Multispectral-Polarimetric Sensing for Detection of Difficult Targets.

W A Hubbard, G J Bishop, S J Clement
BAE SYSTEMS Advanced Technology Centre
Filton, Bristol, BS34 7QW

G Innes, D Hayter
QinetiQ
Malvern, Worcestershire WR14 3LG

Abstract

The benefits for the detection of difficult targets have been demonstrated for multispectral and polarimetric imagery in differing conditions. The spectral differences between target and background have been seen to provide an enhancement to target discrimination. However, false alarms can occur mainly due to spectral variations in background materials. Complimentarily, polarimetric imagery has been used to detect man made targets by exploiting the reflective characteristics of man-made objects and the suppression of background clutter; but polarimetric imagery for a detection process can be limited by the geometry and nature of targets. The intention of this work has been to investigate whether adding the polarimetric to the multispectral information decreases background induced false alarms whilst maintaining good detection statistics for low contrast targets. This is the third year of the project which has focused on improvements to a data gathering SWIR sensor, developing integrated image processing and display software, data gathering and processing.

Keywords: Multispectral, Polarimetric, Detection of Difficult Targets, SWIR

Introduction

Studies have shown that in differing conditions multispectral [1] and polarimetric [2] sensors can enhance target detectability. It has been demonstrated that multispectral imagery can be used to detect low contrast targets using intrinsic spectral differences between target and background. However, multispectral imagery can produce false alarms mainly caused by spectral variations in background materials. Polarimetric imagery has been used to detect man made targets by exploiting the surface finish of these objects compared to the background. However, the performance of polarimetric imagery in isolation can be limited by the geometry and nature of targets. By adding the polarimetric information to the multispectral it may be possible to decrease background induced false alarms whilst providing good detection statistics for low contrast targets. To evaluate the benefits of combining spectral and polarimetric information, a multispectral-polarimetric sensor operating in the SWIR waveband was constructed. Supporting modelling was also undertaken. The SWIR waveband was selected because commercially available cameras exist. Moreover, it has been observed that a SWIR hyperspectral sensor is particularly effective at defeating targets employing Camouflage Concealment and Deception (CC&D) techniques, as these are conventionally aimed at visual wavelengths. These sensors have also been shown to detect land mines. The SWIR multispectral-polarimetric sensor has been constructed, based around an Indium Gallium Arsenide camera operating in the 1

– 1.7 micron waveband, which operates with a filter wheel to provide spectral information at seven wavebands. Modelling in earlier years of the project assessed waveband selection. A polariser provides s and p-polarisation data at each waveband, and linear polarisation image cubes are formed for the Stoke's parameters S_0 and S_1.

In Year 3 the sensor previously developed [3] has been automated and interfaced with an Image Processing and Display (IPAD) application, enabling polarimetric data to be collected, processed and displayed to a user in better than one frame per minute. The IPAD gives a user the ability to select and display spectral as well as polarimetric information, and also results from applying object detection algorithms.

Waveband Selection

Seven spectral filters have been procured for inclusion in the sensor build to span the 1.0-1.7µm waveband. It was necessary to identify suppliers of filters with the correct performance that are also suitable for use in an imaging system. Some commercially available filters are fabricated on thin substrates and these can distort during manufacture. Imaging is not always a prime application for these filters and small distortions are not an issue. However, for this task, it is crucial that the distortions are very small. The SWIR filters used in the sensor are supplied by Omega Optical, Inc.. The 1.4µm waveband was discarded as there is significant water absorption at this wavelength. In addition, at the longer wavelengths where low signals were found in year two, a wider sub-band was chosen.

In year two it was found that four wavebands together with polarimetric information gave best detection performance. These wavebands correspond to higher values in the covariance matrix generated from the simulated imagery, and also align with high values or gradients in atmospheric transmission in the SWIR region, at 1.0, 1.2, 1.5 and 1.6 µm. The spectral filters selected for year three are given in Table 1.

Centre (µm)	FWHM (µm)
1	0.1
1.075	0.05
1.125	0.05
1.175	0.05
1.225	0.05
1.3	0.1
1.55	0.2

Table 1 – Spectral Sub-bands

SWIR Sensor Build

The sensor used is based on a 320x240 pixel Sensors Unlimited 12 bit digital InGaAs camera operating between 1µm and 1.7µm. The camera lens is a 7.6° field of view conventional glass camera lens. A polariser fitted into a motorised rotation stage is used as the analyser. Multispectral operation in the SWIR waveband has been provided by a motorised rotating wheel into which seven SWIR filters can be inserted, one aperture has been left open for broadband operation (Figure 1).

