Systems for persistent surveillance

Keith Lewis*
Sciovis Ltd, Victoria Road, Malvern, Worcestershire
WR14 2TE, UK
*Previously Research Director, Electro-Magnetic Remote Sensing Defence Technology Centre
E-mail klewis@sciovis.com

ABSTRACT

The requirements for a persistent wide-area surveillance system are discussed in the context of evolving military operations. Significant emphasis has been placed on the development of new sensing technologies to meet the challenges posed by asymmetric threats. Within the UK, the Electro-Magnetic Remote Sensing Defence Technology Centre (EMRS DTC) has supported the research and development of new capabilities including radio-frequency (RF) and electro-optic (EO) systems, as well as work on sensor exploitation, with a goal of developing solutions for enhancing situational awareness. This activity has been supported by field trials to determine the efficacy of competing technologies in relation to realistic threat scenarios.

1. INTRODUCTION

Defence operations are becoming increasingly reliant on the provision of persistent surveillance for a wide range of operational scenarios. Such capabilities are critically dependent on the abilities of advanced sensor systems such as SAR-GMTI radars to address wide fields of regard under all weather conditions and to track multiple targets. However the resolution levels provided by radars don't always provide sufficient information to determine whether or not objects in the field of regard constitute threats. To enhance the threat identification process it is necessary to exploit electro-optical (EO) techniques to ensure that the military commander is provided with sufficient knowledge relating to the intent of hostile force action.

The Electro-Magnetic Remote Sensing Defence Technology Centre (EMRS DTC) was established in the UK in 2003 to provide a centre of excellence in sensor research and development, supporting new capabilities in key military areas such as precision attack, battlespace manoeuvre and information superiority. The DTC was set up as a partnership between UK Industry, the academic science base and the UK Ministry of Defence, to develop advanced and affordable technology in support of mission-oriented defence capabilities. Its field of activity has included RF and Electro-Optic (EO) systems as well as work on sensor exploitation, addressing solutions for enhancing situational awareness and for providing persistent surveillance for military operations.

Over the lifetime of the DTC, the nature of conflict changed considerably with the need to address challenges presented by evolving operational theatres. This placed a high priority on the development of solutions to address specific threats and fast-tracking these to support the front line. It is well-known that asymmetry poses a significant challenge in current operational theatres, with ubiquitous threat scenarios presented by terrorists exploiting both military hardware and commercially-sourced materials and devices. In recognition of this, an increasing emphasis has emerged towards generating information from sensors, rather than just sensing alone.

In addressing requirements for a persistent wide area surveillance system, sensors need to provide information to support scenarios ranging from countering insurgency to force protection. In the latter case, example tasks are countering IEDs (including gathering information on supply chains, manufacturing and assembly), as well as supporting route reconnaissance and forward operating base (FOB) protection. For countering insurgency, there are also requirements to understand patterns of life and to detect/locate time-sensitive targets. Many of these scenarios highlight the need to exploit characteristics of the relevant target sets, which to some extent defines goals for discriminative sensing. In practice, no single sensing modality is capable of providing acceptable detection probabilities with low false alarm rates. This drives the requirement for the intelligent fusion of information provided by disparate sources.

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Goals for persistent surveillance are determined by military context and by the field of regard. Sufficient resolution has to be provided for target discrimination, but this can be relaxed if the goal is purely about tracking the movement of vehicles. Some tactical unmanned air vehicles (eg ScanEagle) already provide useful surveillance capabilities exploiting synthetic aperture radar (SAR) and electro-optic (EO) imagery. Information from the SAR can be used to cue an EO sensor to enhance the degree of target discrimination. However a significant problem met with conventional high resolution EO systems is the challenge posed by the "soda-straw" effect, which inevitably drives the associated need for highly stabilised optical systems and good pointing accuracy, with resulting penalties in their use on unmanned systems.

