UDRC Edinburgh: Signal Processing in the Networked Battlespace

Mike Davies,

Edinburgh Consortium Director

Outline

- Introduction to UDRC Edinburgh
- Research Challenges
- Overview of Research Activities
- How to get involved

Who are we?

Consortium of University of Edinburgh and Heriot Watt University, part of the Edinburgh Joint Research Institute in Signal & Image Processing (JRI SIP),

UDRC Team

- Academic Staff: 9
- Research Associates: 8
- PhD students: 4 + 10 associated PhDs
- Project Management Team:

  Janet Forbes + 2 support staff

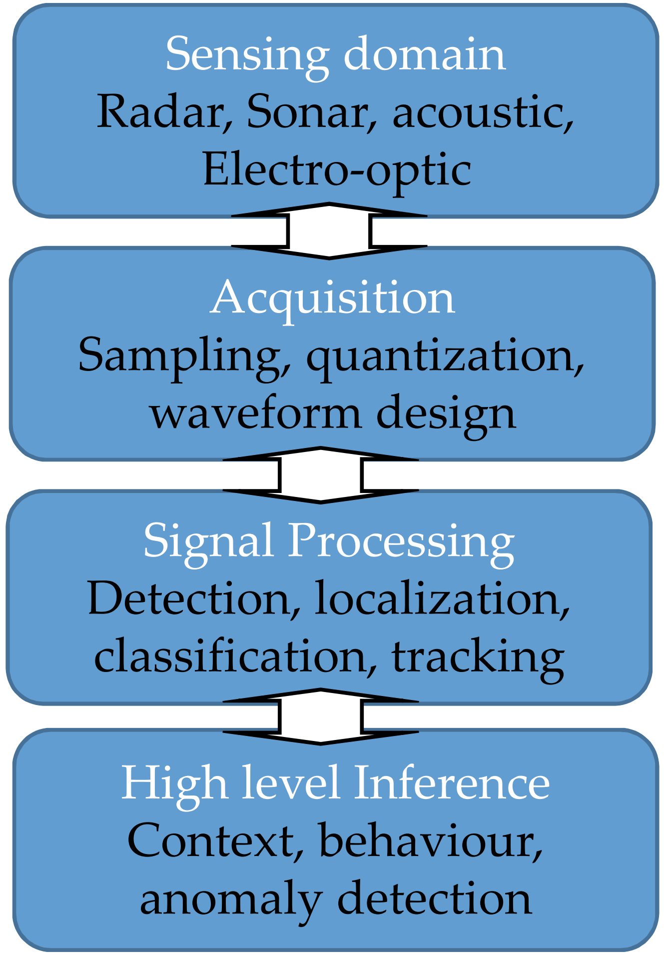
UDRC Research Team

Academics	Research Associates	PhD Students	Project Management
Mike Davies	Mehrdad Yaghoobi	Puneet Chhabra	Janet Forbes
Yvan Petillot	Murat Uney	Jose Franco	Audrey Tainsh
Bernard Mulgrew	Yan Pailhas	Di Wu	Maddy McBeath
Neil Robertson	Eleonora D'Arca	Saurav Sthapit	
Andrew Wallace	Rolf Baxter	+10 assoc. PhDs	
Daniel Clark	Emmanuel Delande		
John Thompson	Calum Blair		
James Hopgood	Shaun Kelly		
Mathini Sellathurai			

UDRC Research Programme

The MOD has significant sensing resources with a wide variety of sensor modalities. Our programme of work builds upon existing sensor technologies in defence and spans the complete signal processing chain from individual sensor modalities to sensor independent algorithms distributed across platforms to generate an integrated network of multi-sensor systems

We are working in all major sensing domains: Radar, Sonar, Acoustic, Electro-optic.



Fundamental Sensing Challenges

- Sensing within acquisition constraints
- Incorporating complex domain knowledge
- Exploiting information feedback through the network
- Communication issues in distributed sensor networks
- Exploiting high level behaviour modelling for anomaly detection
- Doing all this with computational solutions that minimize Size Weight and Power.

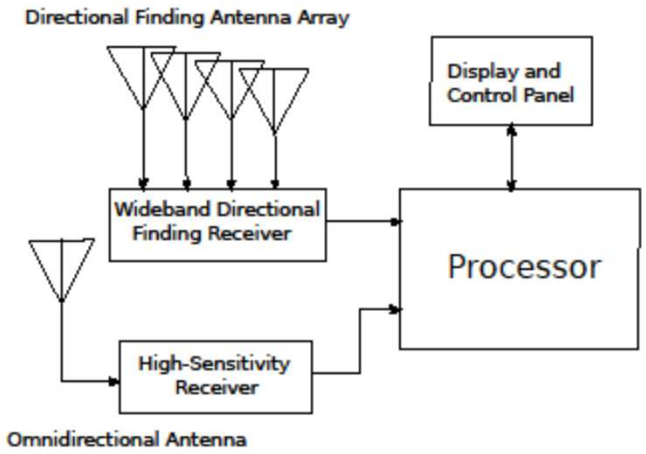
Research Activities

Sensing and Acquisition

Compressed sensing, RF interference suppression, MIMO sonar acquisition, photon counting LiDAR

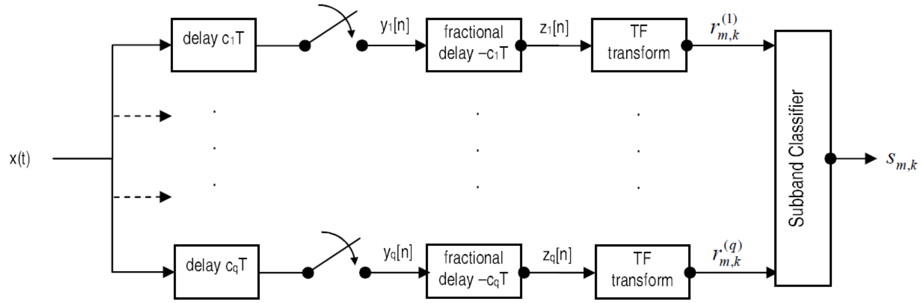
Sub-Nyquist Wideband Sampling in Electronic Surveillance

