TSP. In collaboration with the research on unified detection, localization and classification, this filter will be exploited in a maritime surveillance scenario.

Production of performance metrics, adapted to the ISP filter, for decision making in the context of a closed-loop sensor management system. Two solutions have already been designed: the higher-order regional statistics, drawing from previous work and an alternative solution exploiting information metrics (e.g. the Rényi information measure). We aim to present these results at SSPD.

Efficient Computation of Complex Signals Processing Algorithms

Production of a pedestrian detector which responds to uncertain images with less confident prediction scores. This is an improvement over existing state-of-the-art detectors, which are often extremely overconfident in the presence of uncertain samples. Work on this is ongoing and has been submitted to SSPD.

A paper detailing the results of a power consumption study between FPGA and GPU for object detection was presented at a computer vision applications conference. This quantifies the improvements available in power consumption when using the level of anomalous behaviour in a surveillance video to dynamically choose which architecture to process imagery on. We are able to switch to faster GPU processing when unusual behaviour is registered, and return to lower-power FPGA processing when the observed behaviour is normal.

GPU-accelerated implementations of state-of-the-art image formation algorithms for SAR imaging are currently being developed.

Research Leader: Mike Davies

Research Associate: Mehrdad Yaghoobi

PhD Student: Di Wu

WP1 Sparse Representations and Compressed Sensing

This research investigates the benefits of using prior low-dimensional signal models for defence related applications, including Radar, Sonar and Spectrum Sensing. A simple low-dimensional signal model, i.e. sparsity, has been used in standard Compressed Sensing (CS) is considered here along with sparsity driven algorithms.

This stage of the research investigates how a more advanced signal model can be used for compressive sampling and Size Weight and Power (SWaP) reduction. Such an approach also supports more reliable electronic surveillance and active sensing/imaging systems. Initial focus is on the Radar Electronic Support Measures (ESM), intercept Sonar and Synthetic Aperture Radar imaging systems.

Outcomes

There has been further progress in the sparsity based SAR imaging. This area was also partly funded by UDRC phase 1. From this work a novel technique for autofocus SAR imaging has been proposed, where there exists phase/gain ambiguity in the SAR imaging system. The idea is to model the phase and/or gain ambiguities using the standard techniques proposed for sparse dictionary learning to calibration the

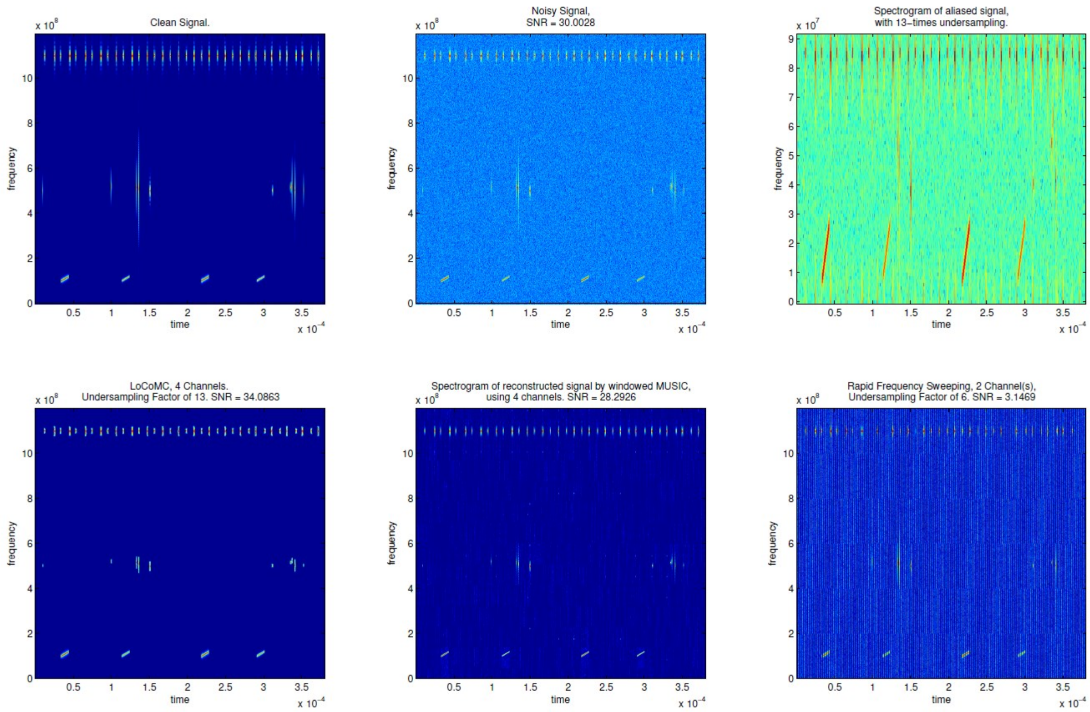


Figure 2. A comparison with other sub-Nyquist sampling techniques. Spectrum of, the clean original signal (top left), noisy Nyquist sampling signal (top middle), a sub-Nuquist sampled channel (top right), reconstructed signal with the LoCoMC using 4 channels (bottom left), reconstructed signal using MUSIC algorithm (bottom middle) and reconstructed signal using rapid frequency sweeping technique (bottom right).

parameters i.e. autofocus imaging [A] This patent application [B] sets out our proposed framework for low SWaP sub-Nyquist sampling which highlights the anticipated key benefits (figure 2).

A further outcome is presented in a paper submitted to ICASSP 2014, on low-complexity sub-Nyquist sampling for radar electronic support measures [C]. This paper introduces a new framework for multichannel sampling of ESM signals, (figure 3) each with a rate much lower than Nyquist, which is the conventional rate for perfect reconstruction of the band-limited signals. The main contribution here is on introducing a low-complexity reconstruction algorithm for the radar pulse reconstruction. The new algorithm has a complexity which is suitable for implementation in real time using a reconfigurable hardware, e.g. FPGA. This work will be extended with a more comprehensive comparison with the state of the art sampling techniques for the Radar ESM, and we will submit the results to the SSPD 2014 conference. A complete report will also be offered to IEEE Transactions on Aerospace and Electronic Systems in April 2014.

This research has already attracted the attention of two companies, with defence related applications. The aim is to incorporate the new technique for Radar and Sonar applications. We are currently in contact with them to find the best possible approach for the knowledge transfer.

Another paper has been submitted [D], which investigates a comprehensive comparison between the proposed method in [1] with the state of art industrial approach to Radar ESM, i.e. Rapid Frequency Sweeping (RFS) method. The proposed framework has a continuous monitoring of the spectrum, in the contrast with the RFS which observe each band at a time. The processing gain of the RFS would then be limited for the lack of continuous monitoring of the spectrum.

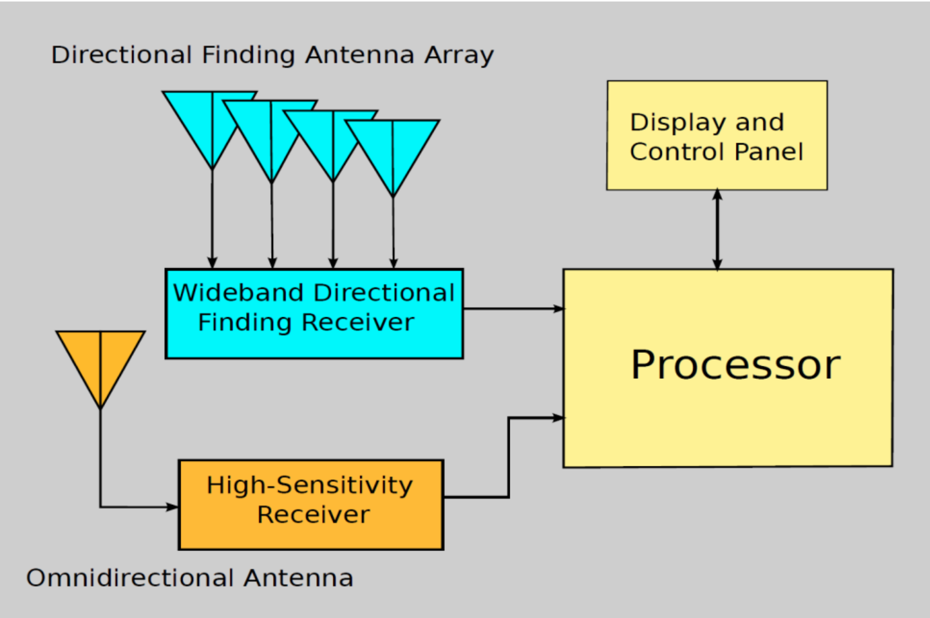


Figure 3. A typical Electronic Support Measure system. Our focus is now on the High Sensitivity Receiver.

A paper was submitted to SSPD which investigates the problem of efficient sampling of wideband radar signals for electronic surveillance using a parellel sampling structure. Here an implementation technique is introduced which reduces computational cost and improves accuracy[E].

A paper[G] was also submitted which proposes a new synthetic aperture radar image formation algorithm which simultaneously mitigates radio frequency interference while forming an image. The proposed method minimises these detrimental effects by leveraging the approximate sparsity of ultra-wideband synthetic aperture radar images.

Progress

Sub-Nyquist sampling schemes have been investigated and as the efficiency of the sampler is our main focus; we have investigated various compressive sampling techniques to identify the most appropriate approach for ESM. Three approaches; Random Demodulator (RD) [1], Modulated Wideband Converter (MWC) [2] and Multicoset Sampling (MS) method [3], were identified as the most successful CS settings. The complexity of the sampling process can be divided into two parts; the analog hardware design and the Digital Signal Processing (DSP) unit, see figure 4. The main focus therefore is to present an efficient DSP unit for this application.

Firstly, we investigated the analog hardware proposed in multicoset sampling method. This method uses a filter-bank to delay the input signal with various delay values. The output signals are sampled at a rate much lower than the Nyquist rate, and therefore have aliasing in each subsampled signal. The goal is to reconstruct the reference signal, using the collection of delayed signals, known as coset signals. The reconstruction algorithm in MWC relies on the joint sparse representation of the multicoset signals and the construction algorithm in [3] relies on dominant subspace identification, where it needs a SVD decomposition. These methods do not computationally scale well and the application to our problem setting is difficult.

Our proposed framework relies on the digital fractional delay (DFD)'s, followed by a time-frequency transform. We have chosen the Short-Time Fourier Transform (STFT) at this stage of project, and a simple subband classifier. The subband classifier is based on the maximum value of the multicoset signals after a linear operator, i.e. a Harmonic Frame. This allows the whole process to be implemented using linear filters and a simple nonlinear operator, i.e. maximum

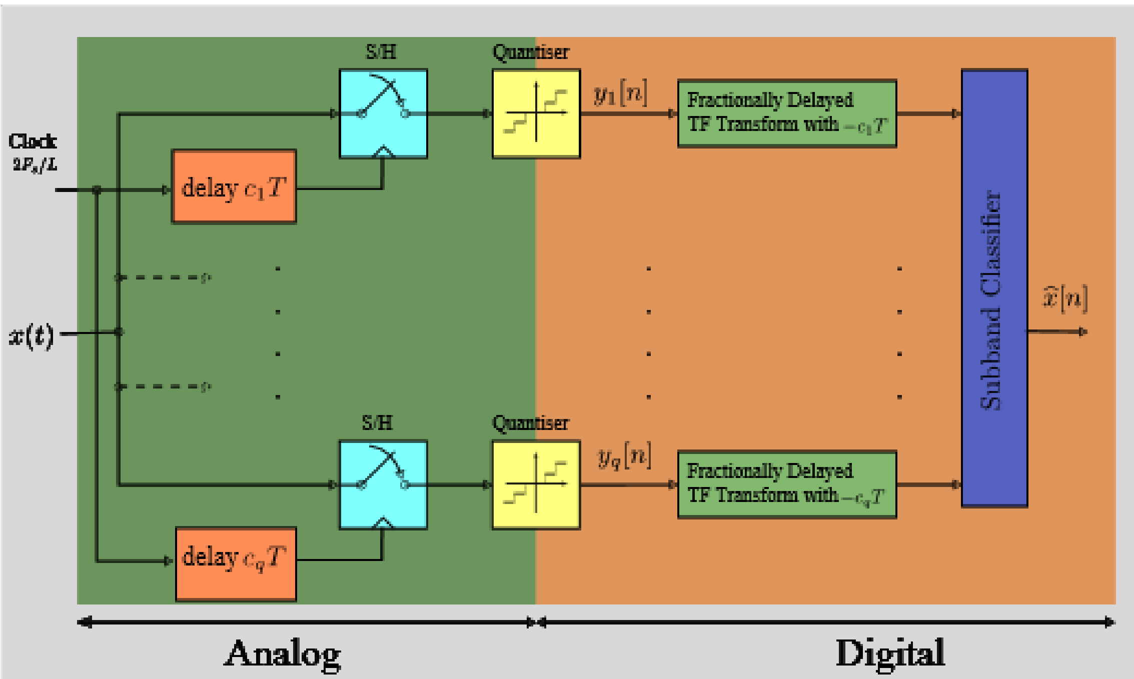


Figure 4. The proposed Low-Complexity MultiCoset sampling framework

value operator. In this framework, we selected appropriate delay values and the filter implementations to yield the most accurate signal delays.
In the second quarter we investigated the model parameter and filter selections, as follows:

Delay values selection
To be less affected by the noise, a set of delays were chosen which generate an incoherent harmonic frame meaning that the harmonic functions generated have to be dissimilar. If we appropriately choose the downsampling factor and the number of multicoset signals, there is a guarantee to achieve the best possible incoherent frame, known as the Grassmannian frame. Here, we derived a set of optimal Grassmannian Harmonic Frame (GHF)'s for that purpose, using a random search. We have also found that particular sets of GHF's are preferred as they only have small or large fractional delays, which are easier to be implemented as a filter in the other block of the proposed framework.

Digital Fractional Delay Filters (DFD)
The DFD of the coset signals has an important role in the success of the overall sampling algorithm. Research to find the best way to implement such a filter was undertaken. We found that a subband implementation of the DFD filter is an efficient approach, as we already have a subband decomposition of the signal in the next stage of the algorithm. The order of the operations can therefore be swapped to simplify the filter implementation and also to decrease the filter artefacts.
Good progress has also been made in the sparsity based SAR imaging, partly funded by another Dstl grant. Here, we proposed a novel technique for autofocus SAR imaging, when there exists phase/gain ambiguity in the imaging. The idea here is to model the phase and/or gain ambiguities using the standard techniques proposed for sparse dictionary learning to calibration the parameters, i.e. autofocus imaging.

We investigated the optimal parameter selection and efficient algorithm implementation. The DFD filter was fully embedded into the STFT time-frequency implementation for the best performance, in that period. The achieved boost in the output SNR is between 0.5 to 1 dB. The implementation of an alternative TF transform, i.e. Chirplet, was started in Q3 and is now completed. Some sensitivity and robustness analyses were also carried out.

In Q4, a comprehensive comparison with Rapid Frequency method began. Early results for our method are very promising, in a comparison with the RFW method, which is shown to lose some processing gain, as it only senses part of the spectrum, while any event in the other part of time-frequency will be missed.

PhD research - Compressed sensing/processing

Di Wu has commenced his work on the super-resolution approaches looking at how to resolve the original compressible signals from partially acquired samples. The applications which are related to signal acquisition and reconstruction, especially the ones for processing non-band-limited signals with sub-Nyquist sampling rate, can benefit from such techniques. A potential application of interest is the super-resolution in SAR/GMTI. He has also been working on Raman spectral deconvolution in order to qualitatively analyse the components of chemical mixtures, as well as possible unknown substances, and determine the concentrations by leveraging the sparsity of components, compared to the whole chemical library [F].

Future Direction

In the next stage we will focus on the CS for imaging. This includes sub-Nyquist techniques for tomographic based imaging systems and super-resolution techniques for improving the Rayleigh resolution, incorporating signal prior information. These will help to reduce SWaP of the imaging systems like Synthetic Aperture Radar/Sonar (SAR/SAS). It will also reduce the scanning time in these systems. We will investigate the high-dimensional SAR systems, e.g. 3D SAR and GMTI SAR, to accelerate the imaging, to reduce the computational complexity of reconstruction, and improve the reconstructed signal resolution.

The current line of research will continue looking at wideband compressive sensing, by considering other relevant settings. The super-resolution spectral sensing is another important scenario which will be investigated and will help us to identify the target more accurately.

Research Leader: Bernard Mulgrew

Academics: Daniel Clark, John Thompson, Neil Robertson, Mathini Sellathurai

Research Associate: Murat Uney

WP2 Distributed multi-sensor processing

The objective of this research is to address challenges in the detection and tracking of targets with networked sensor platforms of various modalities. Distributed solutions which avoid a single designated processing centre are investigated in order to meet with the requirements of performance, flexibility and fault tolerance under resource constraints such as limited communication bandwidth and energy,

We aim to develop methods for sensor fusion and registration in such networks. We are interested in solving the sensor registration when noisy measurements of these quantities are not available, and only the measurements from the targets are the source of information. The next stage considers the concept of the network as a sensor and aims to investigate distributed detection in networks of sensors that are comparably less homogenous in their capabilities.

Outcomes

We developed a cooperative scheme for self-calibration and applied for sensor self-localisation in fusion networks. Preliminary results of this work have been accepted at the IEEE Statistical Signal Processing Workshop 2014 [H].

In this work, we considered geographically dispersed and networked sensors and collected measurements from multiple targets in a surveillance region. Following a distributed fusion paradigm, each sensor node filters the set of noisy target measurements collected with given probability of detection in an environment of false alarms from clutter and surroundings. The filtered multi-target information is, then transmitted to the neighbouring nodes in order to be fused with the local information and hence improve upon the myopic tracking accuracy. In order to do that, however, the respective sensor locations need to be identified as the information centre of its reference frame. We solved the sensor localisation problem based on only the information shared to perform distribution fusion. In addition, our solution is fully decentralised and enables sensor self-localisation in a network coordinate system based on non-cooperative targets.