Over its lifetime, the EMRS DTC has supported a number of sensor-related activities, both from the point of view of developing new sensor technologies and in the exploitation and benchmarking of those sensors in field trials held in collaboration with the UK Defence Science and Technology Laboratory (Dstl) at their Porton Down field-test site. In the first trial, held in March 2008, a comprehensive set of static targets was used, both military and civilian. The performance of new sensors was benchmarked against existing sensors, including high-performance TV and thermal imagers. Imagery generated was used to assess algorithms for target detection and data fusion, some of which were developed by the DTC. The second trial, held in May 2010, was centred on two live outdoor exercises involving the launching of simulated improvised explosive device (IED) attacks. Activity was recorded amidst the clutter of every-day activity and forensically examined with action-replay. Sensor teams partnered with processing teams who exploited the high-performance video and imagery to enhance the resolution even further and to detect, recognise, identify, track, and manage target information.

2. COMPONENTS OF A PERSISTENT WIDE AREA SURVEILLANCE (PWAS) SYSTEM

To maintain a full 24-hour, all-weather capability, it is evident that surveillance devices will need to exploit both radio-frequency (RF) and optical (EO) systems. Depending on their eventual application, there may also be a need to support the primary group of sensors with a network of un-manned ground sensors, especially in the vicinity of forward operating bases (FOBs). High altitude sensors (including those on board satellite platforms) can clearly cover a wide field of view, but will be challenged by periods when areas of interest are obscured by cloud cover, or by the timing of satellite orbits. To a certain extent, systems already in operation in the field are capable of meeting some of the sensing requirements of a PWAS system, but they are generally not deployed as part of a network, and there is very little collaboration between the sensors to allow the benefits of cross-cueing to be exploited.

For example, the radars provided on E3D Sentry aircraft are extremely sophisticated and provide enhanced detection particularly for low radar cross-section (RCS) targets [1]. The radar exploits pulse Doppler compression waveforms that increase data sampling rates, which with advanced signal processing algorithms, enhance detection sensitivity and unambiguous range determination and benefit the ability to detect/track smaller targets at greater distances. For UK forces, the E3D platforms are supported by the ASTOR system, incorporating a SAR and GMTI capability in a converted executive business jet [2]. This system (Sentinel) was originally intended for conventional war-fighting operations, tracking armoured formations and conducting strategic reconnaissance tasks, but has been adapted for use in a number of different roles, providing value in support of counter-insurgency (COIN) operations in Afghanistan.

To provide higher degrees of resolution, especially around FOBs, the various RF systems can be supplemented by EO systems fitted to towers or flown on aerostats. As an example of the latter, the UK is fielding PGSS (persistent ground surveillance system) as a component of the Cortez base surveillance control system [3]. This is configured with an L-3 Wescam MX-15 electro-optic/infrared sensor, as well as full-motion video and acoustic sensors. Such surveillance systems will help detect, identify and track insurgent activities, particularly those concerned with planting improvised explosive devices or planning day or night ambushes in complex environments. The new system also will improve automated target tracking capability and offer better target detection and identification, by employing multi-spectral imaging.

New imaging systems are constantly under development. As an example, PV Labs has developed a system incorporating an airborne 128 Mpixel camera into a look-down gimbal with full steering for flight freedom inside targeted areas, with unparalleled image stabilization [4]. This is associated with a real-time image processing and data storage system capable of dealing with the emerging streams of information. The management of imagery emerging from such sensors, including geo-registration via metadata tags is perhaps one of the greatest challenges in determining the success of such a PWAS system. However the "holy grail" of seamless PWAS integration has yet to be realized and it is evident that in the future, a greater reliance will be placed on the use of unmanned air systems (UAS). These will require new forms of sensor to meet criteria in relation to size, weight and power.

3. DTC RESEARCH ON ADVANCED RF SYSTEMS

The EMRS DTC has pursued a broad range of RF sensing topics, including technologies as diverse as ground-based HF (30MHz) surface wave radar, VHF (80MHz~400MHz) forward scatter radar, airborne radar from P-band (450MHz) up to X-band (10GHz) and low terahertz (250GHz) passive imaging. The scope of the research programme has ranged from very low TRL theoretical investigations through to successful airborne demonstrators at TRL 5/6. Researchers have been drawn from Universities, SMEs, large companies and research institutes, including a number of overseas organizations.