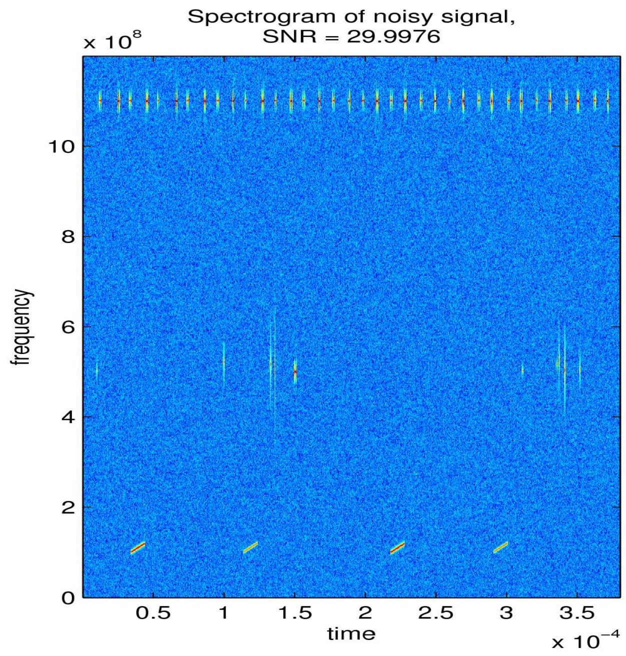
- Modern ES systems need to monitor huge bandwidth (20-40GHz)
- Conventional method of Rapidly Swept Superheterodyne Receiver (RSSR), only monitors narrow band instantaneously
- Compressed Sensing offers additional functionality of persistent wideband monitoring



Sub-Nyquist Wideband Sampling

- Using a few (e.g. 2-5) delayed aliased channels;
- Signals can be de-aliased using a simple non-iterative algorithm.
- Assumes signal components are sparse in Time Frequency
- Complexity is extremely low: can be processed in real time





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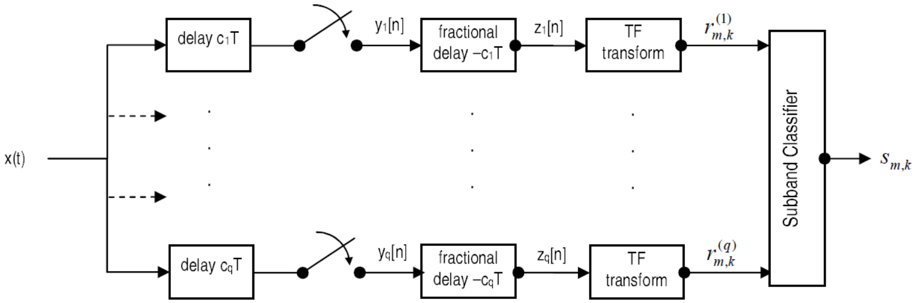

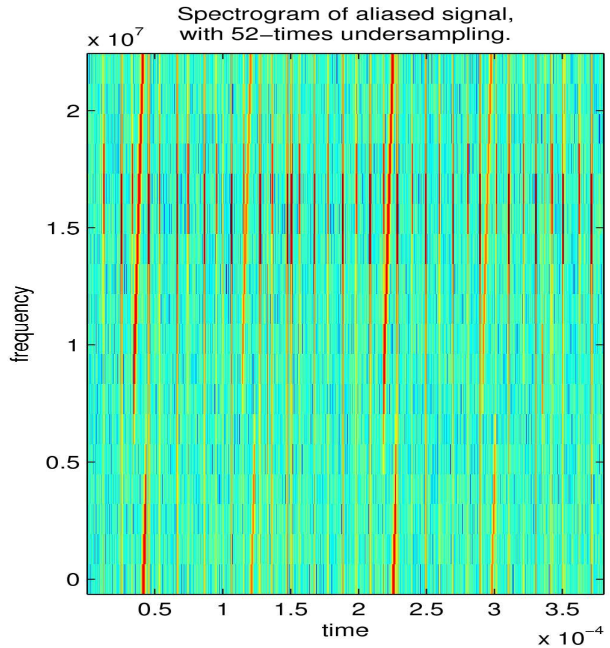

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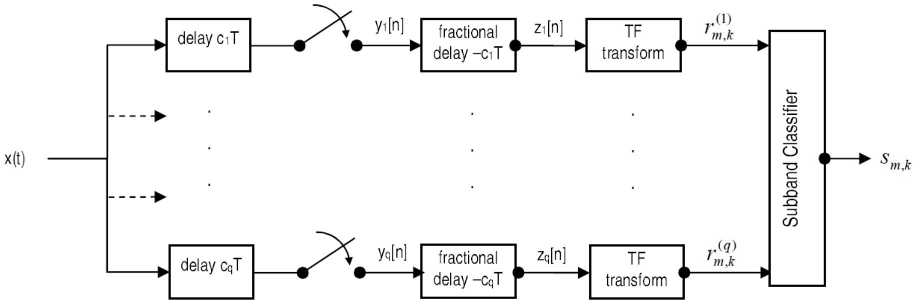
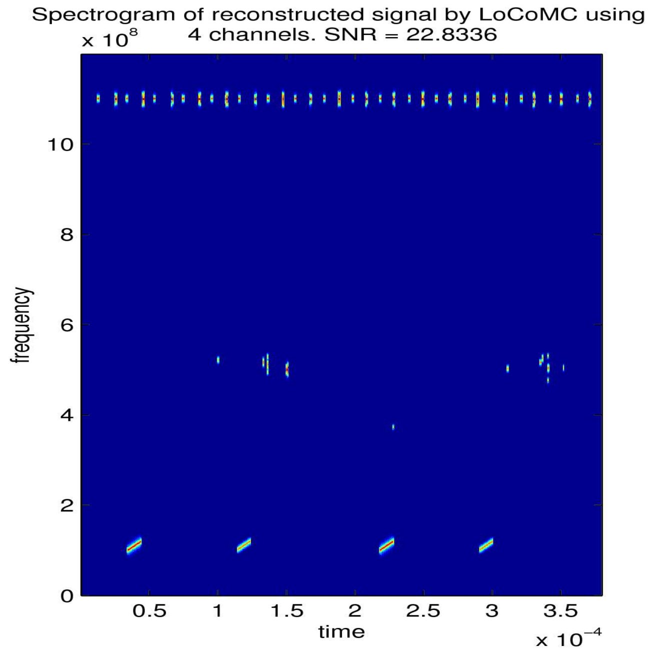
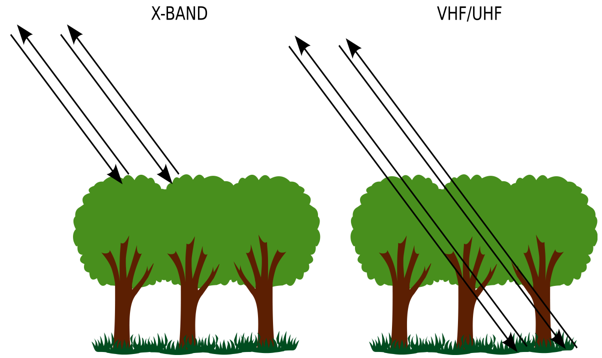




Compressed Sensing in LF SAR

Why use VHF/UHF Spectrum for SAR?