This work enhances the capability of locating sensors based on only target measurements. Our solution features the integration of information provided by multiple targets without explicitly solving any data/track association problems and in a cooperative and scalable manner. This is an important capability for such networks when additional devices such as GPS are not available (e.g., under-water sensor networks) or reliable (e.g., presence of jamming). An extended version of this article will be submitted for publication in a technical journal.

We have also introduced a scalable centralised sensor localisation and target tracking algorithm in order to solve the intra-cluster problem in fusion networks. This approach is described in a publication submitted to SSPD.

A UDRC Technical report [I] which also contains the EO/camera calibration application using the node-wise calibration likelihoods entitled "multi-sensor calibration for fusion networks" has been produced. Parts of this report will be organised as articles to be submitted to technical journals in the field. For example, our cooperative scheme in sensor self-registration - a problem in which sensor orientations also need to be estimated along with locations will be submitted to IEEE Transaction on Signal Processing.

In this report, we provide details of our investigation on the sensor calibration problem in networks of sensors in a surveillance scenario. We focus on scenarios in which the network can use only the measurements from the targets and the information shared for distributed fusion for calibration. We provide a probabilistic framework which allows us to tailor scalable and cooperative solutions for a variety of scenarios including single tier, hierarchical fusion architectures and different modalities. We also discuss how different sources of calibration information such as noisy distance measurements based on the incoming (communication) signal strength can be integrated into this framework. This technical report serves as a basis for further publications from the first part of this work package. Utilising work from this report a paper has been submitted to the SSPD 2014[J]on a network of bearing only sensors in a surveillance scenario where an an online solution is proposed.

We have developed MATLAB libraries implementing Belief Propagation for Gaussian (parametric) and non-parametric (continuous) Markov Random Fields during our investigations. These libraries are released within UDRC use and will be released under GPL licences, shortly.

Our collaborative work with WP5 on regional variance in expected number of targets has been accepted for publication in IEEE Transactions on Signal Processing [V].

Progress

In multi-sensor fusion problems, sensor calibration refers to specifying the parameters necessary to relate a point in the target state space to sensor measurements in the absence of any uncertainties. Often, a subset of these parameters could be found using measurements from on board devices such as gyroscopes whereas the remaining should be estimated based on target measurements. In order to facilitate multi-sensor exploitation, the relations among the reference frames of different sensors should be fully known. Sensor locations and orientations, often referred to as sensor registration parameters, specify these transforms, the estimation of which is our main interest in this area.
As it is often feasible to compensate for sensor orientations using on-board gyroscopes, the node localisation problem in sensor fusion networks has been investigated.

The sensor nodes in these networks perform local filtering on the measurements from the targets in their field of view. They then communicate the posteriors produced by the filters to their neighbours with respect to the underlying communication topology. The Bayesian solution to the centralised version of this problem uses the well-known predictive parameter likelihood [4] based on all the target measurements collected across the network and throughout the time the targets are tracked [5]. With regard to the distributed problem in which the nodes do not transmit their observations, we identified two main challenges in developing an appropriate (distributed) solution, in the light of our previous experience [6, 7] and an extensive literature review which we completed in Q1 and Q2.

The first challenge is the specification of likelihood functions based on the information transmitted between sensors as opposed to the complete network-wide measurement history in the centralised solution. In Q2 we developed node-wise separable parameter likelihoods for a pair of sensors linked with a communication link and exchanging multi-target information for the purpose of distributed fusion. These functions can be evaluated for a selection of the respective calibration parameters based on only the incoming multi-target information and local target measurements. Moreover, they can be used with Random Finite Set (RFS) multi-target representations in which case

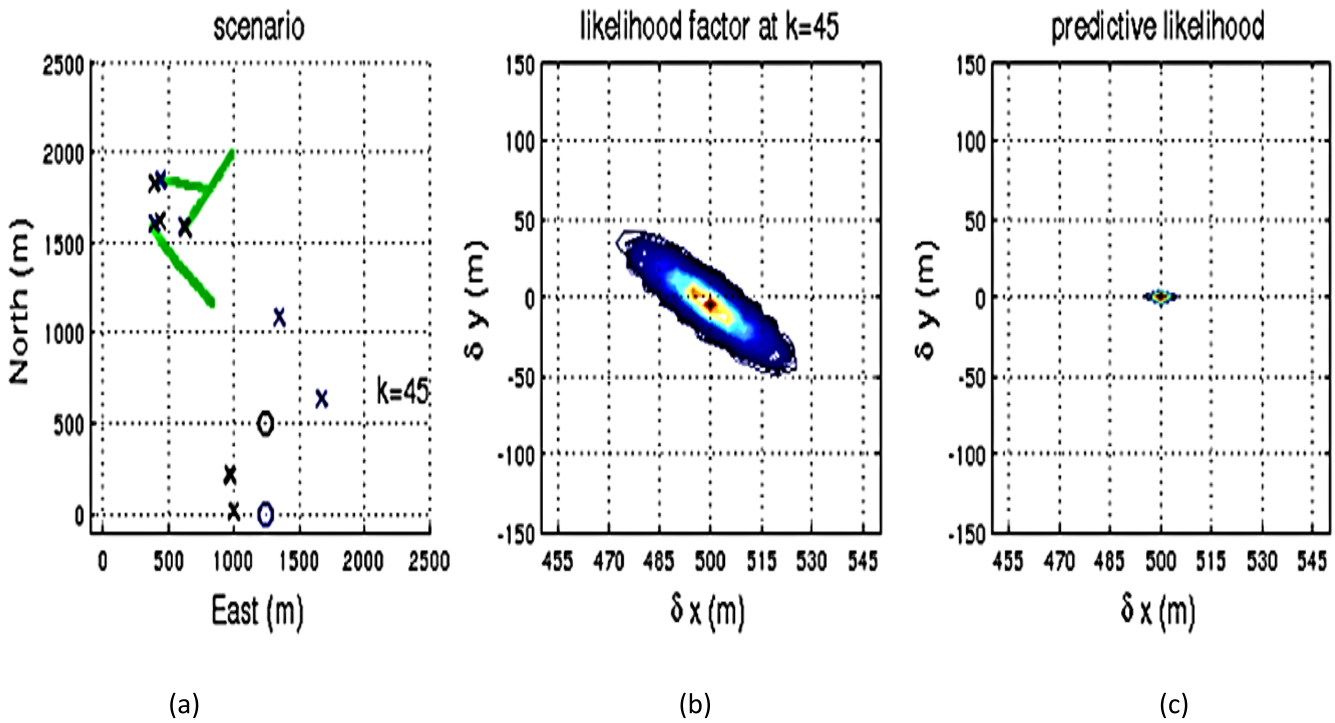


Figure 5. Node-wise separable likelihoods for sensor localisation based on target measurements: (a) Sensors (circles) target tracks (green dots) and range-bearing measurements projected onto the Euclidean plane (crosses). (b) Contour plot of the instantaneous update for the likelihood at time step k=45. (c) Contour plot of the node-wise separable localisation likelihood obtained by recursive updates over 45 time steps.

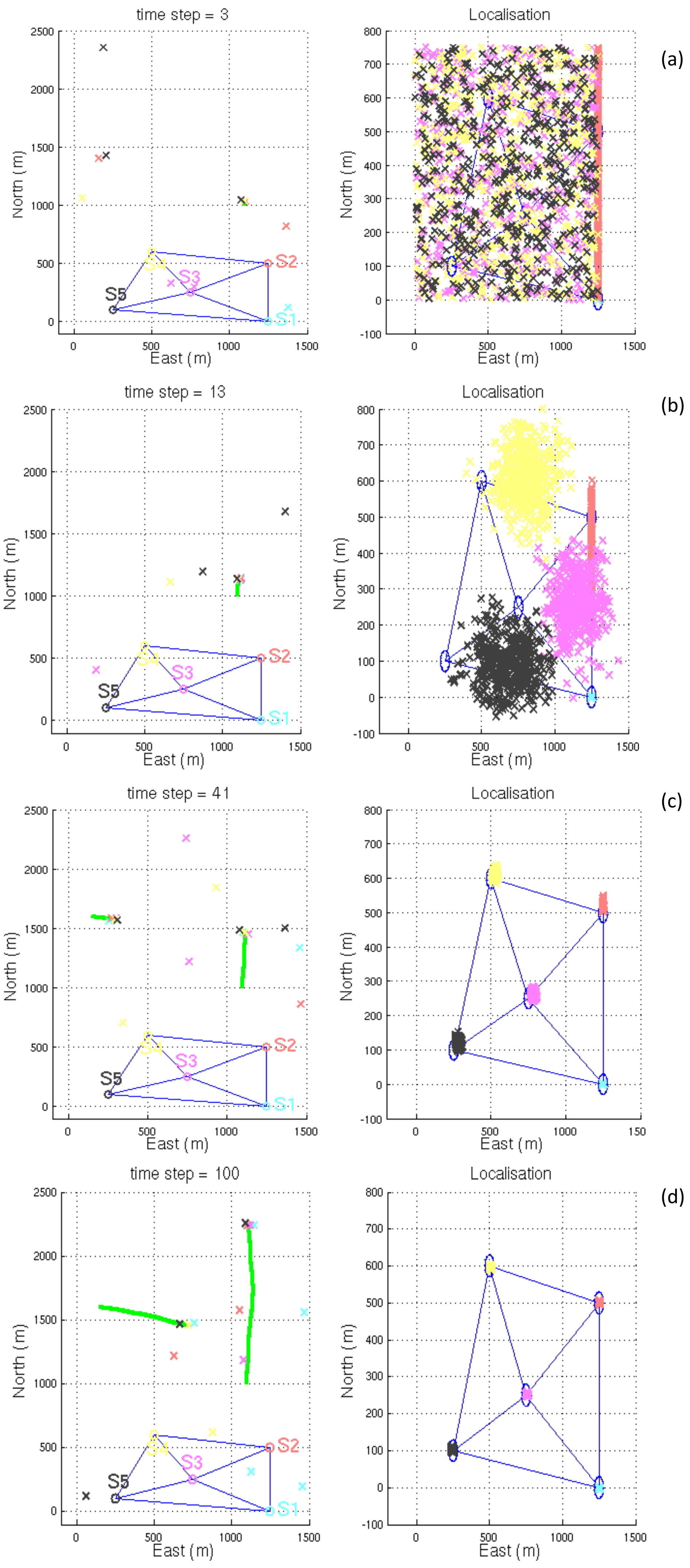


Figure 6. Snapshots from a typical run of the proposed algorithm in an example multi-target scenario. (a) Sensor network and the target measurements (‘x’s with colours in accordance with the sensor number) with particles representing non-informative prior distributions of sensor locations. (b) Multi-sensor multi-target scene on time step 13 with sensor location distributions updated using LBP messaging (c) Cooperative localisation iterations at time step 41 (d) Cooperative localisation results for time step 100.

contributions from multiple targets are incorporated without the need to solve any (data/track) association problems (Figure 5).

The second challenge in distributed sensor calibration is the identification of a network-wide inference mechanism that provides a consistent combination of the local results obtained using the local parameter likelihoods.
There are a number of algorithms that can be used for this purpose which approximate, for example, to the maximum-likelihood solution [8, 5] or the marginal distributions conditioned on the network-wide measurements [9]. In Q3, we adopted the latter approach and used our node-wise separable likelihoods to construct a pairwise Markov Random Field (MRF) model of the problem. Such a model allows us to exploit the distributed estimation mechanism provided by Belief Propagation which is an iterative message passing algorithm for statistical inference. Our model has time recursive edge potentials updated by the local target measurements. We iteratively update these potentials and then use BP for self-calibration (Figure 6).
We demonstrated the capability of our node-wise separable likelihoods in a heterogeneous sensing environment for finding the intrinsic (model) parameters of an EO-camera sensor using a GPS sensor on board a collaborative vehicle moving in the surveillance region . Our approach allows us to calibrate the sensor by integrating over time the noisy information provided by a detector with high uncertainty and false alarms. We also considered the centralised problem and provided a solution which features scalability with the number of sensors using our triangular MRF models. We demonstrated this algorithm for localisation of bearing only sensors which form a cluster. In a hierarchical sensing structure, it is reasonable to consider such clusters as forming the first tier which in turn would need the distributed problem solved among such clusters in the second tier.

Collaborative work with WP5 has developed a novel concept for sensor fusion and management: region-based variance on the number of targets. Murat Uney realised these algorithms using Monte Carlo computational methods and designed experiments for the demonstration of how this quantity varies for selected regions, for example, around concentric circular regions around targets.

Future Direction

Our current work addresses fusion and registration problems partly related to the Sono-Buoy Challenge. In particular, we have proposed solutions for the intra-cluster and second-tier localisation problems in the absence of related measurements other than those from the targets. We have assumed that target measurements are filtered adequately using one of the well-known algorithms. A distributed fusion problem that we will address is the intra-cluster task of filtering with signal delays related to propagation [10, 11] as well as network package delays.

Another line of investigation will be in methodological aspects of communication efficient distributed Bayesian/non-Bayesian inference. Possible exploratory investigations include adaptation of recent work on statistical decision making under model misspecifications for distributed fusion and quantifying the effects of "double-counting" in distributed fusion using tree re-parameterisations of Markov Random Fields.

Research Leader: Yvan Petillot

Academics: Daniel Clark, James Hopgood

Research Associate: Yan Pailhas

PhD Student: Jose Franco

WP3 Unified Detection, Localization and Classification

The aim of this work package is to understand and model difficult and complex environments. Traditional algorithms for detection, classification or identification are based on simplistic models of noise, clutter or multipath. Most of them therefore fail to achieve useful or meaningful results. The aim is to develop realistic physical based models for the full sensing chain from the sensors themselves to the complex interaction with clutter/target and propagation into the environment. A physical understanding of the clutter rather than ad hoc and simple statistical models will help to develop new DLC (Detection, Localization and Classification) algorithms with optimal performances with reduced computational power as well as in situ environment adaptability for greater robustness.

Outcomes

Research interest is novel from an academic perspective and has concrete applications in the maritime military domain. We have developed a generic Multiple Input Multiple Output (MIMO) model for narrow and wideband sonar systems. This model lays the foundation for any future research in the MIMO domain and justifies from a theoretical viewpoint the use of hybrid models for sonar simulations.

We have demonstrated the multiple advantages including automatic target recognition and super resolution imaging of using MIMO sonar systems for area surveillance. A paper on this subject has been submitted to the Journal of Oceanic Engineering [K]. This paper introduces a unified formulation for sonar MIMO systems and focuses on the target detection and recognition capability. The multiplication of the number of transmitters and receivers not only provides a greater variety in term of target view angles but provides also in a single shot meaningful statistics on the target itself.

We have also demonstrated that assuming the independence of the views and a large enough MIMO system target, recognition is possible with only one view from the full system. By studying the detection performance of MIMO sonars we have also demonstrated that such systems solve the speckle noise and decorrelate individual scatterers inside one cell resolution.

MIMO systems can achieve super-resolution images and surpass the resolution given by equivalent SAS (Synthetic Aperture Sonar) systems. We have identified applications for such systems and we are working closely with WP 5 on sonar MIMO dynamic systems which are intrinsically linked to the fusion / tracking problem.

A 3D MIMO simulator has been developed for this purpose and several scenarios have been explored showing the advantages of new multi-object trackers applied to MIMO sonar systems. Two invited papers on this subject will be presented at the Underwater Acoustics Conference in June 2014 [L, M].

In [L] we studied the correlation between views in MIMO sonar systems where we used the distance correlation introduced by Szekely [12]. From the correlation we derived the inter-views distance correlation matrix which assessed the correlation of the full MIMO system (i.e. the dependencies between each view). This independence measure matrix gives a guideline to how to build truly uncorrelated MIMO sonar systems and will maximise the system performance. [M] presents a MIMO simulator that can compute synthetic raw data for any transmitter/receiver pair in multipath and cluttered environment.

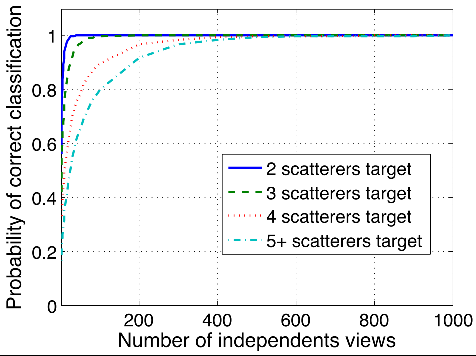


Fig. 7: Correct classification probability against the number of independent views for 4 classes of targets (2, 3, 4 and 5+ scattering points targets).

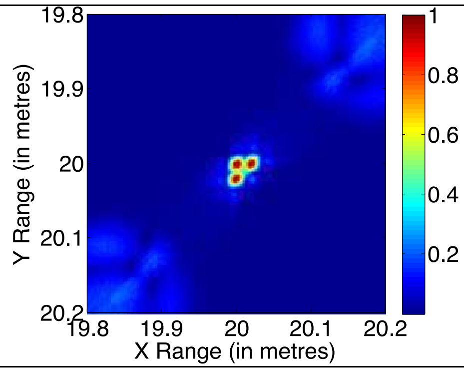


Fig. 8: 3 scatterers target MIMO image using 10 transmitters and 10 receivers with 3 metres spacing.

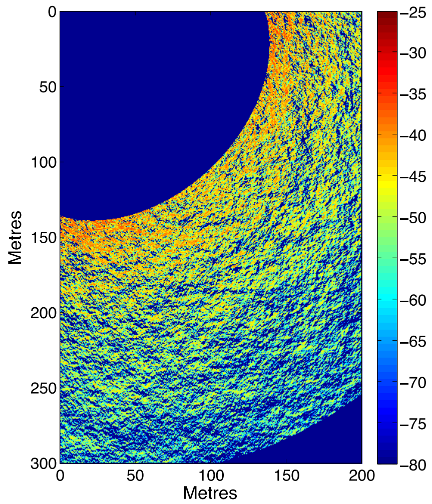


Fig. 9: Bistatic reverberation strength in dB of a fractal sandy-mud seafloor (Tx at [0m 100m], Rx at [100m 10m]).