As already indicated, SAR imagery can provide high resolution at substantial stand-off ranges and some systems are already well-established. The EMRS DTC programme has focussed on more advanced SAR concepts, including tomography and interrupted modes of operation. In the former activity, a team comprising eOsphere, the University of Edinburgh and the German Aerospace Centre DLR have deployed a multi-frequency, multi-polarisation SAR test-bed in trials to provide ground-truthed SAR datasets [5], with the following outcomes:

- Successful processing of multiple-pass SAR data to produce 3D tomographic SAR imagery, which has demonstrated the ability of low frequency (L-band and P-band) SAR to detect targets under foliage.
- The development of a novel polarimetric detector, which has shown the benefits in the detection of small man-made targets and can be used with both single-pass and dual-pass polarimetric SAR.
- Demonstration of improved target discrimination by exploiting SAR imagery measured at different frequencies.

In the context of multi-functional UAV systems, TW Research [6] explored the feasibility of exploiting an interrupted SAR technique to enable multiplexing of radar operations with other tasks eg ESM, EW or communication operations. Techniques were successfully demonstrated using real data that avoided any significant degradation in the SAR imagery. This can find application both in existing systems and future multi-function systems.

In the area of multi-function wide-band RF Systems, SELEX-Galileo [7] and BAE Systems [8] separately developed technologies for wide bandwidth (>4:1 frequency range) dual-polarised electronically scanned antenna arrays capable of providing wide scan angles (60˚) in two dimensions. This key enabling technology for multifunctional RF systems on UAVs exploited element mutual coupling effects that, in previous designs, were considered undesirable.

Strategies exploiting bistatic SAR using transmitters of opportunity can locate objects of interest in operational theatres without drawing the attention of hostile forces. In a world-first experimental demonstration, the University of Birmingham used non-co-operative transmissions of standard navigation satellites (eg GLONASS and GALILEO) in conjunction with a simple airborne receiver to produce bistatic SAR imagery [9]. This technique offers significant potential for covert, persistent wide area surveillance. Currently the transmission characteristics of the satellites limit the achievable resolution and stand-off range, but future developments could substantially improve performance.

The University of Birmingham also developed the technology for a network of simple, low cost ground-based sensors that operate as forward scatter radars [10]. Operating at VHF frequencies, these nodes do not need to be accurately located and could even be air-dropped. This form of sensor network offers a unique capability for purposes such as the persistent surveillance of remote border areas and FOB protection. The forward scatter sensor can also discriminate between different types/scales of targets and the network can provide reasonably precise location. Significantly it has also been show to be capable of sensing intruders within buildings using sensors that are located outside the building, with penetration through walls with a total thickness in the region of 2m.

In a different approach, a study by TNO in the Netherlands [11] successfully combined SAR and MIMO radars to demonstrate the capability to image *inside* buildings, conceptually using a 'drive-by' vehicle-borne radar. This was found to be capable of locating objects such as steel cupboards, drawer units and people inside rooms.

The DTC has supported research on multiple-input multiple-output (MIMO) RF techniques to enable the development of novel radars required to survey large areas, either for imaging purposes or simply for rapid search. A team from Teledyne in Australia has achieved remarkable success, and has demonstrated MIMO systems ranging from a 35GHz imager for security scanning [12] to an 8GHz system designed as a 'sense and avoid' sensor for UAVs [13] and an 8GHz Multi-Beam Radar Altimeter [15] intended as a low visibility landing aid for helicopters in operational environments.

In the areas of sub-THz sensing, experiments were carried out using a 250 GHz system developed by Thruvision [15], which successfully detected objects hidden on people as well as locating shallow buried objects, both metallic and non-metallic. The latter was found to complement the capabilities of passive IR detectors.