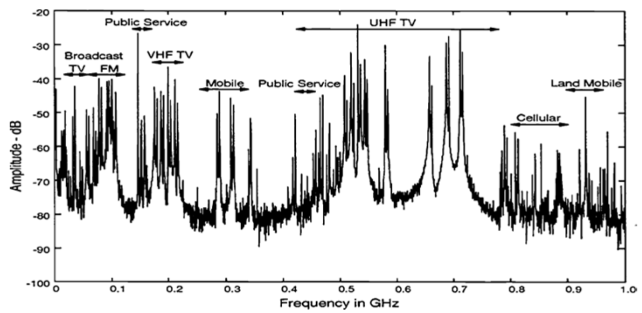
- Foliage Penetration (FoPEN) Radar
- Ground Penetration Radar (GPR)
- Scattering is dependent on wavelength



Issues with UHF/VHF spectrum

SAR systems affected by Radio frequency interference (RFI) Interference Types:

- SAR chirp must be notched to avoid restricted bands
- Other spectrum users can interfere with SAR
- Intentional jamming.



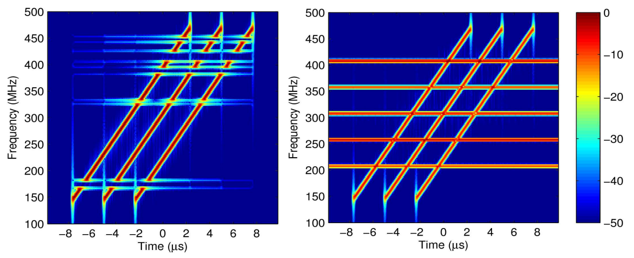
Impact on Image Reconstruction:

- SAR chirp waveforms notched and receive signals corrupted with additional RFI across the spectrum

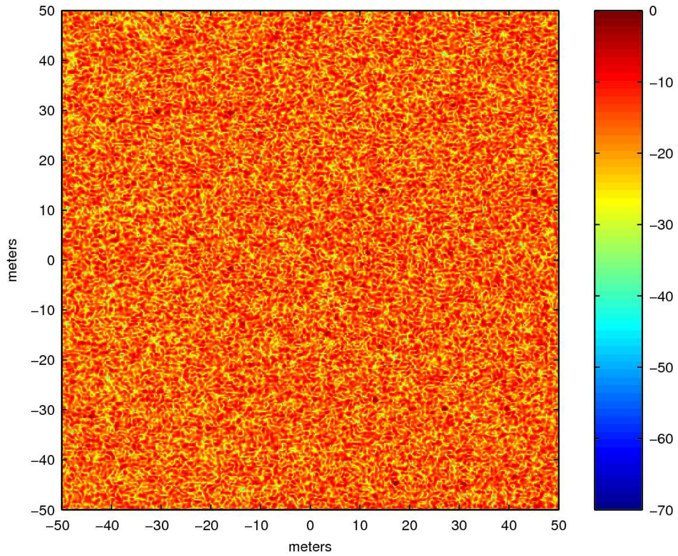
- With no RFI suppression the back projection reconstructed image will be completely useless;

- Suppressing RFI with a linear filter before back projection improves things but there is still considerable interference.

- Sparsity based RFI suppression using iterative forward-back projection completely removes RFI distortion.



No RFI suppression



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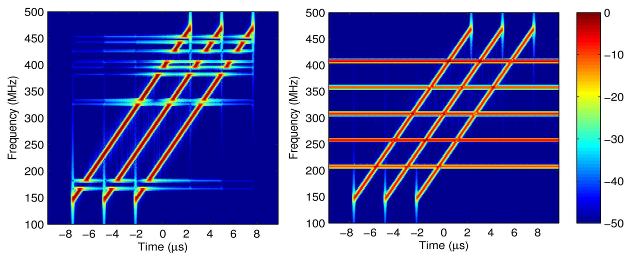
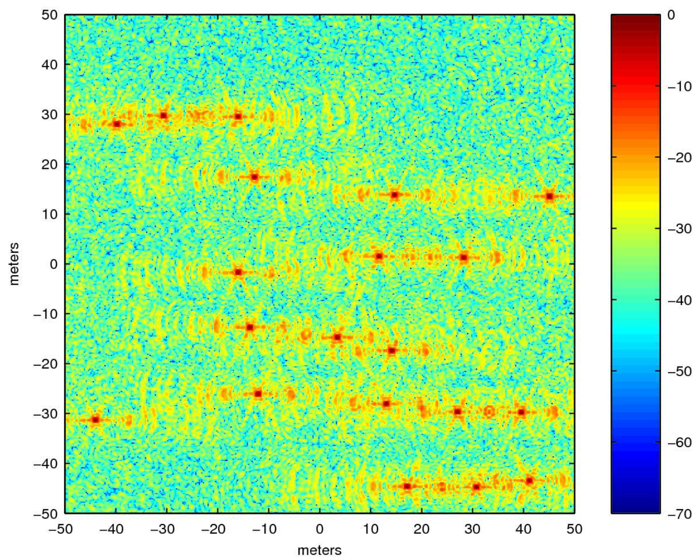


Linear filter RFI suppression



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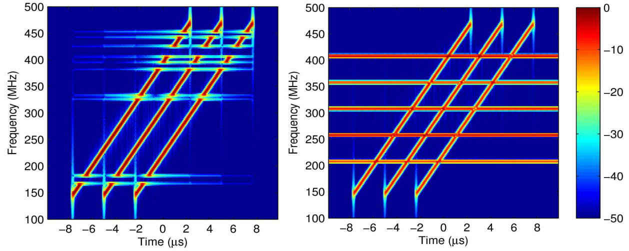
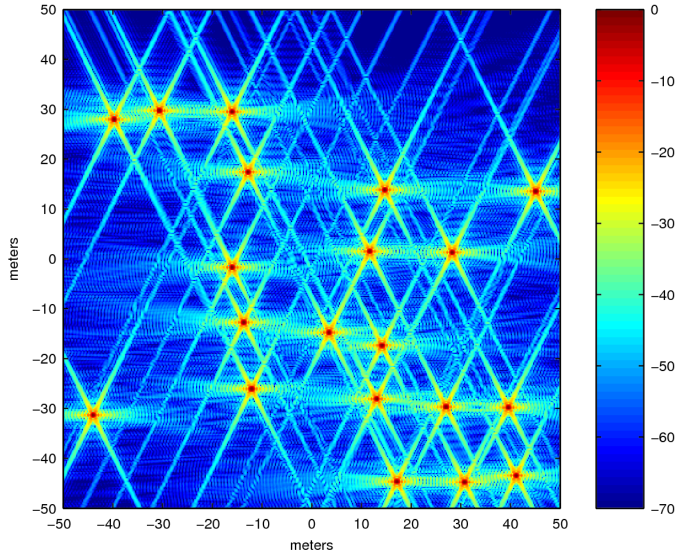