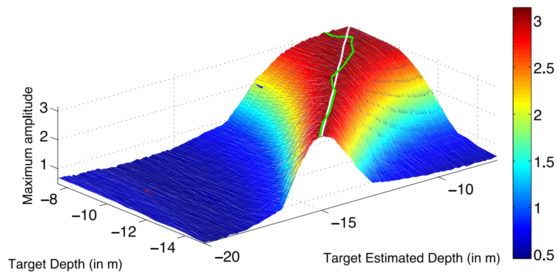


Fig. 10: Autofocus function to maximise, white curve: real target depth, green curve: estimated target depth.

A submission to SSPD [N] demonstrates that using large MIMO sonar systems it is possible to perform automatic target recognition with a single shot and also to achieve superresolution imaging.

Progress

We have focused on underwater acoustic sensors. The theories and the resulting algorithms will be developed for sonar image processing and underwater acoustic signal processing. However we believe that a great part of the resulting work will be directly applicable to similar coherent sensors such as RADAR or LIDAR.

Early in the project we identified a number of UDRC challenges that could benefit directly from the output of this work package. A close reading of those challenges gave us an insight of expectation of the overall work as well as the type of real life problems that confront the operational teams. The Dstl vision has been clarified during a meeting. We have focused our attention on the “Reliable automated detection and identification of underwater objects using unmanned sensor systems” challenge. MIMO has clearly been identified as a possible route to solve numerous practical challenges. We have investigated the MIMO theory and produced a general MIMO model for narrow and wideband sonar based on the target form function that is a more suitable approach for sonar. The MIMO formulation for radar systems stipulates the multi-static relation between transmitters and receivers through the channel matrix. The channel matrix models the wave propagation and target scattering. Several models have been proposed for target scattering. We used a point scatterer model to compute the channel matrix. The finite scattering point model presents an interesting parallel with the random walk problem.

We have explored this close mathematical relationship and have proposed a Bayesian approach to estimate the number of scattering points contained in one pixel (Figure 7). We demonstrated that under certain hypothesis effective automatic target recognition can be done using a single “snapshot” of the scene. Under the same hypothesis and processing the MIMO data in a coherent manner we also demonstrated why super resolution is possible using large MIMO systems. We showed that it is possible to distinguish two scatterers spaced by only one wavelength (Figure 8). Note that the resolution obtained by coherent MIMO sonar systems surpasses SAS (synthetic aperture sonar) resolution. We have also shown the importance of independent views for MIMO systems. A formal definition of independent views has been developed and a MIMO intra-views distance correlation matrix has been derived using the distance correlation [12]. The computation of this matrix leads to an effective design for MIMO systems.

We then developed a 3D MIMO simulator capable of generating MIMO time signals from a full 3D environment. The simulator includes multiple transmitters and receivers spatially separated, bistatic reverberation contributions (bistatic reverberation levels are computed using bistatic scattering models developed by APL-UW [15], Figure 9), multi-paths (bottom and surface bounces), fractal seabed elevation map, different types of seabed sediments, mid-water targets. We demonstrated that even with a coplanar MIMO system (TXs & RXs in the same plane) it is possible to estimate the depth of an underwater target with great accuracy using autofocus algorithms (between 10 and 50 cm precision depending on its position in the water column for a target at a range of 400 m, Figure 10).

We ahve collaborated closely with WP5 and designed a harbour surveillance scenario where a particular harbour area has to be protected. An underwater intruder launched from a boat penetrates the restricted area. The output of the MIMO simulator feeds the new multi-object tracker developed by WP5 [15]. As the tracker keeps the track history of each target, it is then possible to relate the intruder with the boat that launched it.

Outputs of this work have been submitted to Journal of Oceanic Engineering [K] in the form of one journal paper and to Underwater Acoustics Conference 2014 with two invited conference papers[L, M]. A summary of MIMO sonar systems will be presented at the SSPD 2014 conference in September [N].

PhD Research - Estimating targets in scenarios with spatio-temporally correlated clutter

The goal of this project is to develop robust algorithms to process sensor data and produce reliable estimates of the state of contacts of interest in scenarios with challenging clutter patterns, such as the maritime environment. The data is expected to come from heterogeneous sources, such as sonar, radar, ESM, vision, and more. Some of these sensors only provide partial information about the state of the observed targets (e.g. bearings-only sensors like cameras and passive sonar), so it is important to use information from multiple sensors to obtain an accurate picture of the situation. An initial goal of the platform will be to fuse the data in order to provide an operator with a single representation for the incoming data from the sensor suite where all the incoming information is exploited to obtain accurate tracks for any present contacts of interest. Another problem to tackle will be automatic sensor calibration, where the reference frames of each sensor must be registered in order to accurately integrate the information they provide.

Jose Franco started his PhD in January, with the initial aim of implementing a multiple target tracking tool for maritime scenarios which is fed by information from multiple sensors. The plan is to base this in Emmanuel Delande's implementation of the novel multi-object filter which would allow this to be carried out despite having noisy, cluttered data from each sensor. To achieve this, Jose has been investigating material on measure theory and probability material to better understand the theoretical notions of the filter, alongside preliminary versions of the paper documenting the filter. He has also participated on trials for MarCE Task 3.009 which involved data acquisition in a maritime scenario using Dstl unclassified data to enable better understanding of the situations under which the filter testing data was acquired. The progress so far consists on having attended MarCE trials for data gathering in a maritime environment and studying novel filters and possible implementations to tackle these problems

Future Direction

We have identified three areas of work that Dstl are interested in and that is in line with our research interests and expertise:

SAS study beyond imaging will investigate the information that is lost or not used in the image formation process that could improve target detection. We have initial results on coherence and permanent scatterers. Data is now required to validate this. Dstl has provided access to element-level data from MUSCLE SAS. We will explore with SAS manufacturers and users to collaborate and get access to data (FFI in Norway, DRDC in Canada and ATLAS UK). The aim of the study would be to demonstrate that additional useful information not present in the image can be extracted.

Sonar simulation will be evaluated and the effort required to produce simulators at different frequencies and levels of accuracy (multipath, target and seabed interaction) will be investigated. Discussion will take place with ART-UT and APL-W in the US who are very active in the field. NICOP is also an option.

Dstl will shortly provide a report on passive acoustics to set the scene and helps us qualify our input. There are strong links with other research packages within the Consortium.

Research Leader: Neil Robertson

Academics: Andrew Wallace, James Hopgood

Research Associate: Rolf Baxter

PhD Student: Puneet Chhabra

WP4 Context Driven Behavior Monitoring and Anomaly Detection

The challenge is to identify and classify behaviours as normal or abnormal, safe or threatening, from an irregular and often heterogeneous sensor network. Although some general principles may be applied, there is unlikely to be a unified approach that can be applied across different sensor domains; for example, tracking moving 'blobs' in radar or sonar data is quite distinct in dimension, mathematical and applied treatment from tracking human subjects in CCTV image data. In this work package we focus specifically on the problems of using electro-optic (video, IR, LIDAR) and audible data to monitor behaviour and detect anomalies, thus addressing a number of specified areas of interest and challenges. In particular we address detecting anomalous behaviour in audio-video sensor networks which addresses the problem of statistical anomaly detection, in video pattern recognition and combined video and audio sensors. This can be applied to tracking people and objects in surveillance networks.

Mobile vehicle monitoring, resource allocation and situational awareness task addresses the problems of signal detection in high dimensional feature spaces, and of the extraction of meaningful targets in clutter, as part of situational awareness of a mobile platform.

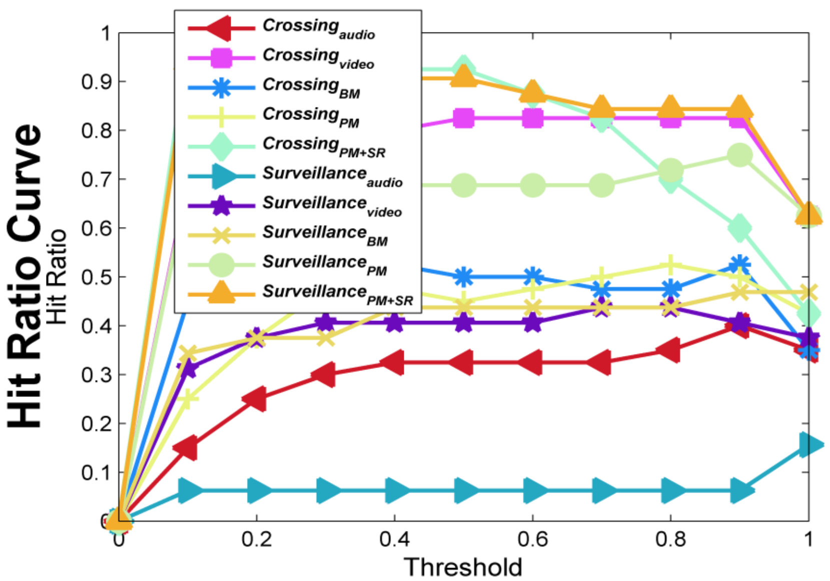


Figure 11. Joint audio-video processing outperforms single modality and previous joint methods

Outcomes

We have developed new algorithms for: audio localisation and tracking; video detection (person, gait, and head) and tracking; head-pose estimation in range and video sensors as well as contextual segmentation techniques and higher-level inference. A code repository is under development in the Visionlab at Heriot-Watt University to combine the outputs of associated PhDs and RAs on other projects into a single location.

Work has developed new features for automatically partitioning signals derived from video into contextual zones for improved anomaly detection in a challenging "big data" problem [S].

We have engaged with industry and Dstl to refine the research goals, plan and develop exploitations routes as well as engaged in knowledge transfer to staff in UK Defence Industry (Roke, Thales, and QinetiQ).

The research has been reported in a number of conference papers published at the leading IEEE Signal Processing Society conferences ICASSP and ICIP. Further to this we have published 1 journal paper and submitted 1 journal paper.

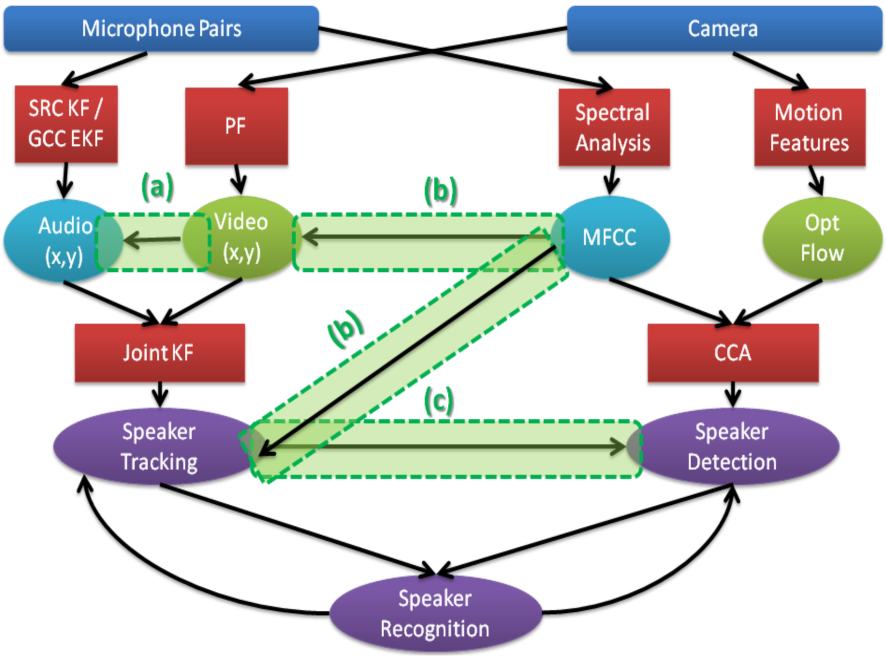


Figure 12. Schematic of new audio-video tracker

Progress

In Q1, we succeeded in combining video motion of people in an indoor surveillance network with audio beam-forming localisation of sound sources. This has improved our ability to automatically discriminate the true speaker from background noise and motion. In a normal conversational mode, this has proved to be a very strong cue (people tend to move and gesture when talking), see figure 12. We have demonstrated improvement over the state-of-the-art and presented this work [O, Q]. This work continued into Q2 and resulted in submission to ICASSP [P, R].

In Q2, due to the success of our capital funding proposal (EPSRC Great Technologies, ROBOTARIUM, £6.1m) we have secured finance (£0.7m) for advanced Signal Image Processing equipment which will enable demonstrators and further experimentation within this work package. In particular we have defined a pair of sensorised mobile vehicles, equipped with heterogeneous and low power computing to gather data and conduct trials “in the wild”. Effort by related EngDs (Iain Rodger, Thales) and RAs (Calum Blair) has contributed to the specification of the necessary equipment. This includes: vehicle LiDAR, LWIR cameras, video cameras, 72-channel microphone arrays, mobile GPU cluster and platforms (VW vans, suitable retrofitted) as well as access to a “supercomputer” cluster and indoor sensor suite.

Rolf Baxter extended our previous work on the high-level analysis of human activity in video. This work is relevant to the “Networked Battlespace” in that time-ordered detections are shown to be unhelpful when sparse examples are available for training. A new “bag of features” approach was extended and submitted to Pattern Recognition [T].

In the short term video is the focus and we are addressing the challenge of jointly tracking, exploiting contextual information and doing anomaly detection, see figure 11. Rolf Baxter re-implemented the state-of-the-art by Pelligrini et al. [14] (ETH Zurich) to show failure modes. We developed ground truth for three surveillance scenarios and began research on the use of focus-of-attention as an *intentional prior* (figure 13). Analysis of these large signals (tracks and head-pose) revealed that there are distinct contexts within human activity, which may lead to enhanced anomaly detection – a task which is normally too subtle for the machine. There are social, temporal and spatial contexts and the challenge is to develop a unified mathematical framework for mobilising these priors. We continue to work on this problem with Roke Manor and have submitted preliminary results to the SSPD conference [U].

PhD Research - LIDAR sampling and full waveform processing for information capture and situational awareness

Puneet Chhabra started his research in anomaly detection in LIDAR signals. This research addresses the Dstl challenges on “Maximising the information capture from LiDAR” and “Algorithms and techniques to manage noisy 3D point clouds”. So far we have identified several technical challenges in detecting partially occluded targets in cluttered environments: urban cities and dense vegetation. We have outlined a framework that takes preliminary steps in detecting such targets. In the last quarter we have identified recent work in the LIDAR domain and have looked at full-waveform, single and multi-spectral LIDAR data. Initial experiments show that point-cloud clustering could be an important step towards part-based object detection and recognition. A first year report will provide a detailed literature survey and associated experiments. We will continue investigating algorithms and techniques that learn both geometric and spectral properties of objects. ACFR and Kitti datasets (Sick and Velodyne data) will be used for such experiments. But these datasets do not provide any spectral information. We see an opportunity to capture new datasets and working with our partners we hope to identify ways in which spectral (multi and hyper) information for individual points can be recorded. This will boost detection and classification accuracy.

Future Direction

We aim to develop processing techniques for the contextual analysis of signals derived from video data of people in scenarios where potentially threatening or suspicious behaviour may be in evidence. The contexts to be considered are: social (groups); spatial (where); temporal (when in relation to pattern-of-life). We will continue to work on surveillance data as a proxy for the scenarios agreed with Dstl (e.g. forward operating base).

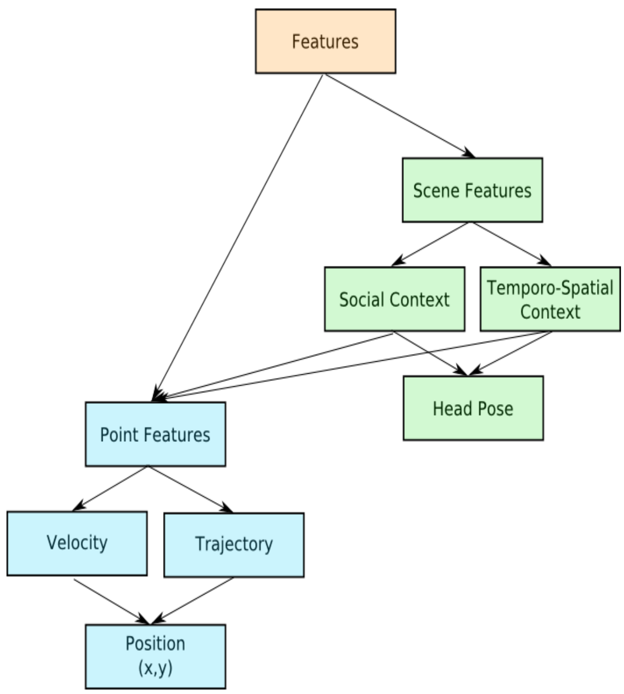


Figure 13. Relation of point to advanced features for intentional tracking

We will set up the Mobotarium sensorised vehicle for deployment of situational awareness algorithms in real-time in outdoor environments and will seek to work on the development of audio anomaly detection algorithms in larger indoor and then outdoor spaces, leveraging the acquisition of a 72-channel acoustic camera from EPSRC.

Research Leader: Daniel Clark

Academics: Yvan Petillot, Mike Davies, Mathini Sellathurai

Research Associate: Emmanuel Delande

WP5 Network Enabled Sensor Management

The aim of this research is to investigate the resolution of sensor management problems involving hierarchical information-based decisions at different levels of the signal processing chain (sensor modes and multi-sensor control policies). The general goal is to provide a unified framework for multi-object Bayesian filtering (i.e. multi-target detection and tracking), multi-sensor data fusion and sensor management.

A novel multi-object filtering framework [19, 20, 21] is the backbone of the developments in this area. We actively participate in the theoretical developments of this framework in order to incorporate elements of the signal processing chain that are needed for the resolution of sensor management problems. These are most notably, the construction of track histories, currently lacking in the Finite Set Statistics framework [25], and the production of information-based decisions to solve Partially Observable Markov Decision Problems (POMDP) in the context of multi-target multi-sensor management problems [23]. In a similar spirit as the Finite Set Statistics framework, we also aim at exploiting these results to derive multi-sensor / multi-target tracking filters following a principled and rigorous approach. In collaboration with other work packages, notably WP3, we also aim at developing sensor models which are well-adapted to the physical constraints of the practical problems to be solved, and can fit within the multi-object filtering framework.