Several research programmes investigated improved techniques for detecting small, difficult targets in sea clutter. Much was learned about clutter characteristics in coherent radar and in littoral regions - most prior research had concentrated on non-coherent radar in the open ocean. These major strides in understanding have been very beneficial to ongoing maritime radar developments. Much of this work was carried out by TW Research [16] but this was complemented by some recent work at QinetiQ [17], which demonstrated potential for significant improvement in performance by exploiting the frequency/spatial frequency characteristics of sea clutter which differ significantly from those of targets. This technique is likely to be of most value in naval radar, although the research also showed the potential for airborne radar.

Some compact radar systems have already been taken forward into production and are available as commercial products. One example is the SELEX-Galileo PicoSAR system [18], which can provide better than 1 metre ground resolution with operation at ranges of up to 20km in a 10Kg package. Such systems enable networked operation and in one experiment, the DTC examined the feasibility of using a pair of helicopter-mounted PicoSARs to improve the precision of target location. Datasets were recorded from several exercises involving convoys of vehicles moving along a long straight road, with other vehicles overtaking or crossing to confuse the tracking of individual vehicles. When using crossed beams, cross-range precision was improved by a considerable factor.

4. DTC RESEARCH ON EO SYSTEMS

In the EO arena, research activities explored new laser sources, novel detector technologies, discriminative imaging and novel optical techniques, with many projects supported at Universities, independent research organisations and within industry. Some of these provided new capabilities for the support of persistent surveillance and extracting pertinent information from the scene.

As an example, a polarimetric QWIP (quantum well infrared photodetector) detector array was developed by Thales under DTC support [19] and assessed for its ability to locate military targets hidden in tree-lines and to identify regions of disturbed soil in the scene. The QWIP array exploits on-chip gratings to achieve the desired polarimetric response avoiding the penalty of complex optical systems. In field trials, real vehicles and decoys were clearly discriminated – the smoother surfaces of decoys provided stronger signatures. However, the extent to which polarimetric imaging can highlight targets was found to depend quite strongly on the nature of the illumination. Targets in the open experienced illumination that was more directional, particularly under clear-sky conditions, and this dramatically enhanced the degree of polarisation. Targets under tree cover received relatively diffuse illumination and exhibited considerably weaker polarisation. Thales have also explored the feasibility of developing a tri-spectral polarimetric QWIP array to enhance the location of sites harbouring potential IEDs [20].

The DTC also supported projects on IR detectors and associated technologies at Selex [21], the University of Sheffield [22, 23] and QinetiQ [24, 25], including work on short-wave infra-red (SWIR) avalanche detectors at Sheffield targeted at burst illumination laser (BIL) imaging applications [26]. High-performance thermal imagers can provide a powerful day/night capability with considerable discriminative capability without always having to resort to polarimetry. Advanced CMT focal plane technologies were exploited in MWIR and LWIR cameras fielded by Selex, whose high spatial resolution and sensitivity enabled them to detect small targets at long range whenever the conditions provided adequate thermal contrast.

Hyperspectral imagers exploit signatures arising from the inability of man-made targets to match predictable spectral reflectance features of the surrounding background. The spectral contrast cannot be removed completely because targets and camouflages contain different materials from the background terrain and vegetation. For example in the VNIR band, vegetation exhibits a "chlorophyll edge" around 700-800 nm, while water absorption bands around 1150 nm and 1400 nm provide valuable contrast. During the field trials, the best detection performance was achieved in the VNIR band, where the imagers exploited the benefit of high-performance silicon detector arrays with close pixel spacing. Reliable detection of vehicle targets around tree lines was achieved at 4.2 km range using industry-standard anomaly detection algorithms in conjunction with a subsequent clutter-rejection algorithm that used a matched filter to reject "anomalies" whose spectra resembled vegetation. SWIR hyperspectral imagery also demonstrated impressive levels of target-background contrast. Efficient anomaly detection was achieved at 1.4 km range. Maximum target-background contrast was observed at wavelengths around 1000 nm, 1250 nm, and 1600 nm [27]. When polarimetrically-enhanced, the discrimination of camouflaged targets in vegetation at lower light levels was enhanced as a result of the dominant role of water absorption bands in natural vegetation, which provided strong contrast against man-made targets.