Sparsity-based RFI suppression

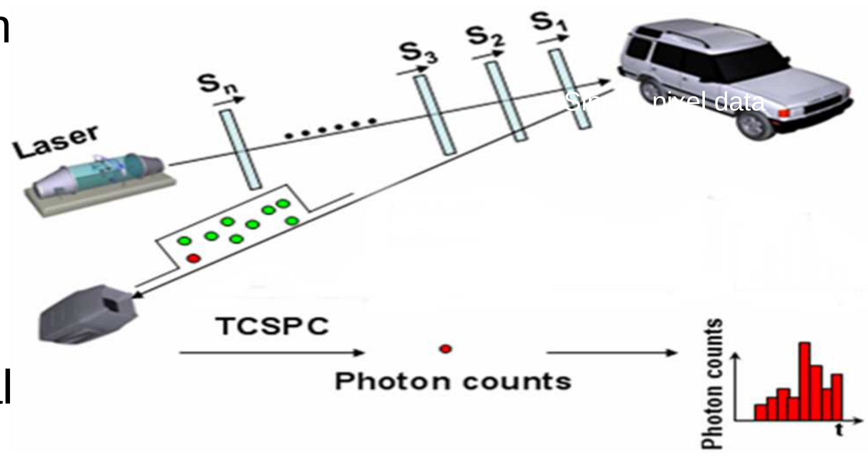


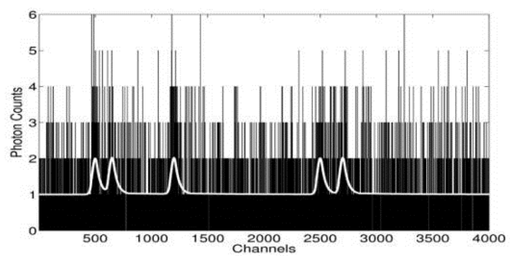
Bayesian Analysis for LiDAR 3D Imaging

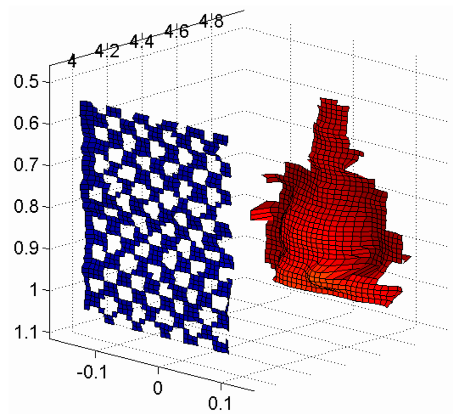
The photon counting LiDAR is sensitive, accurate and covert.

An *unknown* number of surface returns on each pixel from photon counts in a 3D imaging system can be estimated using Bayesian MCMC algorithms.

Future challenges include extending the technology to acquire multi-spectral data, possibly in combination with hyperspectral imagery, managing the noisy 3D point cloud data and optimising the sampling strategy to maximise the imaging rate.

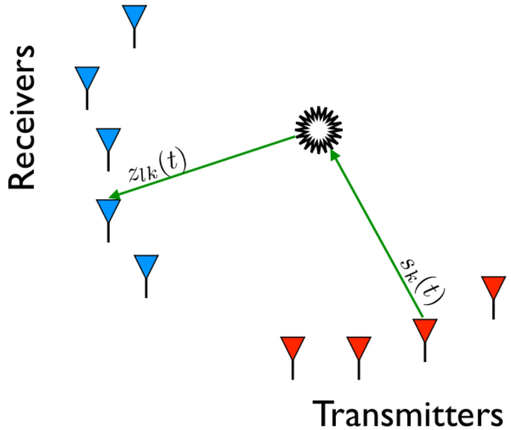


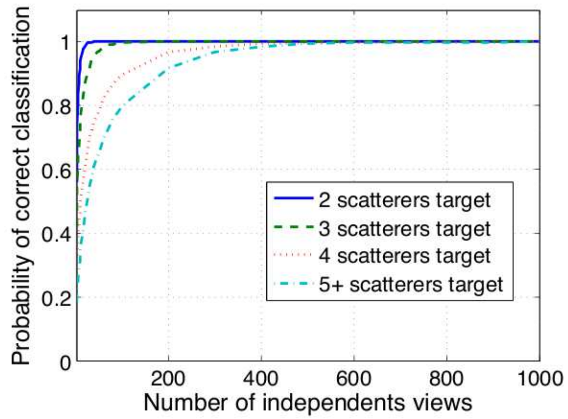




Underwater surveillance: benefit of MIMO sonar

Multiple Input Multiple Output. (MIMO) brings N x M views, better coverage, redundant bistatic views at the cost of greater complexity and synchronisation issues.





Multiple views provide improved capability in object recognition. We can use a Bayesian approach to determine the number of scatterers of the insonified target:

# of views	Correct Class.
10	64%
50	86%
100	92%
200	97%
500	99.81%
1000	>99.999%

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

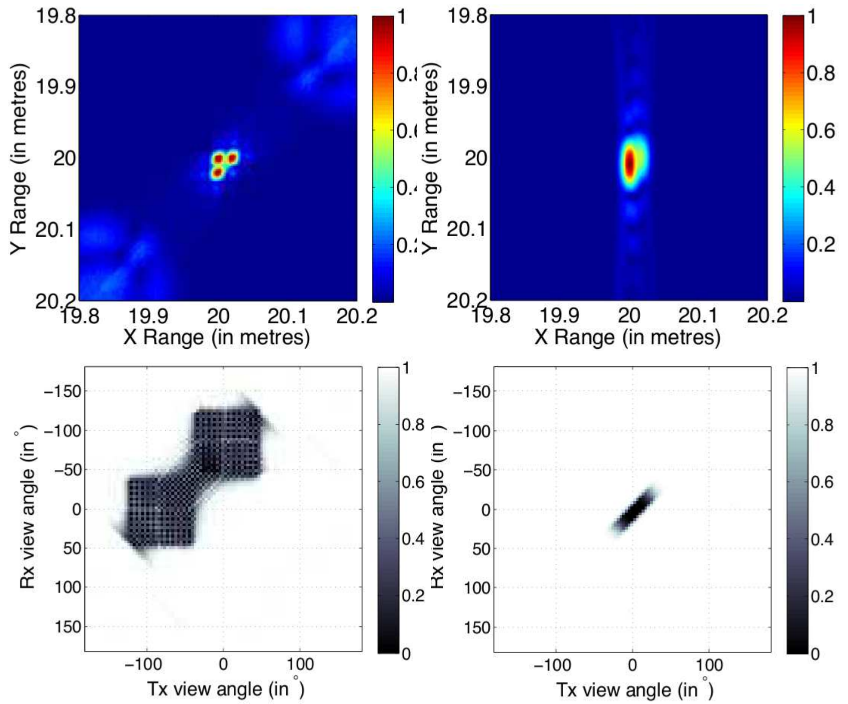
MIMO super-resolution capability

Large MIMO sonar systems decorrelate the scatters between each other and maximize the target response.

To achieve super-resolution we need:

- **Independent views**: the antenna have to be sufficiently spaced to ensure the independence of each view.
- **Decorrelation**: the total number of views has to be large enough to ensure the scatterers decorrelation.
- **Broadband**: in order to achieve the range resolution needed, the MIMO system has to use broadband pulses for range compression.

Sonar images (3 scatterers): (left): MIMO system image and inter-views correlation, (right): SAS equivalent image and inter-views correlation



Processing

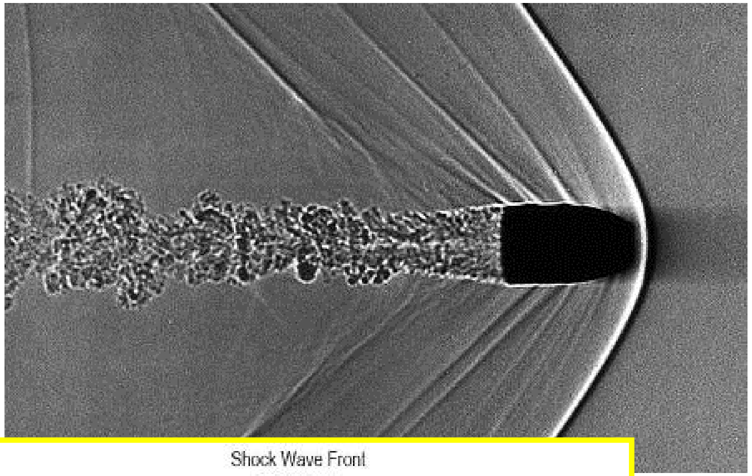
Detection, localization and classification, distributed sensor processing, multi-target tracking, behaviour monitoring/anomaly detection

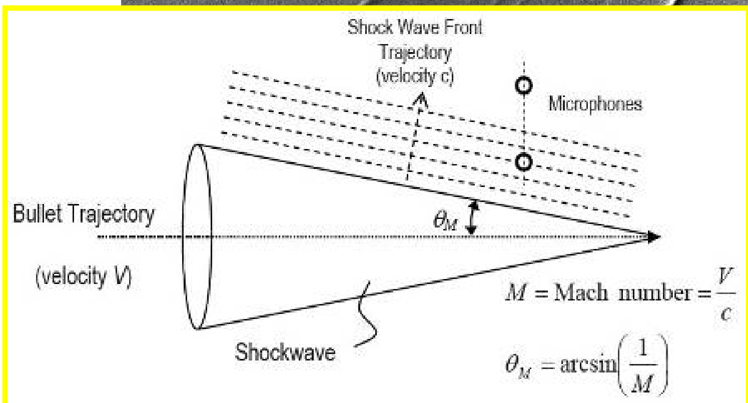
Passive detection and localisation of acoustic signals

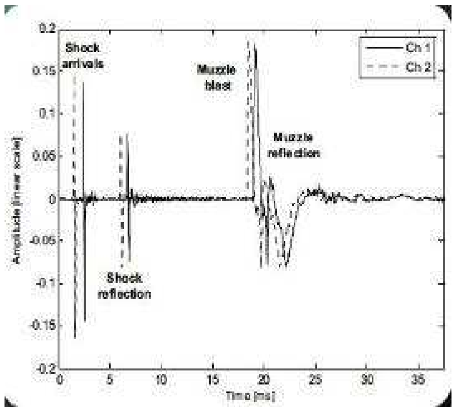
Detection and localisation of acoustic weapons fire in outdoor in-air acoustic environments; e.g. sniper localisation in urban environments.

Assume muzzle blast undetectable, Microphones detect shockwave front only. Analysis of bullet trajectory and shockwave geometry using statistical signal model of *N*-wave.

We have developed joint sequential detection, estimation, and localisation algorithms for trajectory estimation.







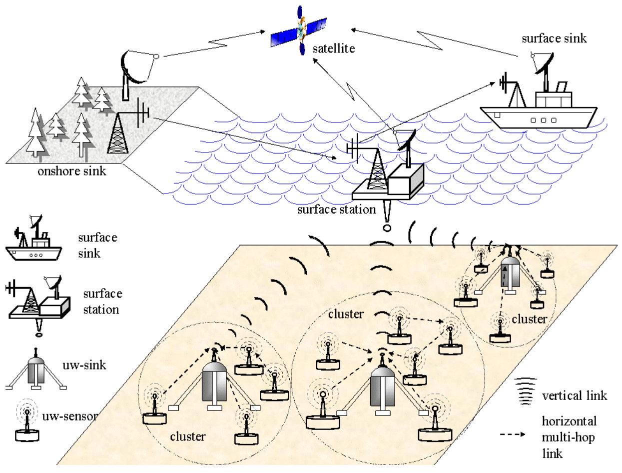
Distributed multi-sensor processing

Multi-sensor exploitation is key to increased situational awareness. We are working on distributed processing to provide scalability and overcome issues of resource limitations (communication bandwidth, power, etc.).

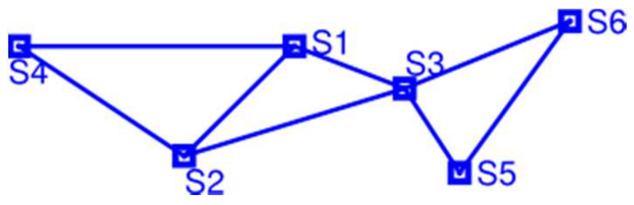
Target applications include:

- Underwater acoustic networks, e.g. passive sono-buoy network for port monitoring
- Perimeter surveillance for intruder detection
- Futures concept of "every man a sensor"

Networks may be sparse, low bandwidth and heterogeneous (mixed radar EO/acoustic).