Outcomes

A regional multi-object variance for sensor control is the first outcome. The higher-order regional statistics developed can be used as an assessment tool for decision making in sensor management problems. The expected target number with associated uncertainty computed in any arbitrary region of the surveillance scene (the surroundings of a position of critical importance, the whole surveillance scene, etc.) provides an assessment of the tracking performance in specified regions of interest for the surveillance activity. Secondly, the regional statistics are relatively inexpensive to evaluate and can be computed alongside the usual filter output [V].This paper introduces the variance in target number, derived from the second-order moment, as a measure of uncertainty on the expected target number in any region of the surveillance area. This high-order statistic is derived and implemented for the Probability Hypothesis Density (PHD) and Cardinalized PHD (CPHD) filters; Monte Carlo computational methods are also presented, see figure 14. The region-based variance is illustrated through simulations of multi-target scenarios and this study shows that the region-based variance should provide a valuable input for sensor management and fusion problems. The regional statistics were later on extended to multi-Bernoulli processes, another representation of a multi-target configuration widely used in multi-object filtering [W].

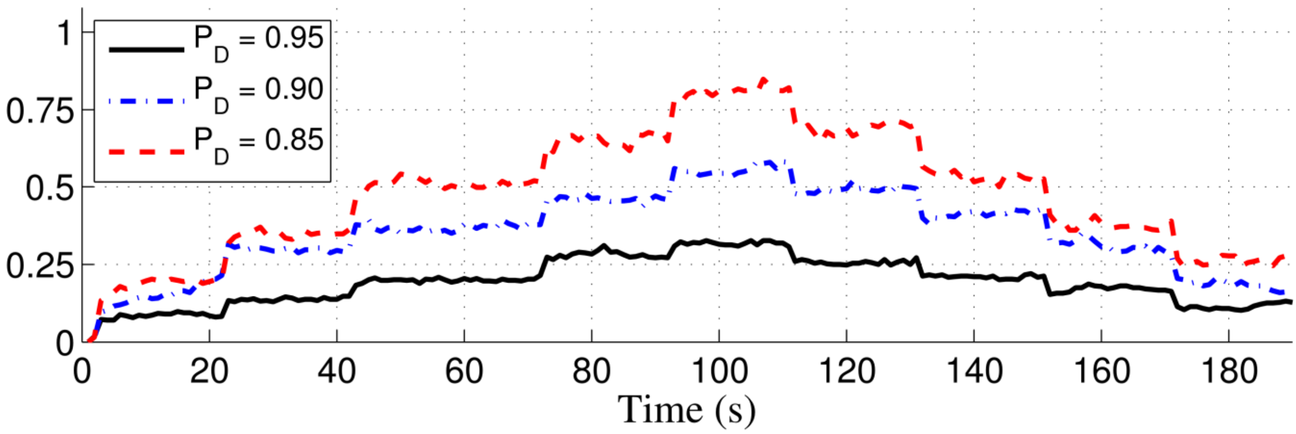
Exact multi-object tracking filters. The design and implementation (Matlab with embedded C) of the Independent Stochastic Populations (ISP) filter, drawn from the novel multi-object framework we are currently developing, is a cornerstone for the future developments of this work package. Providing that the targets behave independently (i.e. no correlated motion or correlated measurements), and that detected targets produce a single measurement per scan, this multi-object filter aims at providing a near-optimal solution to the tracking problem. In particular, it offers good performances in challenging scenarios where targets are crossing, the clutter level is high and/or the probability of detection is low. In addition, it maintains a track history for each detected target. This filter is the topic of a journal article in preparation, for a submission in IEEE TSP and this filter will be exploited in a maritime surveillance scenario in collaboration with WP3.

Information-theoretic sensor control for multi-target tracking. The design of the two performance metrics for the ISP filter, the regional high-order statistics and the regional information measure [X], provides the first step for the evaluation of the information gain in a closed-loop sensor management problem [23]. Both solutions are promising and could fit as complementary elements in the design of a reward function for the decision policy.

Progress

The first period focussed on the construction of a novel performance metric available to multi-object filters and exploitable in close-loop sensor management problems [23]. While the tracking community involved in Finite Set Statistics has mainly focussed on providing a unified approach for multi-object filtering and multi-sensor data fusion, few research papers relate to sensor management for multi-object filtering.

A recent approach exploits an information-theoretic metric to assess the global situational awareness (i.e. in the whole surveillance scene) [26]. In general sensor management problems, especially when the sensor coverage is limited, a more adapted metric would be able to provide a local assessment of the situational awareness in any region of the surveillance scene including the whole surveillance scene itself in order to help the operator decide where the sensor coverage is lacking and where it is redundant before reallocating the sensing resources.



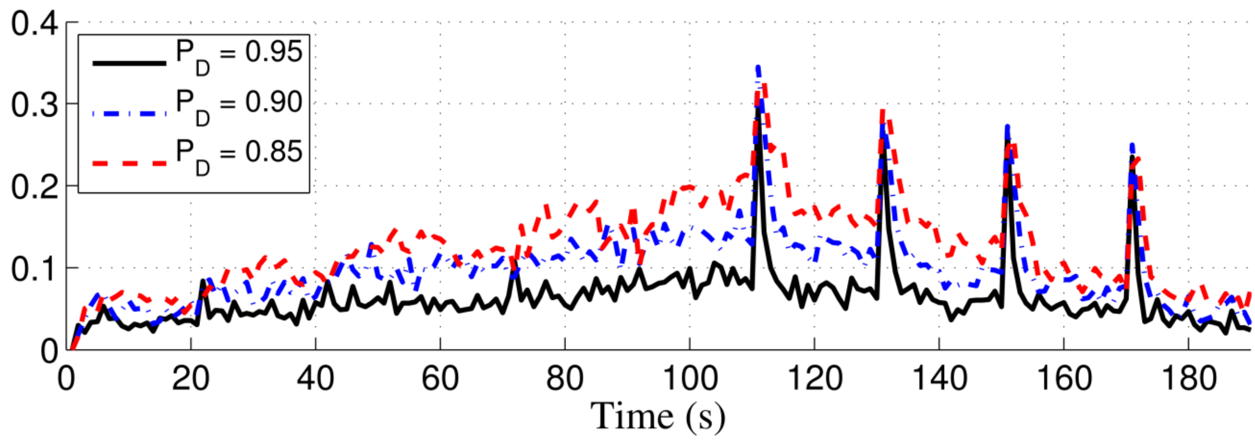


Figure 14 Regional variance in target number, integrated in the whole sensor's field of view, for the PHD (above) and CPHD (below) filters tested on a common scenario and with different probability of detections

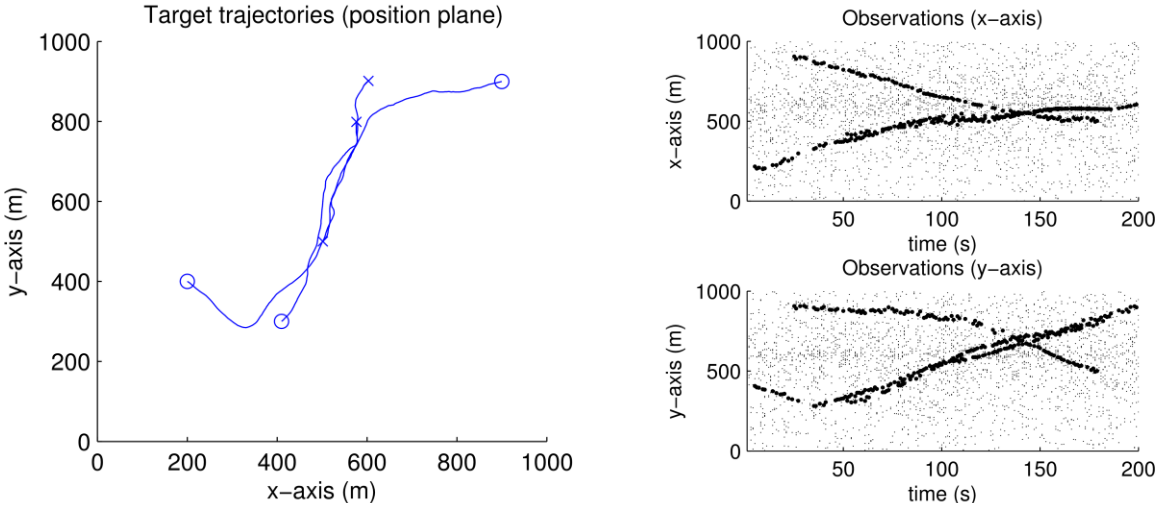


Figure 15 Challenging scenario with crossing targets. Left: true trajectories of targets (2D plane). Target births are marked by circles, target deaths by crosses. Right: observations produced by a radar (SNR = 9 dB, P_fa = 1e-4, P_d = 0.65).

The main reason why a region-based information metric is unavailable is that the usual multi-object filters; PHD filter or CPHD filter do not provide second-order information on the local target number, that is, an uncertainty associated to the estimated target number in any region of the surveillance area. Based on the results of an early research study [29, 30] and recent developments in functional derivation for point processes [19], we implemented and tested on simulated scenarios, for both the PHD and CPHD filters, the concept of regional variance in target number [P]. Following this study, we proposed the construction of the regional statistics for multi-Bernoulli processes [Q].

A limitation of the regional statistics, shared with the information propagated by the usual multi-object filters [27, 28], is that they describe the population of interest as a whole and do not provide an individual description of each individual. This has important consequences for sensor management problems, because one may not discriminate potential sensor controls relatively to the information gain they provide for specific individual(s) of interest.

Time in Q3 was spent on the implementation of a novel multi-object filtering solution, the Independent Stochastic Populations (ISP) filter. Exploiting the concept of target distinguishability introduced in [31], the ISP filter propagates, within a well-defined probabilistic framework, individual information on potential individuals or targets which have already been distinguished through associations with past observations, and collective information on the population of indistinguishable, because yet-to-be-detected, individuals.

The aim of this filter is to provide the optimal solution to the multi-object Bayesian filter for independent targets and it is significantly more computationally expensive than well-established multi-object solutions such as the PHD or CPHD filters. For this reason, we favoured an implementation in C than in Matlab, and we completed the first efficient implementation of the ISP filter in C code.

This filter was tested on challenging scenarios (target crossings, with significant clutter and/or low probability of detection) where the individual information propagated on each target is likely to produce better results than the usual multi-object filters (figures 15 and 16). A first version of the paper is expected to be released on ArXiV before mid-April, and a submission to IEEE TSP will follow soon. Collaboration with Yan Pailhas and Jose Franco has been established for a future exploitation of the ISP filter for a maritime surveillance scenario.

On another aspect, novel performance metrics have been developed to incorporate the ISP filter in a closed-loop sensor management problem [23]. Since the ISP filter is a multi-object propagating individual information on detected targets, the range of available performance metrics is wider than for the PHD or CPHD filters, and they could be used as complementary tools in the design of a sensor decision policy. The regional statistics [P], also available in this context, are particularly easy to evaluate and inexpensive to compute in the case of the ISP filter.

Another approach was explored through the information measures such as the Rényi divergence [24]. Exploited in multi-object filters derived from the Finite Set Statistics framework [25], it had been previously exploited to produce a reward function evaluating the information gain of a specific sensor action in the estimation of the multi-target state in the whole surveillance scene [32]. Incorporating the concept of target distinguishability, we produced a reward function based on an information measure that is target specific (i.e.the information gain on the localization of each track appears explicitly in the performance metric) and

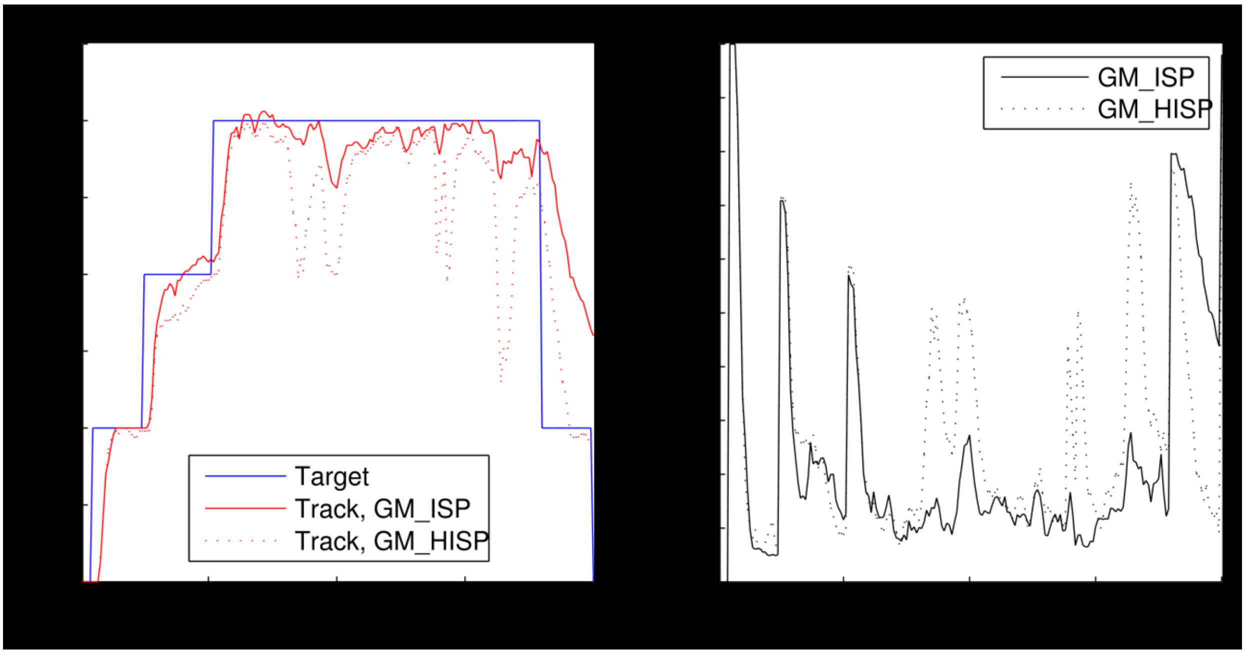


Figure 16. Simulation results comparing the ISP filter to the HISP filter [13]. Left: estimated target number. Right: OSPA distance. The target probability of survival in the filtering model, set at almost one except at the edges of the surveillance scene, does not match with the ground truth since the targets are disappearing in the middle of the scene. This voluntary ill-match between the model and the reality, interesting to study in its own right, explains the drop of performance in the last period of the scenario.

region specific (the evaluation of the information gain can be restricted to any arbitrary region of the surveillance scene, including, in particular, the whole scene). This solution is not restricted to a specific information measure such as the Rényi or the Kullback-Leibler divergence and if necessary, a different parameter alpha can be set for each target, depending whether the emphasis in the information gain must be made on the predicted or the updated track [Q]. Performance measures exploiting the Cramer-Rao lower bound are available for single-target tracking [33], and the study of the adaptation of its multi-target extension [34] to the multi-object filtering framework started is ongoing.

Future Direction

The first axis of development is the design and resolution of sensor management problems for multi-target tracking exploiting the ISP filter and the performance metrics we have recently designed. Discussions with Dstl on sensor management for single target tracking using performance bounds [31, 32]; have been engaged on this point. In addition to the design of relevant sensor management scenarios for multi-target tracking, an important future step will be to broaden the range of admissible sensor actions (i.e. available options from which the operator must choose at each decision time). Following [35,36], we have recently proposed a modelling of range-bearing sensors (with eventually Doppler) for which, with a given set of physical characteristics (bandwidth, beamwidth, etc.) one can select two of the three stochastic characteristics that will impact the filtering process - SNR, probability of false alarm, probability of detection – the last one being constrained. In our current formulation of the problem a sensor action is defined as a triplet (SNR, p_fa, p_d) and the reward function for such an action is the expected information gain based on the performance metrics we have designed so far. In the longer term, we will therefore explore the incorporation of changes in physical characteristics as part of the control, and the integration of an incurred cost in the reward function (e.g. for energy consumption).

Development will also centre on the extension of our novel multi-object filtering framework in order to broaden the capabilities of the tracking algorithm. An envisaged improvement is the incorporation of target classification in the probabilistic framework, in order to be able to discriminate primary targets from secondary objects, which must still be tracked to provide a better estimation of the multi-target configuration but play a secondary role (at best) in the shaping of the sensor decision policy. New developments in this domain are likely to increase the computational complexity of the proposed solutions, and a more efficient implementation of the ISP filter (using parallel processing and/or a translation to C++/Java) will be necessary in the near future.

Research Leader: John Thompson

Academics: Andrew Wallace, Neil Robertson

Research Associates: Calum Blair, Shaun Kelly

PhD: Saurav Sthapit

WP6 Efficient Computation of Complex Signals Processing Algorithms

This research allows the deployment of complex signal processing algorithms in a wider variety of devices and environments. To do this we are concentrating on three of the Dstl technical challenges which cover 3D SAR Processing, Accreditable machine learning or data-driven techniques and Reducing SWaP.

The first part of the research in efficient parallelisation of sensing processing focuses on two discrete approaches to this problem each dealing with a different domain.

Our SAR work focuses on the hardware acceleration of state-of-the-art algorithms generated, in particular the acceleration of compressive sensing (CS)-based synthetic aperture radar (SAR) image formation algorithms. Many of the state-of-the-art SAR image formation algorithms for systems with sensor constraints are based on techniques from the CS literature. Such systems include three-dimensional (challenge 5), ground moving target indicator (GMTI) and low-frequency (LF) SAR

For CS based image formation algorithms to be computationally feasible, fast forward and backward algorithms for the SAR observation model must be available. Computationally efficient algorithms for these forward and backward operations (the fast re-projection and back-projection algorithms) were developed in UDRC phase 1. In this work we aim to investigate the use of graphics processing units (GPU) to exploit parallelism in these algorithms to further reduce the image formation times of CS

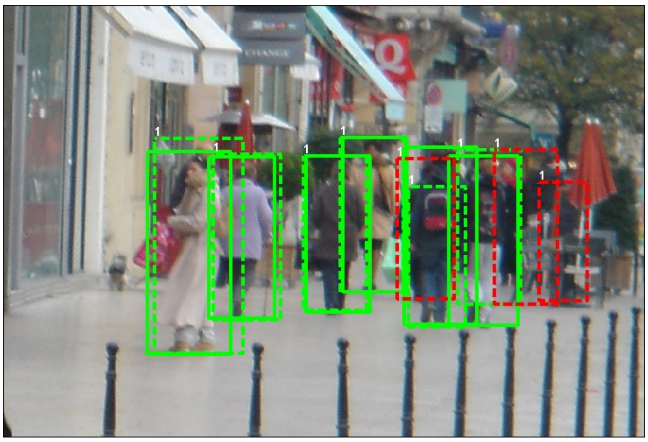


Figure 17: State of the art classifiers are overconfident, labelling false detections (right, red) with same probability as true ones.