The Specim Eaglet hyperspectral imager [28] is an example of an aerial push-broom system, which can scan a wide field of view rapidly and efficiently. In airborne trials the system used both spectral and spatial cues to warn of abnormal events in a scene. This could play a valuable role in base protection, and urban surveillance scenarios. In field trials this was used together with a Riegl LMS Q680 scanned 3D LIDAR system [29] to demonstrate powerful target detection/confirmation capabilities.

Selex has developed a 3D SWIR laser imaging system [30], which provides complete range-intensity information at each pixel and represents an important step forward from established BIL imaging techniques. The field trials provided an extensive first set of imagery of vehicles and other targets at different orientations and under different conditions, and provided a valuable stimulus to the development of processing/display techniques to exploit the powerful new capability.

A project at Heriot-Watt provided a way forward for covert active imaging exploiting photon-counting techniques [31]. To achieve its goals, the DTC project had to pursue a means of implementing faster processing for imaging using its scanning time-of-flight architecture. This utilised a time-correlated single-photon counting technique, in conjunction with data analysis algorithms, to produce three-dimensional depth images of scenes using very low laser power levels. Range ambiguity was avoided using pseudo-random sequences of 850nm pulses at a 1GHz clock frequency, which provided a range resolution of a few centimetres at a range of 330m.

Research on novel optical techniques covered a number of topics including synthetic optical apertures [32], wavefront coding [33], coded aperture imaging [34], and a concept for developing compact monolithic ring laser gyros by direct writing of waveguides in laser gain materials [35]. QinetiQ's project [34] aiming at a polarimetric camera exploiting coded aperture imaging techniques was a project that levered separate investment by DARPA, but ultimately demonstrated some of the challenges associated with applying the technique for discriminative imaging.

A project on lucky sub-frame imaging [36] explored different techniques for image recovery from video sequences distorted by atmospheric turbulence. The project was originally founded on an idea to exploit an optical module producing phase-diverse images, which were compared to find "good" parts of the individual frames in the video sequence. The image was then reconstructed, like a jigsaw, from the lucky components. In the course of the project, it was found that this technique limited application to narrow bandwidth cameras. The technique was therefore applied to narrow-band BIL imagery, which is also very badly degraded by atmospheric turbulence [37]. As well as the distortion BIL has in common with non-laser imagery, it also suffers coherence effects. The technique was found to give good correction. However, in carrying out this work, it was also found that the phase diversity technique could be replaced by a simple image processing metric and that the image recovery method could be applied to any imagery.

A project was also supported to explore techniques for enhancing signal-to-noise (SNR) in coherent LIDAR using a Multimode Local Oscillator [38]. This was in support of coherent detection LIDAR and exploited QinetiQ's multi-mode interference approach to improve mode mixing. Since the returned beam in a LIDAR suffers significant spatial decoherence due to atmospheric turbulence, there is reduced overlap between it and the local oscillator field leading to reduced signal-to-noise. QinetiQ's solution was to decrease the spatial coherence in the local oscillator thus increasing field overlap. A factor of 4 increase in SNR was demonstrated with an increased target detection probability of 3 and lower false alarm rate. This indicates the potential of the technique for lowering the laser power requirement for Doppler LIDAR sensing or the increased range that might be expected. However, to date the technique has not been exploited in defence-related LIDAR, probably because laser sensors predominantly use direct detection. There is an obvious application to environmental sensing for wind velocimetry.

The airborne trials provided opportunity to assess the performance levels afforded by a 128 Mpixel helicopter-mounted electro-optic imaging turret from PVLabs [4], in collaboration with SELEX-Galileo. The system provided a 4 km^2 field of view, with sufficient resolution to view and track vehicles and people from altitudes of 10,000 ft. The recorded imagery could be selectively viewed and rewound to track backwards through complex movements. The system successfully tracked vehicle movements during the trial and included coverage of movements to and from some buildings that were deliberately hidden from other sensors, so this sensor makes a vital contribution to unravelling the insurgent activity.