Underwater sensor network (Akylidiz et al. 2005)



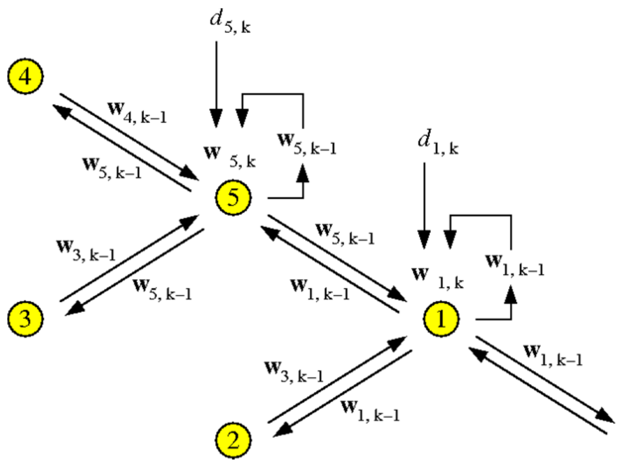
Graph of admissible communication links

Distributed multi-sensor processing

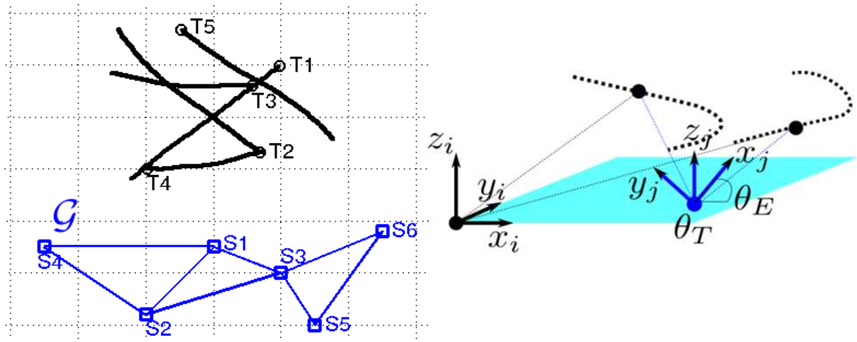
Aim is to develop scalable and reliable methods for distributed sensor fusion, registration and detection that can be realised by a networked system.

The key tools are:

- Approximate statistical inference on graphical models, e.g. Non-parametric Belief Propagation;
- Distributed Maximum Likelihood and optimization;
- Accelerated consensus algorithms and diffusion learning.



Information flow in a diffusion learning network

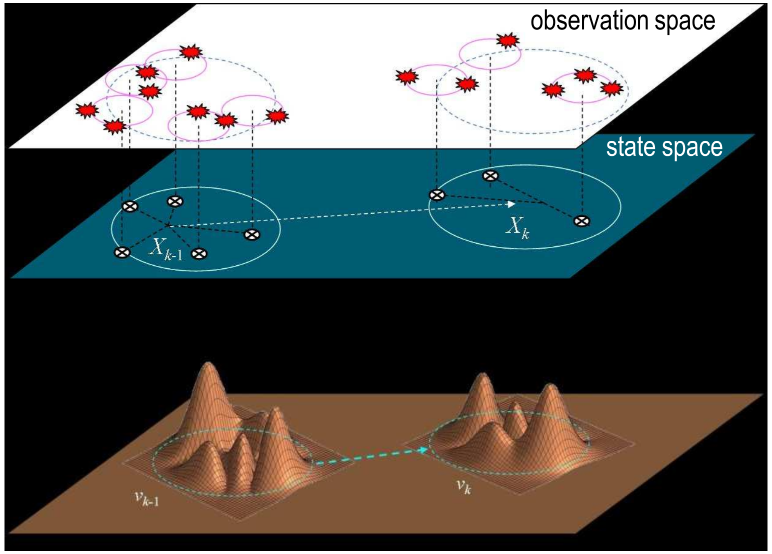


Current investigation focussing on cooperative sensor localisation by exploiting non-cooperative targets and propagation of local likelihoods

Multi-target tracking and sensor management

Multi-object Bayesian estimation framework: Stochastic population of objects modelled with point processes (or Random Finite Sets)

- Recent field of development (early 2000's);
- Adapted to detection/tracking problem with unknown number of targets;
- Unifies system uncertainties (target number, target localisation, noised measurements, missed detections, etc.).



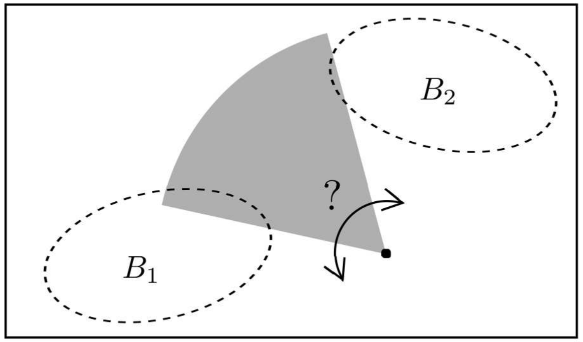
Previous work has focussed on multi-target tracking and data fusion. We are extending this approach to encompass hierarchical sensor management.

Sensor management for multi-target filtering

For sensor management problems where sensor coverage is limited a local assessment of situation awareness is desirable to guide the reallocation of resources.

Recent developments [Clark and Houssineau] in multi-object filtering allow exploitation of higher-order statistics on point processes, notably the *regional variance in target number*.

Source: http://www.nollywoodone.com/latest-additions/9009-the-u-s-military-s-real-time-google-street-view-airborne-spy-camera-can-track-an-entire-city-in-1-800mp.html



This provides multi-target trackers with regional information on target activity in any region B of the surveillance scene;
The goal is to develop new sensor control policies using this regional variance measure.