Figure 18: Gaussian process classifiers generally provide lower confidence (probability ~=0.5) in uncertain regions (right,red).

based algorithms.

Work on improving accreditable machine learning is also being undertaken alongside a Dstl challneg on Size Weight and Power (SWaP) where a scenario is used involving pedestrian detection in images and video. This is an active area of vision research and classifiers developed for this problem perform well when retrained on other vision tasks (object detection and surveillance). This approach can also be applied to any classifier system from which reliable probabilistic classifications are desired.

This could be considered as part of a larger system, where uncertain detections or areas are investigated by a human or remote sensor. Our aim is to generate fast, low-power detections which are accurate and have a reliable level of confidence associated with each. If an unusual data sample is presented to the detector which is considerably different from the training data, this should be reflected in a low confidence in the classified output.

Current state of the art detection algorithms are optimised to produce accurate detections at the expense of reliable confidence scores, which often results in classifiers which are massively overconfident in their predictions. We aim to investigate techniques to improve this score generation while preserving the accurate performance of current state of the art classifiers. We must also consider runtime and memory requirements and investigate techniques to reduce these where necessary.

Outcomes

A paper was presented at VISAPP [Y] based on a power consumption comparison of FPGA and GPU. Here we consider the problem of conserving power consumption while preserving detection accuracy. Consider a visual surveillance scenario where the system is battery-powered or where system power consumption is otherwise constrained. As an example, detection of anomalous behaviour in people and vehicles in an urban environment is used. This paper describes a method for moving processing between processors each with different power consumption and work rates to prioritise low power consumption or high speed, depending on the degree of anomalous behaviour seen at any point in time. Such a topic has not been covered before, to the best of our knowledge. This analysis can in the future be extended to (i) other surveillance tasks and (ii) allow autonomous low-SWaP systems to automatically prioritise power consumption, detection accuracy or detection speed depending on the external conditions they are observing. Analysis of this decision between power/speed/accuracy will be revisited in the second part of the research for different scenarios.

Work based on the progress made on the classification problem titled "Introspective Classification for Pedestrian Detection "[Z], has been submitted to SSPD.

A paper based on the SAR work [A1] was accepted for a presentation at the IEEE Radar Conference.

A paper on fast back-projection algorithms has been submitted to SSPD

[B1] and investigates the application of multi-core central processing units and graphic processing units, to further speed up a recently proposed fast back-projection algorithm.

Progress

Progress in this work package can be split into the domains of SAR and vision. Considering SAR first, the progress has involved modifying the fast algorithms so they are suitable for GPUs. Fast (re/back)-projection algorithms have two main components, recursive decimation/upsampling and standard (re/back)-projection. These two components cannot be done in parallel. However, within these components, parallelism may be exploited. A list of modifications to the algorithms which allow them to exploit a parallel processing platform is below.

The standard (re/back)-projection algorithms were modified to make use of recent advances in non-uniform FFTs (NFFT) to reduce the memory usage. Memory usage is highly constrained on GPUs.

The loop ordering of the computational elements in the standard (re/back)-projection algorithms was modified so they are now independent. The independent elements can be used as parallel threads on a GPU.

The recursive decimation/upsampling structure in the algorithms has been replaced by a loop structure. Loop structures are more suitable for parallel processing than recursive structures.

Initial investigation into the choice of decimation/upsampling kernels based on speed and accuracy.

Considering the problem within the vision domain of accreditable classification, progress has been made in understanding and improving the performance of current state of the art classifiers and progress is outlined below.

We Identified weaknesses in current classifiers: current machine learning algorithms such as support vector machines (SVM) and Adaboost with decision stumps or decision trees (aka Random Forests) generate high-scoring detections when presented with feature vectors which are outliers compared to the training data. This is an inherent trade-off of the ability to return hard decisions for those points close to the boundary between positive and negative training samples.

We identified weaknesses in techniques for generating probabilistic classifications from raw classifier scores: techniques such as sigmoid fitting can produce probabilistic outputs from raw scores but points far from the decision boundary are erroneously reported as high-confidence detections. Platt scaling and isotonic regression approaches can be effective in this regard.

We have developed trained classifiers which take better account of predictive variance: Gaussian Process Classifiers (GPCs) take better account of predictive variance than existing approaches. We have had promising results by using these, see figure 16 and 17 (performance is close to state of the art). However, GPCs work by storing all the training samples for use at test time and rely on covariance between test and training samples. Memory requirements and computation time for these calculations are proving prohibitive, especially when considering future deployment into embedded systems. Metrics which take into account the introspective quality we are looking for and deviation of current classifiers from the ideal case: measures based on the error rate (precision and recall etc.) do not capture the difference in confidences from different classifiers. [34] has identified entropy as being a useful measure which rewards appropriate uncertainty better. Similarly, an mean-squared error (MSE)-based approach is also appropriate. Using reliability diagrams we can rank existing classifiers and our modified ones in order of their approach to the ideal, well-calibrated case.

PhD Research - Signal Processing and Anomaly Detection for Multi-Sensor Systems

Many signal and image processing algorithms are computationally intensive and demand efficient solutions that enable them to operate in real time. Recently, there has been significant interest in multi-core processors, GPU and FPGA that enable parallel processing of complex signal processing algorithms. This project will study new algorithms that can process data from multiple sensor types, such as video cameras and microphones. The objective is to develop efficient real time implementations of algorithms for tasks such as detecting objects or people in a scene. Saurav Sthapit is currently exploring smart-phones as an embedded platform with sensors and computational capabilities. While there are many problems such as limited energy, limited computing power, localisation etc.; the benefits easily outweigh them. We have implemented computer vision algorithms such as Face Detection and object tracking on mobile phones (Android). We are looking at the energy ccost of running these algorithms versus. sending the sensor data for further processing using Wi-Fi, Bluetooth or 4G. The next step is to develop intelligent algorithms for person detection and tracking people across multiple sensors. Unique features would be generated and communicated between nodes in order to track objects. Anomalies could be detected if between the scenes, the object appears, disappears or changes abnormally etc.

Future Direction

Plans for remaining work in WP6.1 involve completing the evaluatiion and improvement of the performance of classifiers. This will be followed by a parallelised GPU implementation of a real-time introspective GP classifier. From August we will start work on WP6.2 (Implementation of Distributed Signal Processing Algorithms). This will involve liaising with Dstl for a study into “Distributed Processing within an RF sensor network” and may also include work in conjunction with WP4 and the use of the EPSRC funded Mobotarium equipment at Heriot-Watt University to consider the effect of static and moving sensors, communication and sensing in a network with low-SWaP devices.

Plans for our SAR work include the Exploitation of parallelism in both decimation/upsampling and standard (re/back)-projection using a GPU and the quantification of the effect of parallelism on the computational time of CS based SAR image formation algorithms.

Linkages

Related activities and linkages

The Edinburgh Consortium maintains strong links with other areas of signal processing for defence. These links are with academia, defence and industry. Some of the synergies and linkages are listed below:

Other MOD Led programs:

Edinburgh has started to engage with the MarCE (Maritime Collaborative Enterprise) program as well as the Dstl National PhD Program. We are also involved in discussions with the ITA program.

We are also involved in the newly formed Robotics and Autonomous Systems Alliance between Edinburgh and Heriot-Watt University which recently secured £7.2M of capital equipment funding which will enable us to access data and test algorithms more easily.

Discussion is ongoing with Dstl with regard to potential projects and the Dstl Enabling Agreement has now been finalised.

PHD and EngD students

A number of students are supervised by the Edinburgh Consortium and these link in with signal processing for defence.

Underwater depth-imaging using a time-of-flight single-photon counting technique

PhD: Aurora Maccarone, Heriot-Watt University, Dstl, SUPA
Lead Supervisor: Andrew Wallace, Heriot-Watt University

The time-correlated single-photon technique has emerged as a candidate for use in LIDAR and depth imaging applications. The high sensitivity and time resolution possible with single-photon counting has made this approach a candidate also for underwater applications. The aim of the project is to develop a single-photon counting system that could achieve centimetre xyz resolution at stand-off distances of 10-100 metres. The purpose of this project is to investigate the use of state-of-the-art single-photon detection techniques and assess performance in underwater depth imaging, by developing prototypes and demonstrating these systems in a variety of underwater conditions.
Poster can be found using this link *Underwater depth imaging using time-of-flight single-photon counting approach*

Multistatic single data set radar detection in coloured gaussian interference

PhD: Bogomil Shtarkalev, University of Edinburgh
Lead Supervisor: Bernard Mulgrew, University of Edinburgh

Space-time adaptive processing (STAP) for radar perform target detection in spatio-temporal coloured interference. Traditional detectors rely on target-free training data to form an estimate to the interference covariance matrix. The maximum likelihood estimation detector (MLED) and its generalised counterpart (GMLED) perform covariance estimation and target detection on the single data set in the cell under test (CUT). In this work we extend the algorithms to a multistatic scenario where a multiple-input multiple-output (MIMO) radar system with spatial diversity gains. We show that the proposed algorithms are comparable in performance to the existing methods that need a training data set to perform detection.

Poster can be found using this link
Multistatic single data set radar detection in coloured gaussian interference

Dynamic distance-based shape features for gait recognition

PhD: Tenika Whytock, Heriot-Watt University
Lead Supervisor: Alexander Belyaev, Heriot-Watt University

This project is about recognising a person via the manner and posture of walking. In medical and psychophysics fields, gait is unique. The fundamental healthy walking pattern is similar across people although subtle variations in magnitude and timing aid person discrimination. This work can be used in applications which include surveillance and access control. As gait is a behavioural biometric (compared to physical e.g. fingerprint), no consent or cooperation is required and therefore is unobtrusive and also there is the ability to capture these traits at low resolution.

Poster can be found using this link
Dynamic distance-based shape features for gait recognition

Adaptive switching detection algorithm in Turbo-MIMO systems enabling power savings

PhD: Nina Tadza, Universiti Tun Hussein Onn Malaysia, University of Edinburgh
Lead Supervisor: Dave Laurenson, University of Edinburgh

This project reports on a new adaptive detection algorithm for Multiple-In Multiple-Out (MIMO) bit interleaved coded modulation systems based on switching detection methods for the Fixed Complexity Sphere Decoder (FSD) [1] and the Vertical Bell Laboratories Space-Time Zero Forcing (V-BLAST/ZF) [2]. The main objective of this project is to reduce the complexity and energy consumption of the overall MIMO receiver by developing a switching mechanism within the detector. Turbo-MIMO provides a near maximum likelihood (ML) detection performance, however, due to its iterative nature, the decoding process often leads to unnecessary power consumption especially during ill conditioned channels, where the decoder would be unlikely to succeed in detecting data correctly.

Poster can be found using this link
Adaptive switching detection algorithm in Turbo-MIMO systems enabling power savings

Sparse Representations and Low Rank Approximations for Activity Recognition

PhD: Sushma Bomma, Heriot-Watt University, University of Bern
Lead Supervisor: Neil Robertson

Recently, sparse approximation techniques have found wide use in signal and image processing applications. Sparse representations attracted many researchers in the signal processing community who are interested in effective reconstruction methods. Sparse representation of a signal is a linear combination of few elements or atoms from a dictionary. Primarily developed for robust reconstruction of signals, sparse representations are currently adopted in classification / recognition problems where the goal is more than finding a compact representation. The idea that sparse representations can be used for classification was proposed few years ago. It was shown how to improve the discrimination between classes by introducing a sparse reconstruction term to Fisher's discrimination criterion. The main focus was on the robust reconstruction of corrupted signals by sparse decomposition methods. Later, the discriminative property of sparse representations was observed that is the sparse representations are naturally discriminative over a dictionary constructed from a set of training samples. The approach was successfully applied to face recognition, object recognition etc. Most of the work is on image classification. Inspired by the success of this approach in image classification problems, we want to extend sparse representations for activity recognition. The challenging task in activity recognition is to extract features which give best discriminative sparse representations over dictionary formed by these features.
Poster can be found using this link
[Sparse Representations and Low Rank Approximations for Action Recognition]

Cognitive Radar within Autonomous Systems

PhD: George Tsistrakis, Heriot-Watt University, Dstl
Lead Supervisor: Mathini Sellathurai

Autonomous systems are required to gain knowledge about their environment through data collection and processing so they can make decisions about future actions in order to achieve their goals. The robustness of the decisions made is primarily dependent on the measurements of the environment and the quality of the exploitation of this data, and therefore this situational analysis is critical to the success of the autonomous system as a whole. Radar is one such sensor platform which is often vital for this purpose, and allows robotic and automated systems to work with beyond-human capabilities, due to the radar's capacity to operate in low visibility environments and provide imaging of sub-surface features such as ground penetrating radars (GPR) which has a wide variety of applications, some examples include geological investigations of terrain for mineral ores and planetary exploration, condition of engineered structures, such as bridges, railway tracks and beds and landmine detection, and therefore improvements in the field have high impact on a large number of activities. Further, the radar actively probes its environment and therefore can extract information that is required if used appropriately, but to make this ground-breaking step to be able to autonomously generate awareness, predict actions, schedule sensing, and aggregate sensor data intelligently, the radar system itself has to be cognitive or intelligent in its nature.

High impact applications include autonomous GPR, robotics and real-time sensor networks which can be used for autonomous environmental monitoring of physical and biological indicators, tactical surveillance, disaster prevention, undersea exploration, unmanned navigation, etc. Compared to the significant progress in the application of computer vision based intelligent system design, there is less progress reported to date on studying cognitive radar and related fields such as cognitive sonar. This project aims to enhance the effectiveness of field capabilities of radar technology as well as will produce potential for disruptive technologies. Poster can be found using this link

Adaptive Waveform Design for Cognitive Radar

Contextual Image Processing

PhD: Iain Rodger, Heriot-Watt University Thales, ESPRC
Lead Supervisor: Neil Robertson, Heriot-Watt University

The human visual system can quickly accomplish complete scene understanding, but is limited by information processing. To counteract this and improve situational awareness, sensor suites are constructed to collect and process environment specific information. Target detection systems are critical in situational awareness activities for both military and surveillance applications. Segmentation, detection and tracking stages are common tasks within these. Such systems are, however, hindered by complex, cluttered scenes as well as object occlusions and dynamic lighting. Total scene understanding, akin to the human visual system, should help to overcome these issues. Utilising context and segmentation is one way to achieve this.

Poster can be found using this link
Contextual Image Processing

SAR processing with zeros

PhD: Shaun Kelly, University of Edinburgh, Dstl, EPSRC
Lead Supervisor: Mike Davies, University of Edinburgh

The aim of this project is to develop computationally efficient algorithms based around sparse representation and fast (re/back)-projection techniques to successfully generate SAR imaging in the presence of either spatial or spectral notches in the data that are distortion and artefact free. The broad aim of this research is to explore the application of compressed sensing and sparse reconstruction techniques to preform SAR image formation when spatial and/or frequency notches are introduced into the transmitted/received signals. The key objectives of this research are: to provide computationally efficient algorithms that can accurately reconstruct a SAR image in the presence of spatial and/or frequency notches free from significant distortions and other artefacts; and, to determine, through analysis, the extent and nature of the freedom to introduce zeros into the beam patterns without incurring substantial loss in image reconstruction.

Poster can be found using this link
[RF Interference Mitigation for UWB SAR using Image Sparsity]

Ground-Moving Target Detection and Multi-Channel Radar Imaging

PhD: Stuart Kennedy, University of Edinburgh, Selex ES, The Royal Commission for the Exhibition of 1851, EPSRC
Lead Supervisor: Bernard Mulgrew, University of Edinburgh

This Engineering Doctorate project concerns the detection of slow-moving targets SAR using multi-channel receivers. Such targets are known to be badly focused and often appear at the wrong position in standard SAR processors that do not account for the targets' motion. The work is carried out in close collaboration with, and funded by, Selex ES. Additional support is provided by The Royal Commission for the Exhibition of 1851 through the award of an Industrial Fellowship.

The objective of the project is to develop practical algorithms for moving target detection that can be used in radar systems currently developed by Selex ES. It has the potential to fill a hole in current military radar surveillance capabilities by hugely enhancing the ability to detect slow-moving vehicles and dismounted combatants. There are also many civilian applications, including surveillance for perimeter protection as well as tracking movements of people, vehicles and animals in disaster areas, at public events and in conservation areas.

Poster can be found using this link
[Ground-Moving Target Detection and Multi-Channel Radar Imaging]

Audio-Video Convergence for Surveillance Applications

PhD: Eleonora D'Arca, Heriot-Watt University and University of Edinburgh
Lead Supervisor: Neil Robertson, Heriot-Watt University

Audio signals can provide valuable information for detecting events in video surveillance environments, and can thus be used to strengthen anomaly detection algorithms. By utilising knowledge of a scene's acoustic signature, audio and video events can be correlated and used to identify anomalous behaviour within a scene. Video object localisation and tracking are fundamental to scene monitoring and are pre-requisites for event detection and recognition. However, localisation and tracking are particularly challenging in surveillance scenarios due to the notoriously high levels of clutter and occlusion. The objectives of this PhD are two-fold: to explore the benefits of incorporating audio information into a video tracking system, and to evaluate the benefits of using video information to improve state-of-the-art sound source localisation/tracking and speech recognition algorithms. This has required novel investigation into how audio and video signals can be combined at different levels of semantic abstraction. Furthermore, because speech is a natural way to discerning speaking events, this PhD has specifically focussed on detecting the dominant speaker in a non-meeting environment, with the general principles applicable to surveillance applications for gunshot, fight or violent crowd detection.