A second SELEX-Galileo helicopter-mounted sensor suite, incorporating a PicoSAR radar, a Wescam MX15 turret (VNIR + thermal), and a ground-referencing system, demonstrated simulated radar cueing and hand-over of targets for high-resolution EO observation. High-quality imagery was captured at altitudes between 4,000 ft and 10,000 feet. This suite also provided video imagery for mosaic generation and vehicle tracking with temporal resolution enhancement of features, exploiting the different pixel sampling on successive video frames.

The imagery provided by the airborne Wescam system was found to be extremely effective in overcoming many of the challenges in relation to long-range imagery under hazy UK atmospheric conditions at ranges of up to 43.5km. This was achievable partly because of the excellent geo-pointing and stabilisation characteristics of the MX15 turret.

5. DEVELOPMENT OF TOOLSETS SUPPORTING SENSOR EXPLOITATION

Modern sensor systems are capable of generating large volumes of data as highlighted by the PV Labs systems described above. To ensure that this data is provided to users with minimal latency, it is important to ensure that new software tools are developed in parallel with new sensors. The development path is usually based on exploiting field-programmable gate arrays (FPGAs). The design tools for FPGAs are generally geared to the needs of the small-scale commercial developer (for embedded processing etc). In comparison the military use of such devices tends to be on a much larger scale, requiring multiple FPGAs and development times of years (often longer than the technology refresh rates of the device manufacturers). As a result history has shown that development projects can be frustrated by inefficient design methodologies that become outdated during the course of the programme and are difficult to support into the future.

To overcome these problems, the DTC has supported the development of automated toolsets to translate GUI-based algorithm designs into instruction sets that can be understood by the FPGA devices, exploiting manufacturers' library routines where appropriate. A team at Belfast University [39] used the LabView GUI system at the front end of their process and demonstrated spectacular gains in FPGA design productivity. This was applied to the challenge of super-resolving targets using algorithms developed separately by QinetiQ. The temporal resolution algorithms [40] have separately shown how to super-resolve all moving targets within a moving scene and as such have achieved improved resolution with no reduction in the field of view, something that is not possible with optics alone.

DARPA's VIRAT project goes someway beyond this to develop a toolset to search large volumes of live and legacy video data for specific activities or events. Such datasets inherently contain significant spatio-temporal detail involving for example single person actions, person-person interactions, person-vehicle interactions and movements associated with vehicles themselves. This is considered an essential toolset if sensors such as ARGUS IS are going to be operationally useful to the intelligence community.

In the DTC's programme, several image processing based projects [41, 42] took on the challenge of detecting changes in successive passes over a scene or anomalous behaviour, with one activity addressing full motion video imagery from airborne platforms. To do this the team had to tackle issues of apparent image motion, the detection of moving targets within moving images, the discrimination of abnormal behaviour using transient information and the registration and mosaicing of scenes from irregular non-identical passes over a target area. Some of the challenges of detecting changes in scenes using imagery recorded from separate passes were also addressed, including the effects of shadows in the scene. Measures of false alarm rate and probability of detection were derived for target size expressed in pixels.

During the course of the DTC's programme the threat from IED attacks became more prevalent in evolving military operations. The DTC addressed this through a call for proposals in areas such as remote biometric monitoring (to help identify potential suicide bombers), high-resolution tracking technologies as well as enhanced processing of imagery from new camera systems, notably those exploiting dual band (SELEX-Galileo) and polarimetric (Thales) discrimination. The SELEX-Galileo project utilised their dual band CONDOR camera to exploit the benefits of having spatially registered imagery in both the MWIR and LWIR bands. The initial analysis quickly showed that the combination of bands helped mitigate diurnal effects, allowing the imaging of disturbed soil under most ambient conditions [43]. Thales's polarimetric approach addressed the same IED detection problem but had to solve challenges relating to the use of the camera on moving vehicles [44].