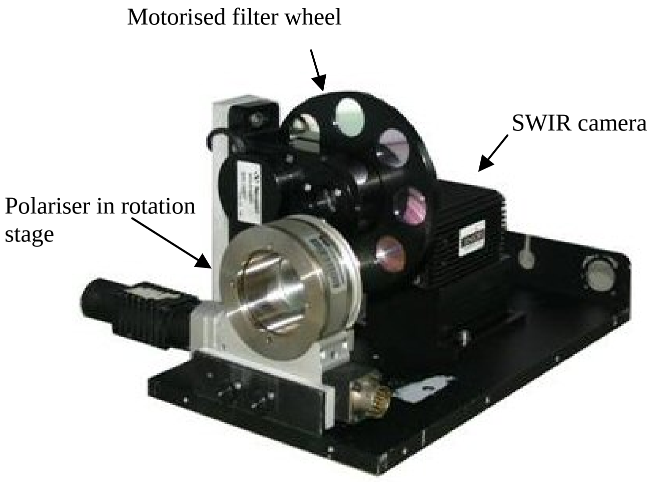

Figure 1 - SWIR Multispectral - Polarimetric Sensor

The scale of this project has not permitted the construction of a sensor that could acquire the polarisation sub-images simultaneously. All components in the sensor are attached to a metal base plate, mounted on a tripod.

Image Processing and Display (IPAD)

An Image Processing and Display application (IPAD) has been developed in year three, which interfaces with the sensor and image acquisition software as shown in Figure 2. It takes less than 1 minute to acquire and process each image.

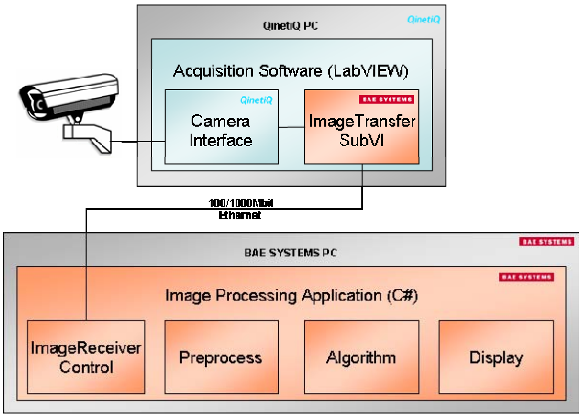

Figure 2 – System Design

The integration time of the camera is controlled through a configuration file read into the acquisition software. Any additional compensation for light levels is addressed through the use of neutral density filters. In operation the polariser was rotated through 0° and 90° at each spectral filter position, and one image was acquired. IPAD receives sets of images for an expected number of wavelengths and polarisations. It registers them and builds the base image cubes for s-polarisation (I_s), p-polarisation (I_p), and subsequently the Stoke's parameters S_0 and S_1.

$$S_0 = I_s(x,y) + I_p(x,y)$$

$$S_1 = \frac{I_s(x,y) - I_p(x,y)}{I_s(x,y) + I_p(x,y)}$$

where $I_s(x,y)$ and $I_p(x,y)$ are the image values at pixel co-ordinates (x,y) at each wavelength for s-polarisation and p-polarisation respectively.

The images at each waveband collected from the SWIR Multispectral-Polarimetric sensor need to be carefully registered, for each of the polarisation states, prior to constructing the polarimetric image cubes. Registration software is available to complete single pixel cross-correlation. Once the necessary offsets have been found for the sensor arrangement using this technique, it is possible to configure the software to apply constant registration shifts whilst building the base image cubes.

The user interface to IPAD allows a number display options to be selected, including the base image cubes, Stoke's parameters at different wavelengths and the results of applying image processing techniques to the collected data.

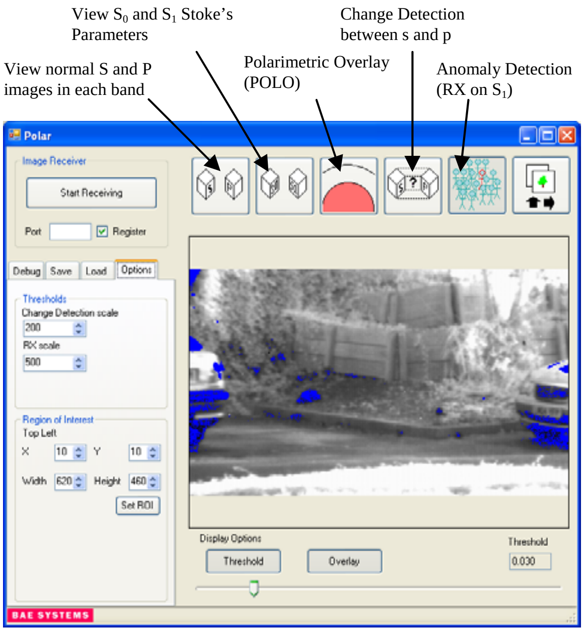

Figure 3 – Image Processing and Display Application (IPAD) User Interface

The user interface with labels to show functionality and displaying one selectable pane (for Change Detection results) is shown in Figure 3.

SWIR Multispectral - Polarimetric Sensor Trials

Two trials were held in year three once the build of the sensor was complete and fully integrated with the IPAD.

