Ministry of Defence

[dstl]

University Defence Research Collaboration in Signal Processing, Phase 3 Application Theme in Imaging and Detection through Complex Media

Closing date: 16:00 on 4 September 2018

This document should be read in conjunction with the EPSRC/MOD call document for the above mentioned project, available on the EPSRC website (https://epsrc.ukri.org/funding/calls/udrcphase3appthemes/).

Technical challenges

The following are unclassified examples of challenges that the research solicited in the call document may seek to address. The list is non-exhaustive and not specific, but the statements provide tangible motivating examples of problems for which MOD is seeking solutions. It is not necessary to address all of these Technical Challenges, and other relevant problems may be presented during the course of the award.

1. Through-wall and in-building observation and imaging with low-frequency radar

Defence and security operations may have the requirement to observe unseen activity in buildings, for example in hostage situations, disaster relief, and for the detection of illegal activity. This may be possible by utilising low-frequency synthetic aperture radar, or by using emitters of opportunity such as WiFi within the building for passive radar. In both cases, there is a significant challenge in unravelling the complex propagation path in order to resolve the scene. As well as multiple scattering, frequency dependent reflectivity and attenuation by building materials and contents may be observed over the range of frequencies collected. Other structural dispersion may also be present. This increases the complexity of the imaging problem, but may also offer additional information to be exploited.

Many of these features can clearly be observed in the Bright Sapphire 2 dataset, a complete k-space low-frequency SAR data dome available to support this challenge. As well as building contents and mapping, it is desirable to observe any current motion and changes over longer periods of time. Similar challenges exist in finding and mapping underground tunnels and facilities, and other modalities, e.g. gravimetry, may also be relevant.

2. Electro-optical imaging through smoke and clouds

Detection, tracking and identification of objects is often undertaken using electro-optical sensors suitable for mounting on smaller tactical platforms, such as helicopters, where larger radar sensors may be unsuitable. These tasks can be compromised by smoke and clouds. Clouds may be formed of a range of particle types and sizes, such as water droplets, sand or snow, may be naturally occurring or man-made, and as such will display various frequency-dependent reflectivity and absorption characteristics. The objects of interest will similarly display varying frequency-dependent responses.

A suitable electro-optical system might consist of a scanning laser with a focal plane-array detector, in which each measurement will contain the response from the target, masked by the back- and forward-scatter of the laser beam through the cloud as well as changes in the ray-path. Reconstruction algorithms are required to extract the information about the object, which may utilise the timing accuracy from single-photon counting, and multiple polar and frequency measurements.

Another possibility is to integrate many electro-optical images over time to obtain the very large dynamic range necessary to view objects of interest through clouds, possibly utilising high-powered light sources. Part of the problem of such a method will be extracting targets from amongst the noise and resolving blurring due to changes in ray path. Additionally, the targets themselves will likely have moved relative to the observer during the course of the integration.

3. Over the Horizon Radar (OTHR)

The accuracy of an OTHR system is primarily driven by our understanding of the complex and varying propagation paths taken by HF radiation through the ionosphere. Modern digital OTHR systems offer the opportunity for a greater level of accuracy than was previously available, opening up new tactical and strategic applications for this sensing methodology. In order to understand the propagation path of HF radiation and therefore operate an accurate OTHR, it is necessary to model in detail the current and near-future state of the ionosphere.

Thus, the challenge involves improving the forward model, incorporating observations from the ground and space as well as other sources of information taken both from live feeds and prior knowledge. The uncertainty of this information and the propagation model must also be accounted for, with both of which varying both spatially and temporally. This is particularly challenging in Polar Regions, due to their turbulent and powerful space weather. It is also desirable to monitor these regions persistently, continuously updating the propagation model, due to seasonally-changing air and shipping lanes which are becoming increasingly important to global trade.

4. Security screening of people and baggage

The detection, classification and recognition of concealed items behind clothing and inside baggage is an area in which advances in imaging and detection signal processing are of clear interest to defence and security users. At transport hubs it is necessary to conduct security processing of passengers without having a negative impact on throughput. Where individual screening is required, security checks proceed more quickly if the passengers are not required to divest clothing. Therefore, signal propagation through clothing and baggage is of interest. This challenge also brings up the issue of personal privacy and the potential use of automated target detection to avoid the need for operator image interpretation. The aim is to obtain a high probability of detection whilst minimising false alarm rate and real-time decision making.

5. SAR in complex environments

The majority of synthetic aperture radar algorithms assume free-space transmission and scattering by stationary isotropic point reflectors on a 2D surface. There are many common real-world situations in which these assumptions are routinely broken: double- or triple-scattering off walls and other objects; moving, vibrating or manoeuvring objects; dispersion due to material type or material structure; and obscuration by large objects, causing radar shadow and obscuration (layover) in the 2D representation of a 3D scene. By breaking the basic assumptions of the conventional algorithm, features such as hyperspectral response, Doppler shift or multiple-scattering introduce artefacts into the image which may be extremely difficult to interpret in isolation and are worse still when combined in a large dynamic scene.

The defence and security user has need for algorithms that are able to deal with these complexities in a variety of use cases, such as detecting, tracking and imaging man-made or manoeuvring objects into or through tree canopies. Such algorithms may make use of additional information in multi-pass (interferometric) SAR; multi-static and multi-polar collections; radar shadow, which has no Doppler shift and highlights 3D objects; wide or multiple frequency bands; or even suggest new novel collection regimes to extract the information required.

6. Hidden target detection and discrimination in soil and building materials

Through-barrier non-invasive sensing is an important issue for defence and security and the detection of discrete threat items buried in soil and concealed within buildings is of particular concern. Further to detection, the classification and recognition of emplaced subsurface items is the long-term goal.

In the case of soil, its natural heterogeneous and cluttered make-up leads to unknown spatially variant attenuation and dispersive properties. In addition, the ground surface and sub-surface interfaces within the soil are invariably irregular adding to the complexity in the propagation of energy. Furthermore, the presence of moisture and vegetation makes the environment more challenging.

The detection of concealed targets in buildings is a similarly challenging scenario. Unknown building construction detail and material properties need to be accounted for. The desire in this challenge is to develop high probability of detection algorithms whilst reducing the false alarm rate. Processing that produces an output allowing real-time decisions is highly beneficial.

7. Through-Water Electro-Optic Imagery Correction

Any remote sensing technology requires atmospheric compensation to correct for scintillation effects and non-uniform absorption across the spectrum. Techniques already exist to perform atmospheric compensation in electro-optic imagery, but these cannot be directly applied to underwater imagery. Underwater remote sensing has the additional problem of omnidirectional surface reflections, underwater scintillation and strong non-uniform absorption, dependent on local turbidity and marine constituents. Limited techniques are available to address these issues within a specified environment. Airborne through-water sensing has to correct for all atmospheric, underwater and boundary effects within the same image. Furthermore, the specific environmental parameters may be unknown, so cannot be fed into standard image compensation algorithms. This challenge addresses the need for a generic method for near real-time correction of airborne underwater imagery that can compensate for both atmospheric and underwater effects in all environments and for all environmental features. Particular emphasis is placed on the through-water part of the problem, as this is the crucial difficulty for current applications. Of specific defence interest are visual, hyperspectral and LIDAR imagery, so complete spectral correction and image recognition need to be considered.

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