Team at Away Day Meeting

Management

The UDRC has established an effective management structure with formal processes to manage issues, research collaborations and communication.

The Edinburgh Consortium is managed by Director, Mike Davies and Deputy Director Yvan Petillot. They meet on a monthly basis along with the Project Manager Janet Forbes to review progress and outputs.

Internal meetings are held quarterly and allow the academics, researchers and the project management team to update on progress, discuss the way forward so ensuring the efficient and effective implementation of the UDRC research.

The researchers meet fortnightly to discuss the status of work, collaboration opportunities and future perspectives. These meetings serve as a forum for the researchers to communicate their work and ideas in order to foster collaboration between different work packages.

One of the successful interactions which allowed the UDRC researchers to develop a good understanding of the expertise areas and experience of the other researchers was an Away Day at the Edinburgh International Climbing Arena (EICA), Ratho. The researchers gave presentations on their research interests and had discussions on possible collaborations before they joined in team building activities. UDRC researchers have also established a journal reading club which will catalyse the interactions further. The reading group started in January and their outcome will be embedded in the research meetings and will open out to a wider audience of fellow researchers.
In October the Strategic Advisory Group (SAG) met for the first time; the purpose of this group is to provide feedback to the consortium on the research it is performing and to ensure that the research output continues to target areas of national and international importance for the defence sector. The value of the research is judged with regard to MoD priorities, academic quality with respect to the best in the world, relationship with other MoD and UK industrial research and the relevance to the needs of the UK defence industry (including practicality of implementation).

The SAG also provides feedback on the engagement activities judging them on the facilitation of stronger links between signal processing research groups, defence industries and the provision to the government defence sector. The members also advise on the development of a single Community of Practise for defence-related signal processing research, spanning academia, industry and government.

SAG Membership

Andy Stove, Thales UK and SAG Chair

Andrew Baird, Dstl

Alfred Hero, University of Michigan

Bob Black, SeeByte Ltd

Bob Elsley, Dstl

John Anderson, BAE Systems

John Griffin, Selex ES

Malcolm MacLeod, QinetiQ

Matthew Lodge, EPSRC

Paul Thomas, Dstl

The SAG meets twice a year and receives a formal report from the Consortium Director to the group. This will be supported by a written document circulated prior to the meeting to allow the members of the SAG to be in a position to comment on its content. The SAG discusses the report, and the Chair verbally conveys their conclusions to the Consortium Director. The SAG's discussions will also be informed by the knowledge which individual members will gain through discussions with the researchers and from attendance at events organised by the consortium.

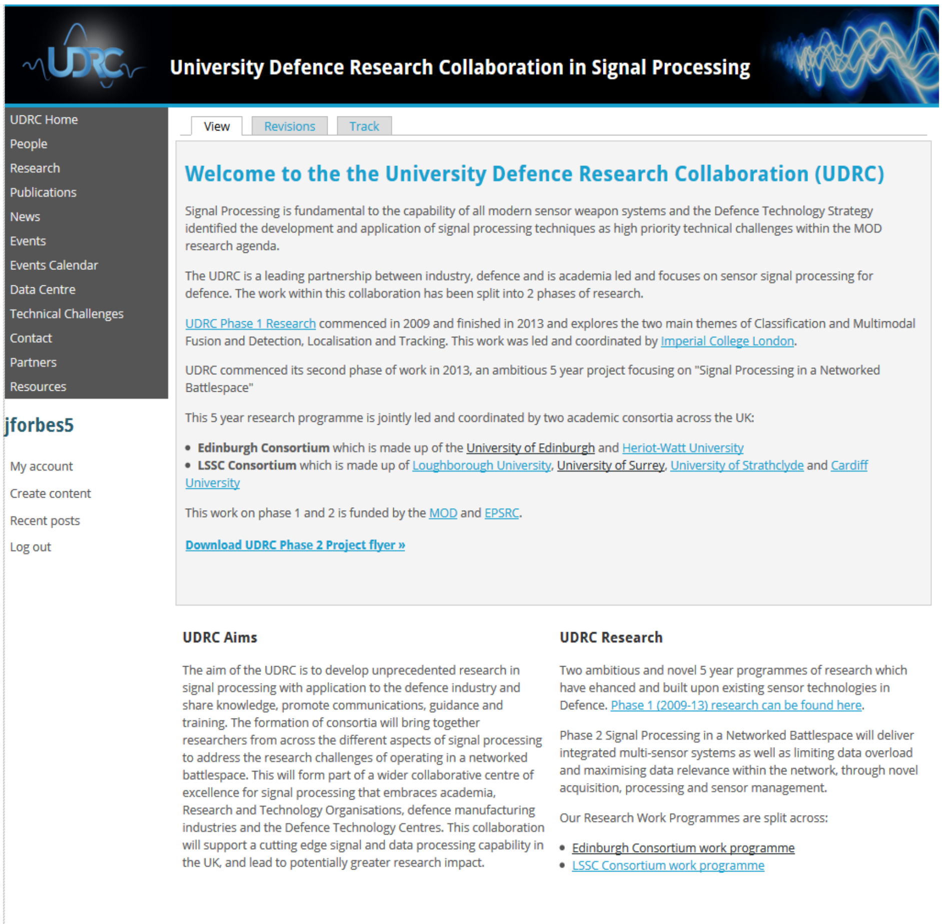
A Supporter Engagement Agreement was circulated in December and has now been formally agreed. It is designed to accommodate the involvement of the industrial partners in the UDRC projects as well as the external independent expert invited to the project. The main focus is on confidentiality aspects covering the Strategic Advisory Board and the technical updates/reviews coming from the respective projects.

A data repository has been set up to allow for the storage of data, research and software allowing both universities to work together more efficiently. This area allows for the storage of data up to 1TB. As well as this, the UDRC Wiki was created in August and proved to be an invaluable resource for the UDRC Team as members who were unable to attend meetings or events have been able to catch up on what they have missed. It holds all templates the Edinburgh Consortium will find useful, along with presentations, reports and minutes of all meetings. It also supports a constantly updated contacts database. As well as holding all the valuable historical aspects of the Project, as the Wiki becomes more interactive between Team members, any information gained can be readily shared and any useful insights picked up along the way can be retained safely on the wiki for future speedy reference. It is hoped going forward that the wiki will become a training bank for any new UDRC members as well as a knowledge bank and digital "think tank".

Engagement

Engagement and communication are key to the success of the UDRC and the Edinburgh Consortium have set up a detailed communication and engagement strategy which aims to create a two way communication channel between UDRC and interested stakeholders.

UDRC Website



SSPD website

The first year has seen the creation of two websites: the first www.mod-udrc.org.uk is a refurbished version of the phase 1 site and outlines the research within phase 2 and introduces the researchers and project team from both the Edinburgh and LSSC Consortia. The website allows for the advertising of UDRC events and related events. Research, publications and data from the phase 1 research can be still accessed if required.

The second website created is www.sspdconference.org which accommodates all information relating to the Sensor Signal Processing for Defence Conference Series, see page 53.

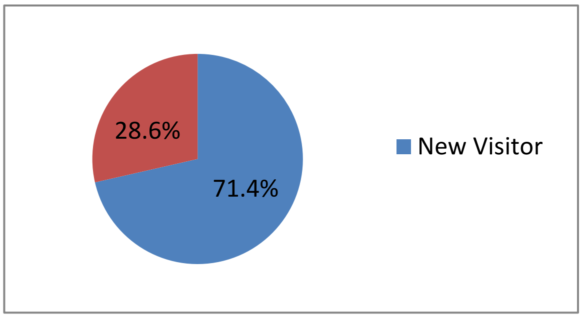
Both websites have been linked to a Google Analytics account where a tracking code has been inserted into the webpages of the site and will allow the reporting of the traffic to the websites. The Audience Analysis feature of this application will enhance our understanding of what the users expect from the site and through the recording of the key words and the sites which referred the user to the UDRC website it is possible to understand what the target audience is using the site for, therefore enabling the Team to determine a trajectory for the online presence of the project.

The programme allows us to report on the geographical location of the IP address of the website user, which will permit a good estimation of how far the awareness of the project has reached. Attracting international recognition of the project could be progressed through analysing the data received from this application.

How many people visited the website?

- Nearly 3000 people visited the website from July 2013, generating 26,416 page views.
- The percentage of new visitors to the site is 71% compared to 29% of returning visitors.
- Traffic to the website has remained consistent with number increases which are primarily due to spikes in traffic relating to the UDRC events such as the Phase 2 Launch and Summer School.

New visitor vs returning

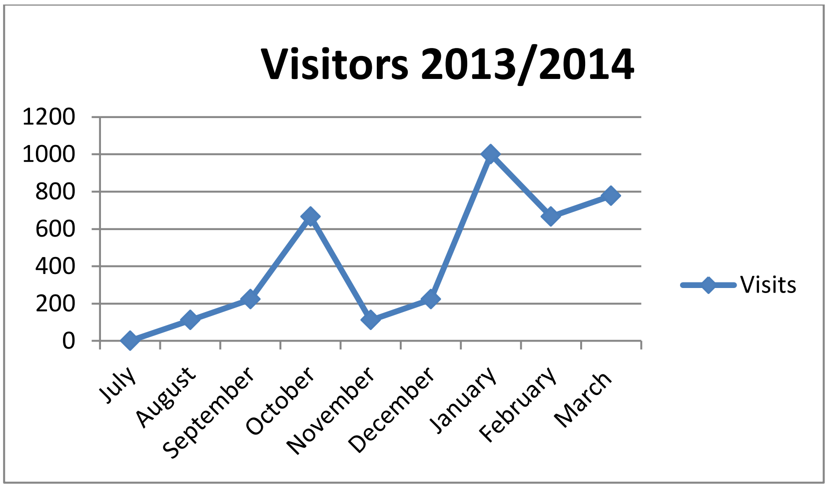


Visitor Engagement

Visitor Type	Bounce Rate	Pages / Visit	Avg. Visit Duration (minutes)
New Visitor	40.00%	8.80	06:08
Returning Visitor	12.47%	9.37	10:10
Average	32.13%	8.96	07:17

How engaged were these visitors within the website?

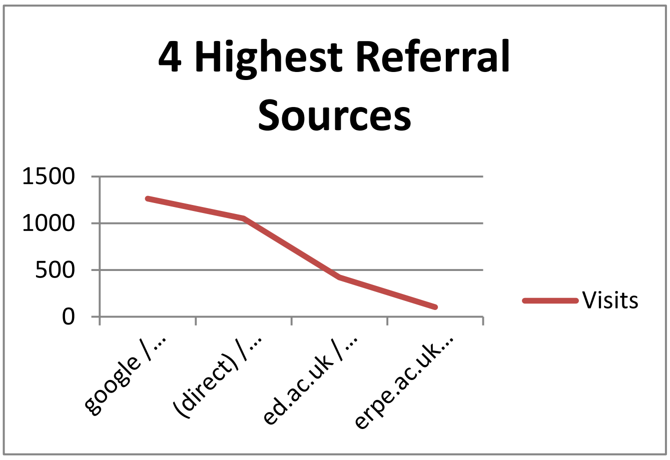
- On average, users visited 8 pages per visit. New visitors stayed on the site for 6 minutes per visit, returning visitors stayed on the site for 10 minutes (Table 1).
- People who returned spent significantly more time on the site depicting the specialist nature of the website.



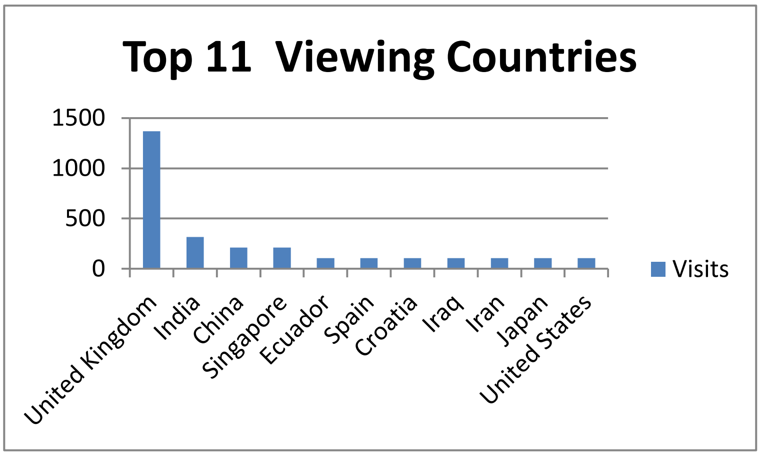
Where do these vistors come from?

- More than 42.87% of visitors came from a Google Search, 35.71% came directly to the site (by typing in the address or using bookmarks or email links), and the remaining came from links in other websites. The two highest referral sources were erpe.ac.uk and ed.ac.uk.
- Just under 50% of visitors are from the UK based on their IP address.

Where visitors come from



Where visitors are based

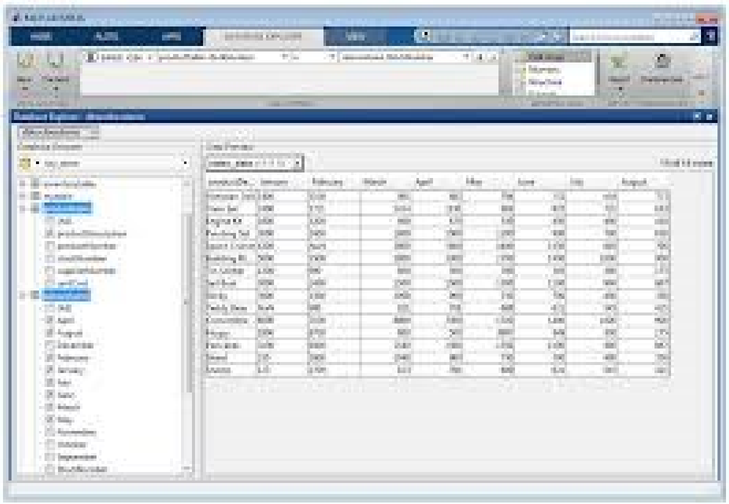


What pages are users viewing?

- The Events page was one of the most engaged with pages, with 30% of all pageviews.
- Primary navigation *sections* – People, Research and the Home page received between 22% , 20% and 26% total pageviews. These results illustrate that the events section of the website is a strong driver of visitors to the site, followed by people and research.

UDRC has recently launched an open group on the professional social networking site LinkedIn. The group is accruing new members from the Signal Processing community. This group allows the UDRC to encourage links between academia and industry on an online platform. The effects of this group allows the project to update, not only the UDRC research staff, but other interested parties of events and relevant articles which in turn could create online discussions. In this group members can start their own topical discussions or threads and share information that will interest the other people in the group and encourage collaboration. LinkedIn is also being used as a tool to generating interest and traffic to the UDRC website. Through connecting to other Signalling Processing social media it is our aim to create an established resource for those interested in Signal Processing for Defence.

UDRC Database



A database of people interested in the UDRC has been established and includes defence, industry and academia including Small and Medium Enterprises (SMEs). This database breaks down the people into interests and also attendance at the different events. Depending on their interest, they will be updated when information becomes available for example on the website, annual reports, publications, and data. They will also be invited to events and the annual conference including an industrial day. They will be given visibility to research and academics through email and web links and they will have the opportunity to sign up for external events, for example the industrial day. Quarterly email updates go out to this group.

UDRC Events

Events

Events are a key part in the success of the research project and as part of the coordination a number of meetings, workshops and events have been organised and managed by Edinburgh Consortium in partnership with LSSC Consortium and Dstl.

Summer School

In June we organised two Summer Schools on Finite Set Statistics, one in Edinburgh and one in the USA. Finite Set Statistics are a paradigm used for multi-object Bayesian estimation, most

notably, for the modelling and derivation of multi-sensor/multi-target detection and tracking algorithms.

There has been an increasing interest in developing accurate estimation techniques for problems in multi-sensor multi-target data fusion and Finite Set Statistics is becoming the dominant mathematical framework for addressing these kinds of problems. However there is often a knowledge gap between the background of signal processing engineers and the mathematical skills required to derive algorithms with Finite Set Statistics.

The objectives of the Summer School were to fill the gap in knowledge for signal processing engineering research students and industrial practitioners and facilitate the process of taking new theoretical developments into practical engineering applications. This created a focal point for research in Finite State Statistics and stimulating new international collaborations in this field. The course was aimed at PhD students, postdoctoral researchers, and researchers in defence organisations with interests in sensor fusion.

Prerequisites were a working knowledge of Bayesian estimation or Kalman filtering. The course covered concepts in probability theory, stochastic filtering, functional analysis, variational calculus, point process theory, multi-object estimation, and practical implementations with sequential Monte Carlo and Gaussian mixture techniques. To ensure that participants are equipped to derive new algorithms for their applications, the School was delivered through traditional lectures and mathematics tutorials on set exercises supervised by leading experts in the field. In addition, the School involved invited international speakers discussing advanced topics.

The first event was held at Heriot-Watt University and targeted the European community.

Summer School Attendees

A lecture at the Summer School Edinburgh

The audience (around 50 people) was composed of academics for the most part (professors, leaders of research team, postdocs, PhD students), but also industrials in defence-related domains. This event lasted five days. The second event was held in Kirtland USAF Base (Albuquerque, U.S.A.) and was hosted by Moriba Jah from the Air Force Research Laboratories. It targeted the North American community involved in the improvement of space situational awareness. The audience (around 20 people) was composed of a few academics, but mainly consisted of engineers from the Air Force Laboratories or from various defence companies. This event lasted four days.

Daniel Clark led the organisation and the selection of the presented material for both events. His team was involved in the organisation and was responsible for the preparation and presentation of a significant part of the exposed material. The people involved in the summer school were Jérémie Houssineau, Murat Uney, Chee Sing Lee, Anthony Swain, Emmanuel Delande and Sharad Naggapa.