Context-based Behaviour monitoring

Context (social, spatial, temporal) informs how people behave. The challenge is to monitor behaviour though electro-optic sensors (video, IR, LiDAR) and audio (microphone arrays)

- Analysts use a wealth of contextual information but hard to quantify
- Automatic Behavioural monitoring through Bayesian networks. Information can be fed back to provide:
  - Prediction of intent
  - Improved detection classification and tracking
  - Pattern of life analysis

Applications include:

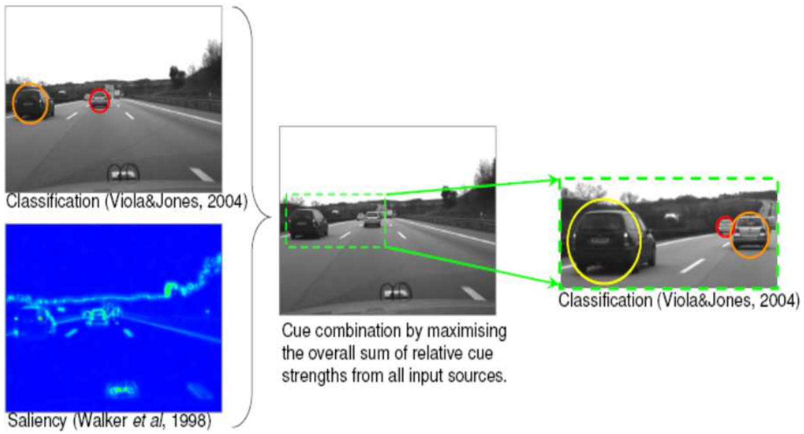
- Concourse monitoring (detecting threats before they're at the gate)
- Airbourne monitoring (UAV)

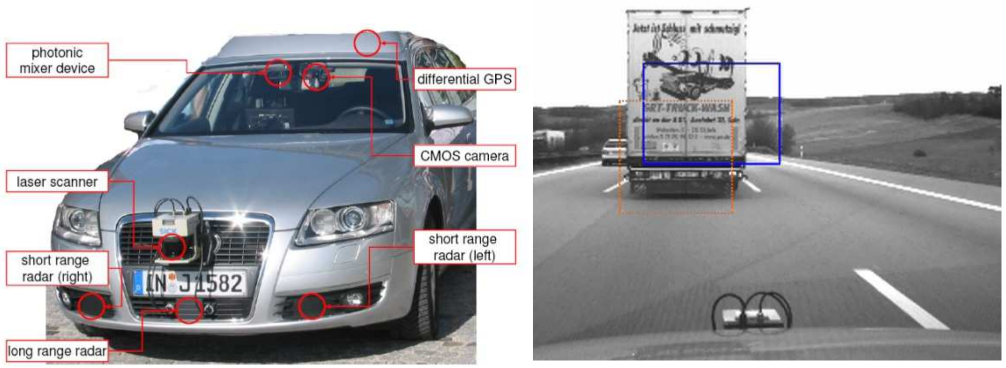
Efficient Computation

Efficient Computation

Processing solutions need to be computationally efficient. Often there is a real time requirement with fixed size weight and power (SWaP).

- Simplify required computations, reduce their number and exploit parallelism
- Map to parallel processors such as General-Purpose Graphics Processing Units (GPUs) and Field-Programmable Gate Arrays (FPGAs);
- Dynamically reconfigure platform support for implementations of complex signal processing tasks
- Goal is to develop computational resource management systems for multi-task multi-sensor platforms

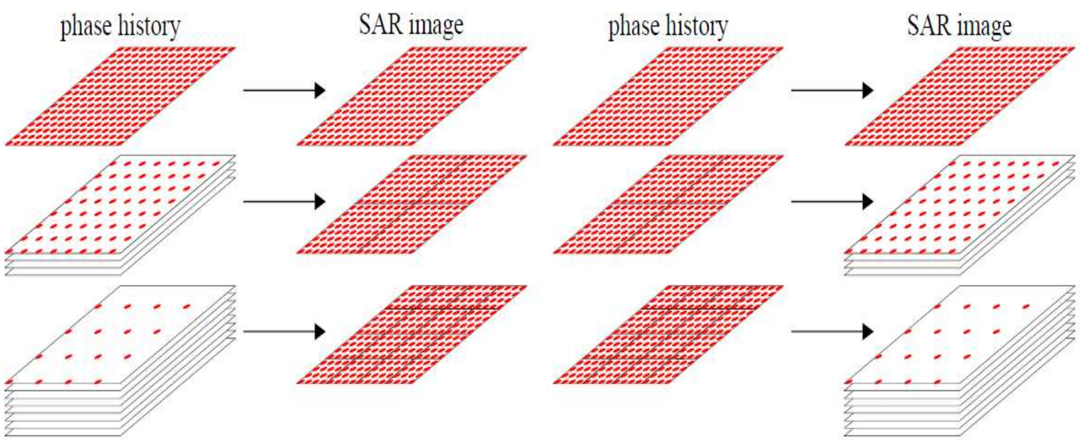




Audi experimental vehicle

Fast Iterative image reconstruction

Bottleneck in most iterative image reconstruction algorithms is the computation of the forward/back projections – conventional solutions restrict to Fourier approximation, e.g. Polar Format Algorithm. However, same decimation techniques can be used much more widely. We have generated new decimation in image solutions with complexity $\mathcal{O}(N^2 \log N)$ and image domain error control.



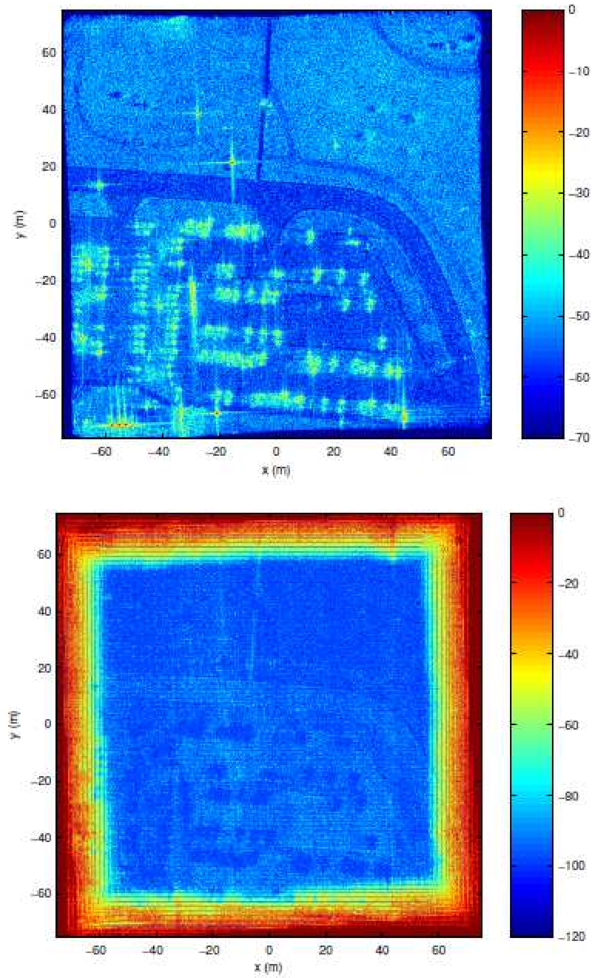
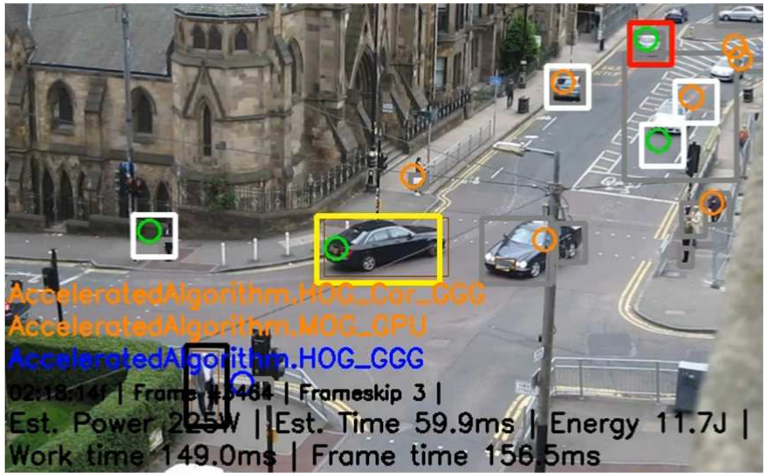