6. OTHER APPROACHES TO PROVIDE PERSISTENT SURVEILLANCE

Searches of published material, both in the scientific arena and in literature from company brochures will reveal many systems that can meet some of the requirements for a persistent surveillance system. Experience gained using existing systems such as the SELEX-Galileo PicoSAR, Wescam MX15 HD, and the PV Labs 128 Mpixel camera in the DTC's field trials demonstrated that:

- Radar/EO cueing and multi-Mpixel camera technologies can provide the basic building blocks for wide-area surveillance and high-resolution target observation in airborne surveillance.
- Real-time tactical ISTAR pictures can be created from airborne EO video. Vehicles and personnel can be tracked and plotted onto a wide-area real-time map generated from mosaiced video frames.
- Movements of vehicles and (in some cases) personnel can be analysed forensically through EO airborne video of a wide-area scene covering ~10 km^2. Movements could be tracked backwards or forwards in time through the imagery to determine which buildings were visited by subjects and by other individuals with whom they met.
- Improved camera technologies (lighter, cheaper, multi-function, improved atmospheric compensation) form important enabling steps towards the sensor networks needed to provide ground-based persistent surveillance.
- Objects of military interest can be detected under very challenging conditions by virtue of their polarising properties, both in the EO and RF wavebands. Roadside anomalies were highlighted vividly from fast-moving vehicles supported by new processing techniques that dramatically reduced the level of clutter. Discriminative EO techniques dramatically reduce the workload of a busy observer. In the RF waveband, airborne polarimetric radar highlighted small objects against background vegetation.
- Advanced radar techniques provide improved resolution to meet the stringent requirements of operation in cluttered environments.

DARPA has been seeking to develop disruptive approaches in the RF and EO regimes, ranging from its ISIS system to the ARGUS and LACOSTE systems. In the EO regime, the vision for ARGUS IS [45] was built around a 1.8 Gpixel sensor in the VNIR comprising 368 focal plane arrays using four sets of optics. It was envisaged that sixteen processors could each process the scene data from the twenty-three 5Mpixel FPAs, providing imagery that can be electronically steered within a 40 km^2 field of view with a ground sample distance (GSD) of 0.15m. Such an advance is only possible because of advances in FPGA technology and small-pixel CMOS imaging sensors.

In Israel, Adaptive Imaging Technologies (AIT) have developed a panoramic telescope that continuously monitors a panoramic field of view while enabling high-resolution views on a number of independent targets within that panorama. The basis for such a system is described by Jacob et al [46] and is based on an array of CCD cells, each addressing at least a portion of the field of view.

Such systems don't provide day-night performance so another DARPA programme (ARGUS-IR) is focussing on developing an IR variant of ARGUS-IS initially based on 256 independent 640x480 FPAs, each with <80mK NETD performance levels [47]. In comparison, the USAF Gorgon Stare wide area surveillance system contains five EO cameras and four IR cameras mounted in two pods under the Reaper UAV. Video output from the cameras is stitched together to provide an 80Mpixel image in the VNIR and 64Mpixels in the IR [49]. The processing and communication challenges associated with such systems can result in artefacts in the image field and latency in relation to the down-link of data-streams to the ground.

In contrast DARPA's LACOSTE programme [48] takes a different approach by exploiting coded aperture techniques, which enabled a much smaller number of FPAs to be used (albeit each with 8 Mpixels), to provide an optical beam-forming system for simultaneous tracking of multiple targets within a wide field of regard, with capability for arbitrary foveation and super-resolution. As such it is an optical analogue of a SAR-GMTI system, avoiding shortfalls in the latter systems when required for providing persistence over large urban areas.

7. CONCLUSIONS

It is clear that the overall design of a persistent surveillance system will depend on the operational theatre for which it is destined. The challenge of data communication and its management is considerable but the availability of intelligent processors will enhance the ability of analysts to derive time-critical information and hence reduce the latency currently associated with the operation of any multifunctional system incorporating collaborating sensors. Nevertheless in the short-term the basic building blocks required for meeting some of the goals required by military commanders are available. However it is likely that evolving military operations will drive the need to provide for spiral upgrade paths as new underpinning capabilities emerge from the research base.

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