Experts from leading research groups in multi-object filtering were also invited to present their work including Ronald Mahler, Ba-Ngu Vo, Martin Adams, Keith Leung, Felipe Inostroza, Mahendra Mallick, and Islam Hussein.

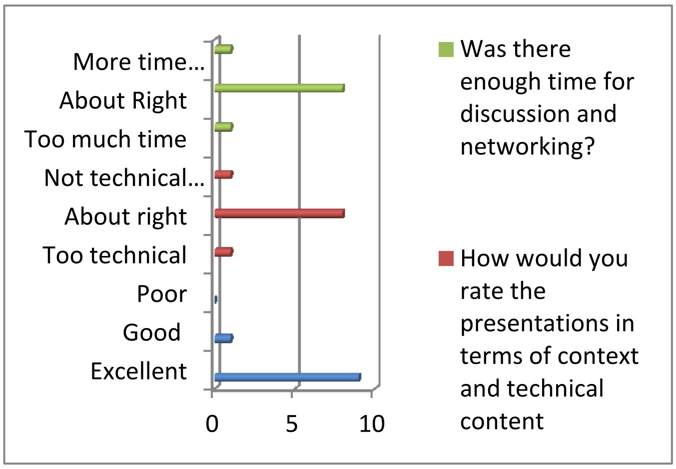
Overall, both Summer Schools were well received by the audience and the presenters were given very positive feedback. The mixture of lectures, tutorials and presentations was appreciated. The tutorials appeared to be a key component as they helped the audience grasp the mathematical concepts exposed during the lecture and marked a clear transition between the theoretical foundations and the derivation of practical algorithms.

Themed Meetings

This year we organised 2 themed meetings: these are lively technical

workshops based on UDRC research which are of interest to defence, industry and academia.

Our first meeting took place in October and covered the subject of Source Separation and Sparsity, see below. It focused on the challenges of signal acquisition, separation and extraction. There are many instances where sensors acquire the combination of a number of interwoven signals that subsequently need to be processed to extract signals of interest or suppress interference. This is particularly the case in the field of Electronic Surveillance.



Source Separation and Sparsity Agenda

Source Dependency Modelling in Frequency Domain Source Separation - Prof. Jonathon Chambers FREng, Director, LSSC Consortium

Exploiting Sparsity in Signal Acquisition, Separation and Processing - Prof. Mike Davies, Director, Edinburgh Consortium

Adaptive Beamforming and Blind Signal Separation - are Higher Order Statistics Really Necessary? - Prof. John McWhirter, FRS FREng, LSSC Consortium

SubNyquist Electronic Surveillance - Dr. Mehrdad Yaghoobi, Edinburgh Consortium

Audio-Visual Dictionary Learning and Probabilistic Time-Frequency Masking in Convolutive and Noisy Source Separation - Dr. Wenwu Wang, LSSC Consortium

RF Interference Mitigation for UWB SAR using Image Sparsity - Shaun Kelly, Edinburgh Consortium

Source separation and electronic warfare; the challenges - Stephen Clark, CEng FIET, Chief Technologist (Electronic Warfare) Selex ES Ltd

Participant feedback

A number of different signal models were discussed in dealing with the source separation challenge, including non-Gaussian signal models, sparse representations and low rank structures. Domain knowledge, such as approximate bearing, expected periodicity, and array geometry, were also touched upon. This meeting explored recent advanced acquisition and separation techniques as well as considering crucial open challenges in the field. Mike Davies, Mehrdad Yaghoobi and Shaun Kelly presented their work at this event. There was also a Dstl Challenge workshop where challenges were presented and the researchers split into groups to address the problems. There were 36 attendees and the feedback implied that there was a good range of talks and that they were pitched at the right level.

Our next meeting in January was a joint meeting between the UDRC and Network and Information Sciences

International Technology Alliance (NIS ITA). This workshop attracted 43 attendees and was centred on developing links with experts within the working groups and exploring topics of common interest and opportunities for synergies within the research programmes. The meeting was divided into 2 sessions Communication and Networks and Distributed /Multi-sensor/Source Processing, see below.

In each of the sessions, presenters from both research areas gave short presentations highlighting the problem area and the technical approach. There was plenty of time for discussion which enabled a number of actions and synergies to be identified. John Thompson and Daniel Clark presented their work at these sessions.

UDRC/NISITA Agenda

Session 1: Communication and Networks

Anomaly Detection in Communication Networks using Data Fusion - David Parish

Relay Networks - Alex Gong

Energy Efficient Communications Systems - John Thompson

Game Theoretic Methods for Resource Allocation in Communication and Radar Networks - Sangarapillai Lambothoran

Tomography of Hybrid Coalition Networks - Kin Leung

Mobile Micro-Clouds - Howard Tripp

Declarative Infrastructure for Network & Security Management - Alessandra Russo

Managing Distributed Services in Hybrid Clouds – Simone Silvestris, Petr Novotny

ITA Experimental Framework - Flavio Bergamashi

Session 2 - Distributed /Multi-sensor/Source Processing

Distributed Multi-Sensor Processing - Daniel Clark

Distributed Processing - Stephan Weiss

Secure Info Flows - Saritha Arunkumar **Inference Management under Uncertainty** – Mani Srivastava

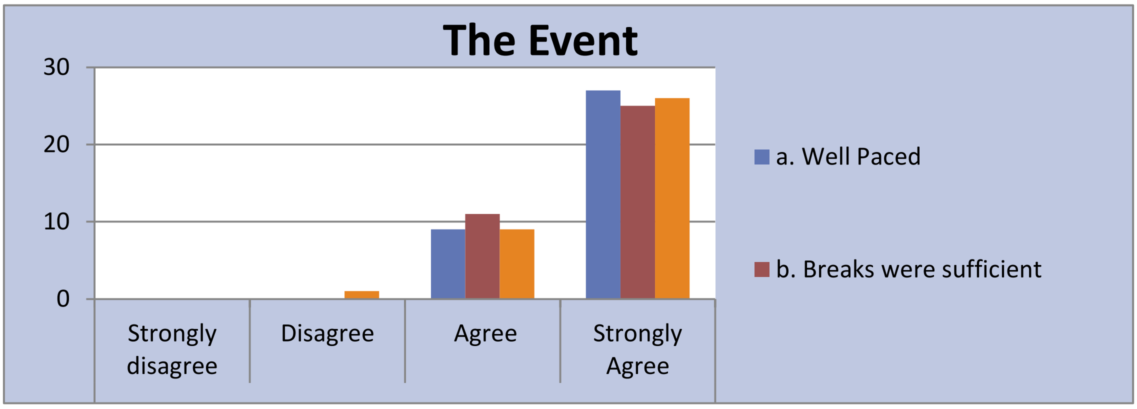
Argumentation & Logics with Uncertainty – Jeff Pan

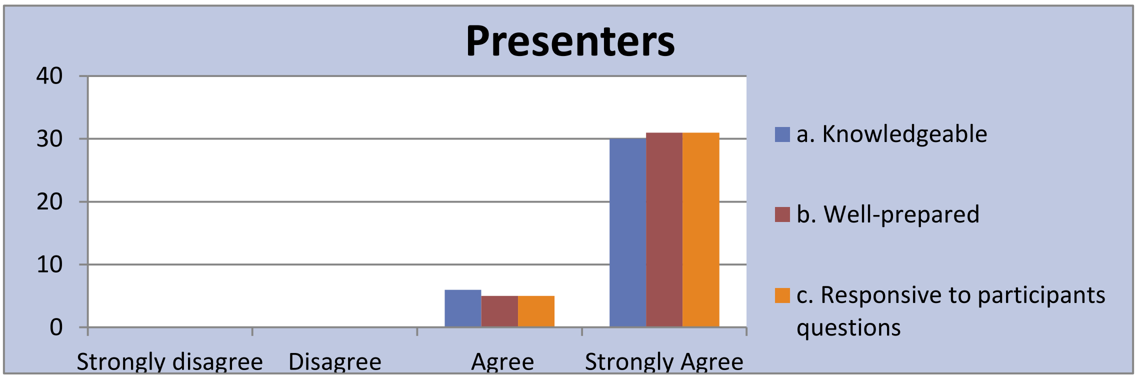
Collaborative Argumentation –Alice Toniolo

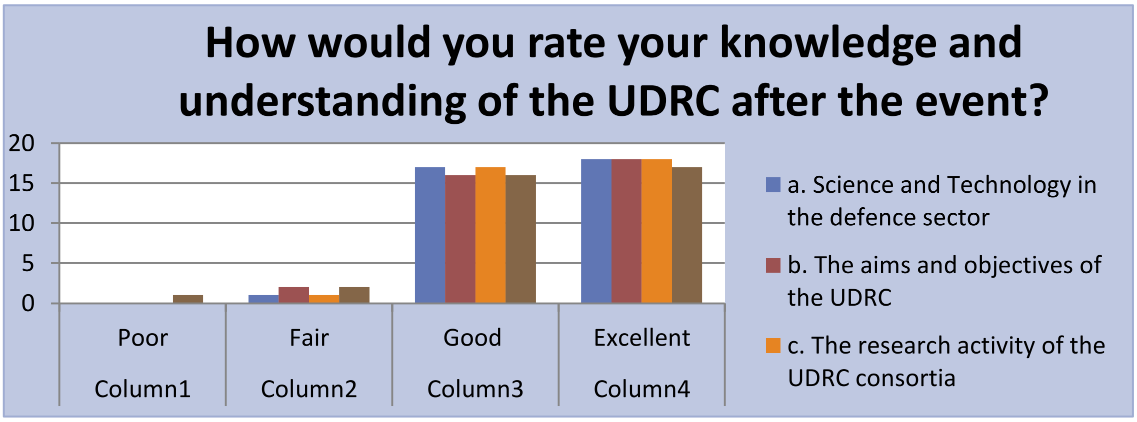
.

UDRC Launch

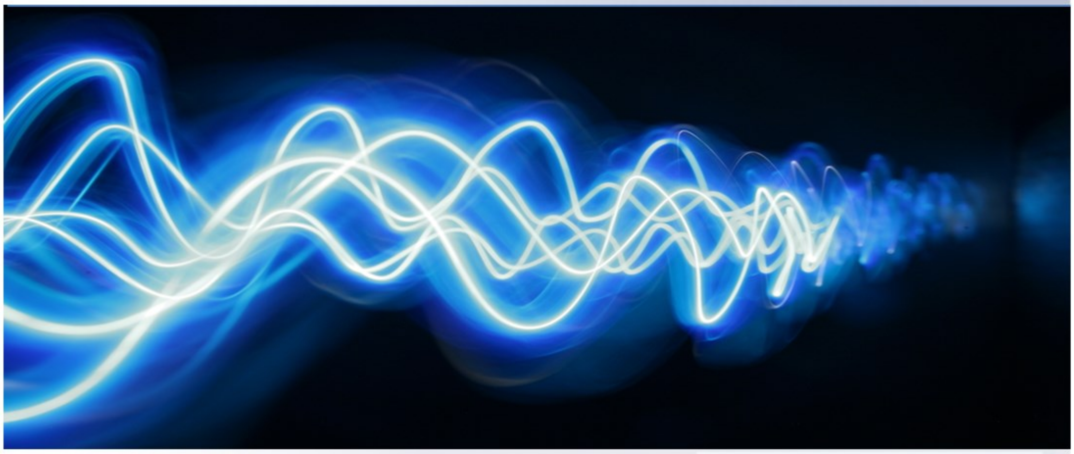
We held the UDRC Launch in December and this was a great opportunity for interested stakeholders to meet the UDRC team and hear about the emerging science technologies in sensor signal processing and the research that is planned over the next 5 years. The Launch was strategically placed directly after the Intelligent Signal Processing (ISP) IET conference. 124 people attended and feedback was positive and a number of organisations have been in touch to arrange follow-up meetings.







Sensor Signal Processing for Defence (SSPD)



Come to the University Defence Research Collaboration (UDRC) Phase 2 Launch

This event will outline the emerging science on Signal Processing in a Net-worked Battlespace. The UDRC Research team will present research in the field of sensor signal processing and explain the studies planned over the next 5 years.

This event is for research, defence, government and industry stakeholders who have an interest in signal processing and defence.

Strand Palace Hotel, 372 Strand, London, WC2R 0JJ

- Date: **Wednesday 4th December 2013**
- Time: **9.30am - 4pm** (followed by drinks and canapés)

If you would like to attend please email to reserve a place.

Key Note Speakers:

- Andrew Seedhouse, Chief Technologist, Sensors and Countermeasures, Dstl
- John Griffin, Director of Innovation, Selex ES

Other contributors include:

- Professor Mike Davies, University of Edinburgh
- Professor Jonathon Chambers FREng, Loughborough University
- Paul Thomas, Dstl
- Dr Daniel Clark, Heriot-Watt University
- Professor John Soraghan, University of Strathclyde
- Janet Forbes, University of Edinburgh

Funded by

dstl

EPSRC
Engineering and Physical Sciences Research Council

UDRC Launch Flyer

Knowledge Transfer Meetings

Our second Industrial knowledge transfer meeting took place in March at Dstl offices. Presentations given were tutorial style talks and were split into the 6 themes outlined below. In addition to these talks, there were poster sessions giving a more detailed viewpoint of the research. There were approximately 50 people in attendance and these were made up of colleagues from UDRC and Dstl.

Themes

Sensing/Preprocessing

Object detection/classification

Multi-sensor techniques

Threat refinement

Sensor Management

Multi-objective sensor management

Future

Signal Processing for Defence (SSPD) Annual Conference

The first Signal Processing for Defence (SSPD) conference under Phase 2 will be chaired by Mike Davies, Jonathon Chambers (Loughborough University) and Paul Thomas (Dstl) and will take place in September at the University of Edinburgh's Pollock Halls over 2 days. It will cater for up to 147 people. Technical sponsorship is provided through IEEE and the publications will be indexed on IEEEXplore. A call for papers has already gone out and the deadline for submitted papers is 4th April. Papers will be submitted from all 6 work packages. A technical committee has been set up and is a mix of academia, industry and defence. The academic keynote speaker will be Professor Randolph Moses from Ohio State University who is an internationally recognised expert on sparsity and radar and will present research on this. There will also be an industrial and military session and speakers for these sessions will be confirmed shortly

This conference series will be run annually: the last conference within phase 2 will take place in September 2017.

SSPD Conference: 8th and 9th September 2014

- **Submission of Paper Deadline: 4th April 2014**
- **Notification of Paper Acceptance: 4th June 2014**
- **Final version of Paper Due: 8th July 2014**

Important Dates:

- **Submission of Paper Deadline:** **4th April 2014**
- **Notification of Paper Acceptance** **4th June 2014**
- **Final version of Paper Due:** **8th July 2014**
- **Conference Dates:** **8th and 9th September 2014**

Technical sponsorship is provided by the IEEE Signal Processing Society and the proceedings will be indexed in IEEE XPLORE.

John McIntyre Conference Centre, Pollock Halls, University of Edinburgh

The conference will be held in Edinburgh on 8th and 9th September 2014 and is organised by the University Defence Research Collaboration (UDRC) in Signal Processing, sponsored by the UK Ministry of Defence (MOD) and the Engineering and Physical Sciences Research Council (EPSRC).

This conference will bring together researchers from academia, industry and government organisations to learn about and present the latest developments in Signal Processing for Defence. . The Conference will feature keynote addresses and technical presentations, oral and poster, all of which will be included in the conference proceedings.

Topics include, but are not limited to, the following:

- *Array Signal Processing,*
- *Image Processing*
- *Radar, Sonar and Acoustic Signal Processing*
- *Multimodal Signal Processing*
- *Multi-Target Tracking*
- *Signal Acquisition and Sensor Management*
- *Data Fusion*
- *Source Separation*
- *Anomaly Detection*
- *Distributed Signal Processing*
- *Low Size Weight & Power Solutions*
- *Target Detection and Identification*
- *Electro-Optic Sensing*

If you have any questions, please contact janet.forbes@ed.ac.uk

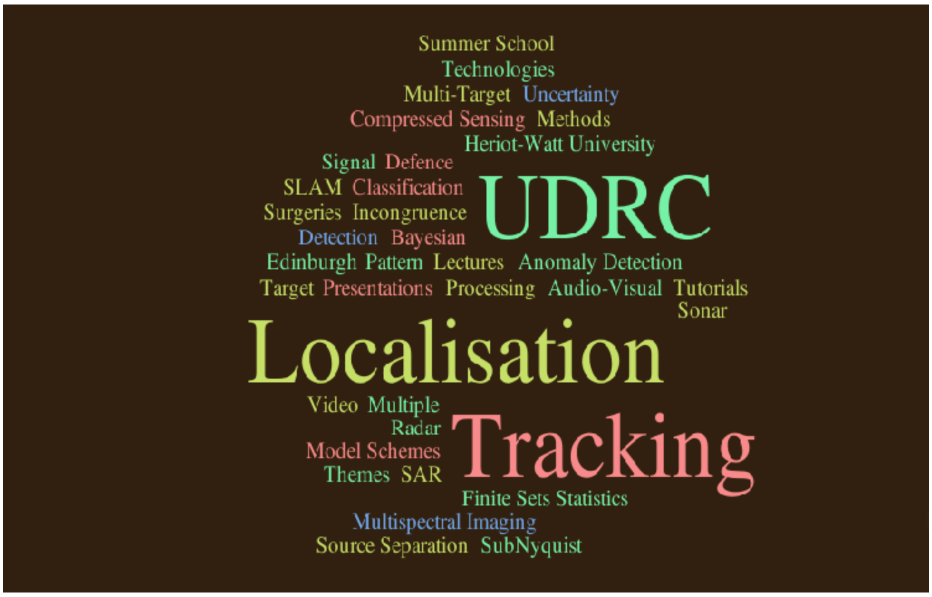
WWW.SSPDCONFERENCE.ORG

Technical Co-Sponsor

IEEE Signal Processing Society

UDRC [dstl] EPSRC Engineering and Physical Sciences Research Council

Flyer – SSPD conference



UDRC Summer School

The second UDRC Summer School will take place in June 2014 at Heriot-Watt University and will cover the following subjects:

- Detection, Localisation and Tracking
- Compressed Sensing
- Anomaly Detection
- Source Separation

Registration is open until the end of March and 80 people have registered interest. People have now been short listed and it is hoped that each day will cater for 60 students.