image domain error control

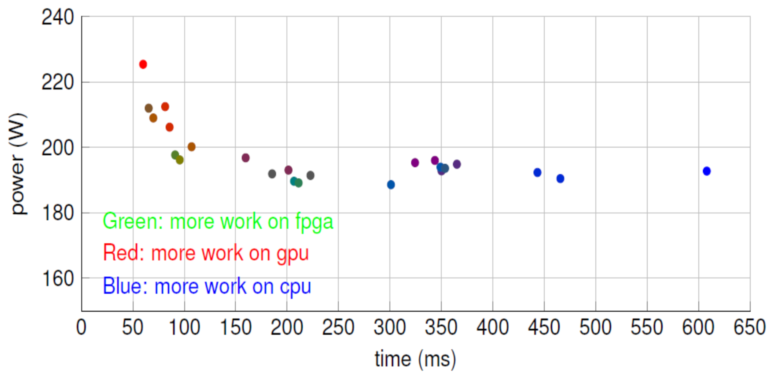
Dynamic platform selection for anomaly detection

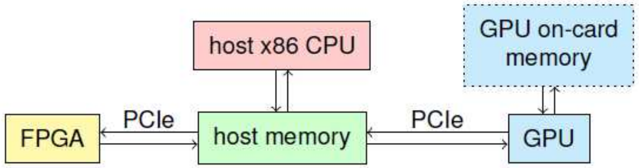
Optimising time/power/latency trade-offs between FPGA,GPU and CPU platforms

- Military and civilian applications;
- Re-map processing between architectures on-the-fly dependent on scene complexity and presence of anomalous behaviour;
- Detections plug into high level processing for crowd monitoring/anomaly detection;
- Goal is to develop real-time probabilistic detections using parallelisable advanced classification algorithms



Car & Person Detection

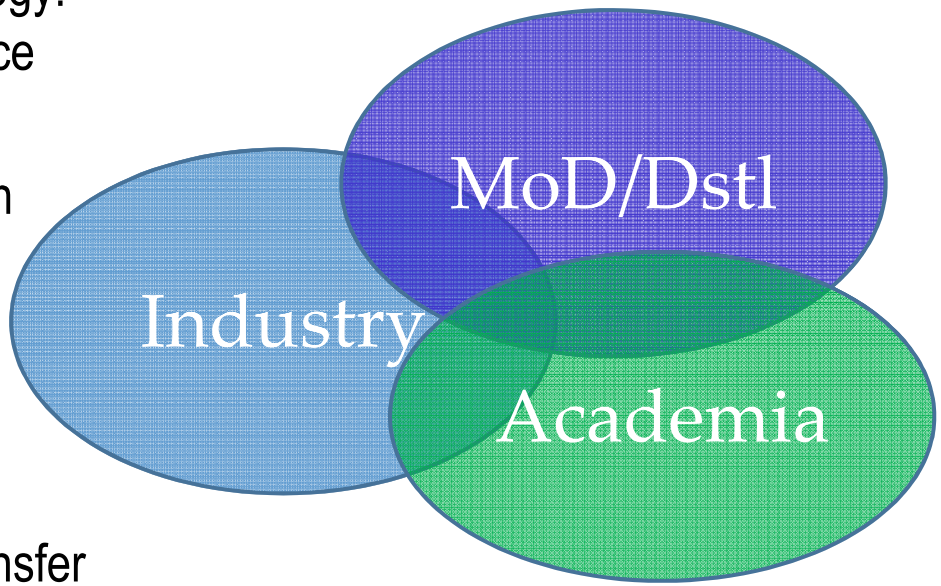




How to get Involved

Impact & Technology Transfer

- Not just about novel science and technology: need to assess the applicability for defence purposes
- Early engagement with industrial research partners provides for industry perspective
- Software and hardware demonstrators to showcase technology
- Identified opportunities for technology transfer will be pursued through spin-out projects, CASE studentships, etc.



Research Partners

Selex ES
A Finmeccanica Company

THALES

QinetiQ
People Who Know How

seebyte

BAE SYSTEMS

[dstl]

EPSRC
Engineering and Physical Sciences
Research Council

Current associated PhDs

- Underwater depth-imaging using a time-of-flight single-photon counting technique; Heriot-Watt University, Dstl, SUPA
- Multistatic single data set radar detection in coloured gaussian interference; University of Edinburgh
- Dynamic distance-based shape features for gait recognition; Heriot-Watt University
- Adaptive switching detection algorithm in Turbo-MIMO systems enabling power savings; Universiti Tun Hussein Onn Malaysia, University of Edinburgh
- Sparse Representations and Low Rank Approximations for Activity Recognition; Heriot-Watt University, University of Bern
- Cognitive Radar within Autonomous Systems; Heriot-Watt University, Dstl
- Contextual Image Processing; Heriot-Watt University, Thales, ESPRC
- SAR processing with zeroes; University of Edinburgh, Dstl, EPSRC
- Ground-Moving Target Detection and Multi-Channel Radar Imaging; University of Edinburgh, Selex ES, The Royal Commission for the Exhibition of 1851, EPSRC
- Audio-Video Convergence for Surveillance Applications; Heriot-Watt University and University of Edinburgh

Contact us at:

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