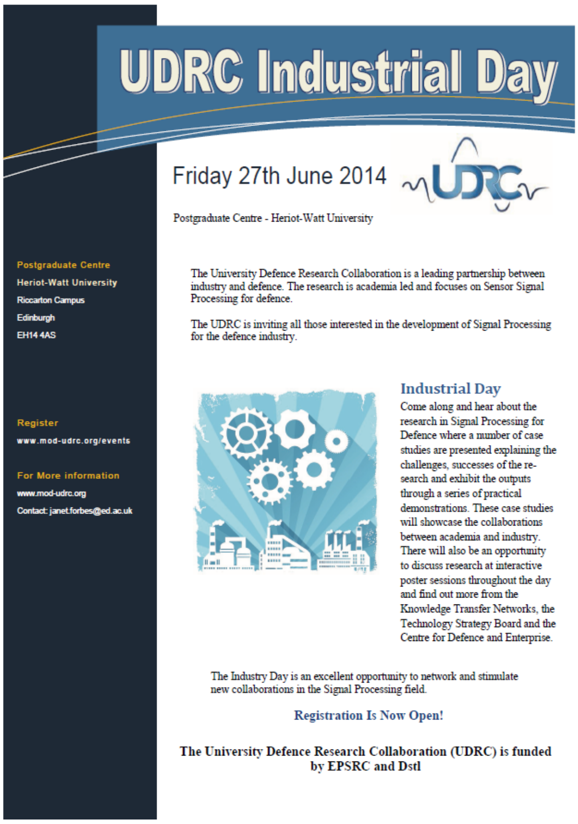
Industrial Day

Specific industrial days are planned where members from the Industrial Affiliation Group will be invited to see presentations and demonstrations of our research as well as holding discussions on possible future collaboration and/or technology pull through. The first industrial day will take place in June 2014 and will be directly after the UDRC Summer School. The Centre for Defence and Enterprise, Knowledge Transfer Network and Technology Strategy Board have all been invited to present as well as specific industry partners to present jointly with UDRC.

Themed Meeting

Meetings planned will be on the following themes:

- Uncertainty and Anomaly Detection - 28th May 2014
- Autonomous systems and signal processing - 10th November 2014.


UDRC Industrial Day

Friday 27th June 2014

Postgraduate Centre - Heriot-Watt University

Postgraduate Centre
Heriot-Watt University
Riccarton Campus
Edinburgh
EH14 4AS

Register
www.mod-udrc.org/events

For More information
www.mod-udrc.org
Contact: janet.forbes@ed.ac.uk

The University Defence Research Collaboration is a leading partnership between industry and defence. The research is academia led and focuses on Sensor Signal Processing for defence.

The UDRC is inviting all those interested in the development of Signal Processing for the defence industry.

Industrial Day

Come along and hear about the research in Signal Processing for Defence where a number of case studies are presented explaining the challenges, successes of the research and exhibit the outputs through a series of practical demonstrations. These case studies will showcase the collaborations between academia and industry. There will also be an opportunity to discuss research at interactive poster sessions throughout the day and find out more from the Knowledge Transfer Networks, the Technology Strategy Board and the Centre for Defence and Enterprise.

The Industry Day is an excellent opportunity to network and stimulate new collaborations in the Signal Processing field.

Registration Is Now Open!

The University Defence Research Collaboration (UDRC) is funded by EPSRC and Dstl

2014 Summer School Programme

Day 1: Target Detection and Tracking

(Yvan Petillot, Daniel Clark, Neil Robertson, Gerard Buller, Robert Lamb)

Fundamentals of Target Localisation and Tracking: The Bayesian Approach

Advanced Tracking using Finite Set Statistics

Target Detection Underwater using Sonar

Detection and Tracking in Video Sequences

Demonstrations: ATR in sonar using SeeByte Software and ATR algorithm and Target tracking examples

Emerging Topics: 3D imaging – acquisition and processing

Application of low-light level, time-of-flight 3D imaging to target identification

Whisky Tasting

Day 2: Compressed Sensing

(Mike Davies, Mehrdad Yaghoobi, Shaun Kelly, Robert Lamb)

Foundations of Compressed Sensing

Optimisation of Convex/Greedy Methods for Sparse Approximations, Low-Dimensional signal modelling

Demonstrations: SAR , SubNyquist

Application: Polarimetric and multispectral imaging with some thoughts given to application of compressed sensing

Emerging Methods: Low Rank Matrix Retrieval, Structures Low Dimensional Models

Day 3: Anomaly Detection

(Josef Kittler, David Parish, Yulia Hicks)

Fundamentals of Pattern Classification

Anomaly Detection: Supervised and Unsupervised Scheme

Applications and Demonstrations

Emerging Topics: Multiple Model Schemes; Incongruence; Handling Uncertainty

Day 4: Source Separation

(Jonathon Chambers, Stephan Weiss, Wenwu Wang, James Hopgood)

Foundations of Source Separation

Sequential Best Rotation Methods and Applications

Convolutive Source Separation and Demonstrations

Emerging Methods: Audio-Visual Methods; Non-Linear Mixing

Publications

[A] Autofocus Techniques for Under-sampled Synthetic Aperture Radar", S. Kelly, M.Yaghoobi and M.E. Davies, IEEE transactions on Aerospace and Electronic Systems, 2013 (Published).

[B] A method of analyzing radio-frequency signals using sub-Nyquist sampling. UK priority filing patent application: 1309783.7, priority filing date: 31/05/2013.

[C] A Low-complexity Sub-Nyquist Sampling System for Wideband Radar ESM Receivers, M Yaghoobi, M Lexa, F Millioz and M Davies, ICASSP, Florence, Italy, May 2014. (Accepted).

[D] A Computationally Efficient Multi-coset Wideband Radar ESM Receiver, M Yaghoobi, M Davies, NATO Specialist Meeting on Compressed Sensing for RADAR/SAR, Tallinn, Estonia, May 2014. (Accepted).

[E] An Efficient Implementation of the Low-Complexity Multi-Coset Sub-Nyquist Wideband Radar Electronic Surveillance, M Yaghoobi, B Mulgrew and M Davies, Sensor Signal Processing for Defence Conference 2014 (Submitted).

[F] A Sparse Regularized Model for Raman Spectral Analysis, D Wu, M Yaghoobi, S Kelly, M Davies and R Clewes, Sensor Signal Processing for Defence Conference 2014 (Submitted).

[G] Sparsity-based Image Formation and RFI Mitigation for UWB SAR, S Kelly & M Davies, NATO Compressed Sensing for Radar/SAR and EO/IR imaging (SET-213 (Submitted).

[H] M Uney, B Mulgrew & D Clark, Cooperative sensor localisation in distributed fusion networks by exploiting non-cooperative targets, IEEE Statistical Signal Processing Workshop, 2014 (Accepted).

[I] Murat Uney, March 2014.Multi-sensor calibration for fusion networks. UDRC Technical Report (unpublished).

[J] Target aided online sensor localisation in bearing only clusters, M Uney, B Mulgrew & D Clark, Sensor Signal Processing for Defence Conference 2014 (Submitted).

[K] MIMO sonar systems: principles and capabilities, Y Pailhas & Y Petillot, Journal of Oceanic Engineering. (Submitted).

[L] Independent views in MIMO sonar systems, invited paper, Y Pailhas & Y Petillot, Underwater Acoustics 2014 (Submitted).

[M] Tracking underwater objects using large MIMO sonar systems, invited paper, Y Pailhas, J Houssineau, E Delande, Y Petillot & D Clark, Underwater Acoustics 2014 (Submitted).

[N] Large MIMO sonar systems: a tool for underwater surveillance, Y Pailhas & Y Petillot Sensor Signal Processing for Defence Conference 2014 (Submitted).

[O] Video Tracking through Occlusions by fast audio source localisation." E. D'Arca, A. Hughes, N. M. Robertson, J. Hopgood. IEEE Int. Conf. on Image Processing, Melbourne, 2013.

[P] Using the voice spectrum for improved tracking of people in a joint audio-video scheme, E.D'Arca, N.M. Robertson and J. Hopgood, IEEE Int. Conf. Acoustics Speech and Signal Processing (ICASSP), Vancouver, May 2013.

[Q] Look Who's Talking, E.D'Arca, N.M.Robertson, J.R.Hopgood, IET Conf. Intelligent Signal Processing, London, December 2013.

[R] Look Who's Talking: Detecting the Dominant Speaker in a Cluttered Scenario, E.D'Arca, N.M.Robertson, J.Hopgood, IEEE Int. Conf. Acoustics Speech and Signal Processing (ICASSP), Florence, May 2014

[S] Contextual Anomaly Detection in Crowded Surveillance Scenarios, M.Leach, E.Sparks and N.M.Robertson, Pattern Recognition Letters, 2013 (doi: 0.1016/j.patrec.2013.11.018)

[T] Recognising Human Behaviour in Data Scarce Domains, Baxter, Lane, Robertson, Pattern Recognition (Submitted)

[U] Tracking with intent, R Baxter, M Leach & N Robertson, Sensor Signal Processing for Defence Conference 2014 (Submitted).

[V] Delande, E., Üney, M., Houssineau, J., and Clark, D. E. Regional variance for multi-object filtering, IEEE Transactions on Signal Processing, 2014 (Accepted).

[W] Delande, E., Houssineau, J., and Clark, D. E. Regional variance in target number: analysis and application for multi-Bernoulli point processes, IET Data Fusion & Target Tracking conference, 2014 (Accepted).

[X] Performance metric in closed-loop sensor management for stochastic populations. E Delande, J Houssineau & D Clark, Sensor Signal Processing for Defence Conference 2014 (Submitted).

[Y] Event-Driven Dynamic Platform Selection for Power-Aware Real-Time Anomaly Detection in Video, C. G. Blair, N. M. Robertson, Intl. Conf. Computer Vision Theory and Applications (VISAPP 2014).

[Z] Introspective Classification for Pedestrian Detection, C Blair, J Thompson,& N Robertson, Sensor Signal Processing for Defence Conference 2014 (Submitted).

[A1] A Fast Decimation-in-image Back-projection Algorithm for SAR, IEEE Radar Conference 2014 (Accepted).

[B1] Parallel processing of the fast decimation-in-image back-projection algorithm, S Kelly, M Davies & J Thompson, Sensor Signal Processing for Defence Conference 2014 (Submitted).

References

[1] J. A. Tropp, J. N. Laska, M. F. Duarte, J. K. Romberg, and R. G. Baraniuk, "Beyond Nyquist: Efficient Sampling of Sparse Bandlimited Signals", IEEE Transactions on Information Theory, vol. 56, no. 1, pp. 520–544, 2010.

[2] M. Mishali and Y. C. Eldar, "From Theory to Practice: Sub-Nyquist Sampling of Sparse Wideband Analog Signals", IEEE Journal of Selected Topics in Signal Processing, vol. 4, no. 2, pp. 375–391, 2010.

[3] P. Feng and Y. Bresler, "Spectrum-blind minimum-rate sampling and reconstruction of multiband signals", IEEE International Conference on Acoustics, Speech, and Signal Processing, 1996. ICASSP-96. Conference Proceedings, 1996, vol. 3, pp. 1688–1691 vol. 3.

[4] Olivier Cappe, Simon J. Godsill, Eric Moulines, "An overview of existing methods and recent advances in sequential Monte Carlo," Proceedings of the IEEE, vol. 95, No. 5, May 2007.

[5] N. Kantas, S. Singh, and A. Doucet, "Distributed maximum likelihood for simultaneous self-localization and tracking in sensor networks," Signal Processing, IEEE Transactions on, vol. 60, no. 10, pp. 5038–5047, 2012.

[6] M. Uney, D. E. Clark, and S. J. Julier, "Distributed sensor registration based on random finite set representations," in SSPD'12, 2012.

[7] B. Ristic, D. Clark, and N. Gordon, "Calibration of multi-target tracking algorithms using non-cooperative targets," Selected Topics in Signal Processing, IEEE Journal of, vol. 7, no. 3, pp. 390–398, 2013.

[8] H. Wymeersch, J. Lien, and M. Win, "Cooperative localization in wireless networks," Proceedings of the IEEE, vol. 97, no. 2, pp. 427–450, 2009.

[9] A. Ihler, J. Fisher, R. Moses, and A. Willsky, “Nonparametric belief propagation for self-localization of sensor networks,” Selected Areas in Communications, IEEE Journal on, vol. 23, no. 4, pp. 809–819, 2005.

[10] U. Orguner, F. Gustafsson, "Target Tracking With Particle Filters Under Signal Propagation Delays," IEEE Transactions on Signal Processing, vol.59, no.6, pp.2485,2495, June 2011.

[11] E. Mehmetcik, U. Orguner, "Centralized target tracking with propagation delayed measurements," 16th International Conference on Information Fusion (FUSION), pp.820,826, 9-12 July 2013.

[12] G. J. Székely, M. L. Rizzo, and N. K. Bakirov, “Measuring and testing dependence by correlation of distances,” *The Annals of Statistics*, vol. 35, pp. 2769–2794, 2007.

[13] Houssineau, Del Moral, Clark. "General multi-object filtering and association measure." *IEEE-CAMSAP* 2013.

[14] Stefano Pellegrini, Luc J. Van Gool: Tracking with a mixed continuous-discrete Conditional Random Field. Computer Vision and Image Understanding 117(10): 1215-1228 (2013).

[15] Clark, D. E. and Houssineau, J. “Faà di Bruno's formula for Gâteaux differentials and interacting stochastic population processes”, arXiv:1202.0264v4, 2012.

[16] Houssineau, J., Delande, E., and Clark, D. E. “Notes of the Summer School on Finite Set Statistics”, arXiv:1308.2586, 2013.

[17] Delande, E., Üney, M., Houssineau, J., and Clark, D. E. “Regional variance for multi-object filtering”, IEEE Transactions on Signal Processing, accepted, 2014.

[18] Pailhas Y., Delande E., Houssineau J., Petillot Y., and Clark D. “Tracking underwater objects using large MIMO sonar systems”, Underwater Acoustics conference, 2014 (in preparation).

[19] Hero, A. O. III. “Sensor management: Past, Present, and Future”, IEEE Sensors Journal, 2011.

[20] Rényi, A. “On measures of entropy and information” Proc. Fourth Berkeley Symp. on Math. Statist. and Prob., Vol. 1 (Univ. of Calif. Press, 1961), 574-561.

[21] Mahler, R. P. S. “Statistical Multisource-Multitarget Information Fusion”, Artech House, 2007.

[22] Ristic, B. and Vo, B-N. and Clark, D. E. and Vo, B-T. “A Metric for Performance Evaluation of Multi-Target Tracking Algorithms”, Signal Processing, IEEE Transactions on, 2011.

[23] Mahler, R. P. S. "Multitarget Bayes Filtering via First-Order Multitarget Moments", Aerospace and Electronic Systems, IEEE Transactions on, 2003.

[24] Mahler, R. P. S. “PHD Filters of Higher Order in Target Number”, Aerospace and Electronic Systems, IEEE Transactions on, 2007.

[25] Delande, E. and Houssineau, J. and Clark, D. E. “PHD filtering with localised target number variance”, Defense, Security, and Sensing, Proceedings of SPIE, 2013.

[26] Delande, E. and Houssineau, J. and Clark, D. E. “Localised variance in target number for the Cardinalized Hypothesis Density Filter”, Information Fusion, Proceedings of the 16th International Conference on, 2013.

[27] Houssineau, J., Del Moral, P., and Clark, D.E. "General multi-object filtering and association measure.", IEEE CAMSAP, 2013.

[28] Ristic, B., Vo B.-N., and Clark, D.E. “A note on the Reward Function for PHD Filters with Sensor Control”, Aerospace and Electronic Systems, IEEE Transactions on, 2011.

[29] Hernandez, M. L., Kirubarajan T., and Bar-Shalom Y. “Multisensor resource deployment using posterior Cramer-Rao bounds“,IEEE Transactions on Aerospace and Electronic Systems, 2004.

[30] Hue, C. Le Cadre, J.-P., and Pérez, P. “Performance analysis of two sequential Monte Carlo methods and posterior Cramer-Rao bounds for multi-target tracking”. Proceedings of the Fifth International Conference on Information Fusion, 2002.

[31] Curry, G. R. “Radar Measurement and Tracking”, in “Radar System Performance Modeling”, Artech House, 2005.

[32] Richard, M. A. “Detection Fundamentals”, in “Fundamentals of Radar Signal Processing”, McGraw-Hill, 2005.

[33] Hernandez, M. L. “Performance Bounds for Target Tracking: Computationally Efficient Formulations and Associated Applications”, in “Integrated Tracking, Classification, and Sensor Management”, Wiley, 2012.

[34] Grimmett, Hugo, Rohan Paul, Rudolph Triebel, and Ingmar Posner. 2013. “Knowing When We Don’t Know: Introspective Classification for Mission-Critical Decision Making.” In *Proc. IEEE International Conference on Robotics and Automation (ICRA)*. Karlsruhe, Germany.

Contact Information

Academic Staff

Prof Mike Davies, Director, Work Package 1 Leader mike.davies@ed.ac.uk

Prof Yvan Petillot, Deputy Director, Work Package 3 Leader y.r.petillot@hw.ac.uk

Prof Bernard Mulgrew, Work Package 2 Leader Bernie.Mulgrew@ed.ac.uk

Dr Neil Robertson, Work Package 4 leader N.M.Robertson@hw.ac.uk

Dr Daniel Clark, Work Package 5 leader d.e.clark@hw.ac.uk

Prof John Thompson, Work Package 6 leader john.thompson@ed.ac.uk

Prof Andrew Wallace, Work Package 4 & 6 a.m.wallace@hw.ac.uk

Dr James Hopgood, Work Package 3 & 4 James.hopgood@ed.ac.uk

Dr Mathini Sellathurai, Work Package 2 & 5 M.Sellathurai@hw.ac.uk

Project Management

Janet Forbes, Project Manager janet.forbes@ed.ac.uk