The first trial was held at Malvern. Images were collected of various objects including a model tank, some objects to represent items of potential interest. The targets were chosen because they had been used in previous stages of the programme and had been considered representative of targets of military interest. They were placed at a distance of around 10m to allow resolving of the smaller targets, against backgrounds of grass, tarmac and concrete kerbstones. Automated data collection was successfully demonstrated and the processed data was later inspected and analysed. It was reported that the subsequent analysis had indicated that good data had been collected, the sensor control was working as expected and that the image mis-registration issues had been minimised, although this was less successful when parts of the first image were saturated (this is used as the reference image in the registration algorithm). Subsequently the ability to set constant whole pixel shifts for registering the images was incorporated into the software; with the shifts being defined as found using the cross correlation algorithm.

The second trial was held at Filton following loan of the sensor and acquisition software to BAE SYSTEMS, where data was taken over an extended period of time. Objects of different materials were imaged, some imagery was taken throughout sunset to visualise SWIR capabilities under low light conditions, and some data was taken of clear skies to confirm illumination polarisation.

The optics and range of integration time available for each of the bands made it difficult to balance the exposures for all bands. Hence in daylight it was often needed to reduce the aperture above F16 and thereby increasing diffraction effects. For some of the processing it was found best to ignore the first waveband at 1 µm, allowing this to saturate, in order to get spectral information at all other wavebands.

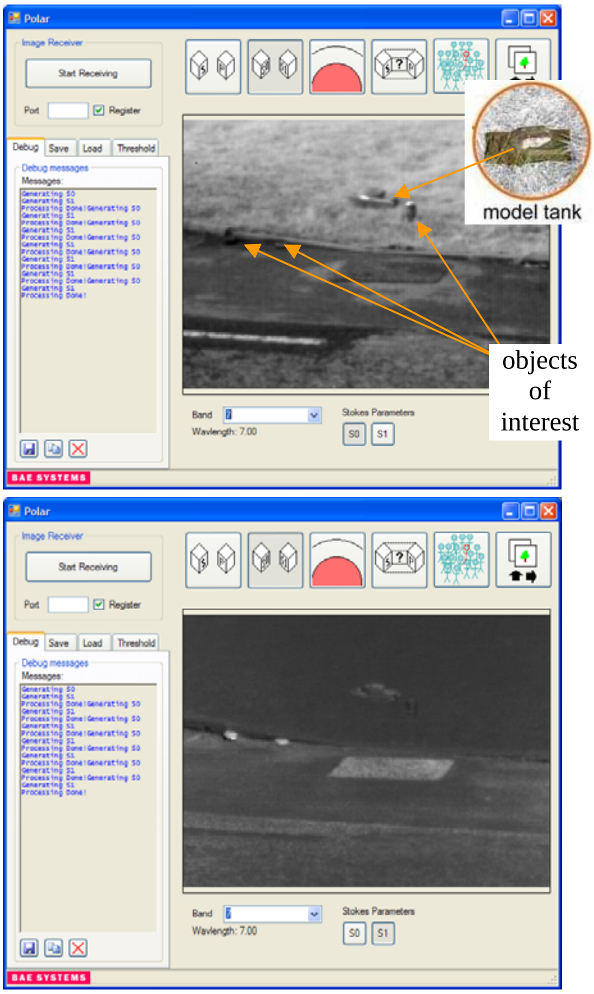

Figure 4 – S_0 and S_1 Images at 1.55µm

Polarisation Overlay (PolO) presents the polarisation data in a user-friendly form overlaid on an S_0 image at a single waveband, where red denotes a predominance of s-polarisation, and blue p-polarisation. This visualisation identifies polarised objects in the scene in order to assist user examination. In Figure 5 PolO demonstrates how this visualisation can assist with detecting polarised objects in a recognisable image.

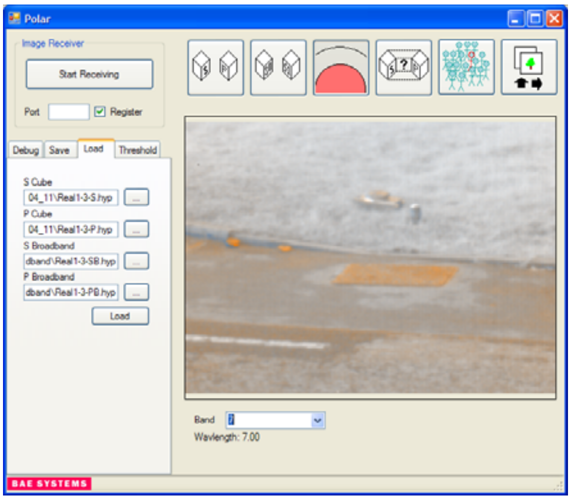

Figure 5 – Kerbside Objects, Polarisation Overlay (PolO)

Combining Spectral and Polarimetric Data

Anomaly Detection [4] has been used to demonstrate improvement in detection capability once spectral and polarimetric data is combined.

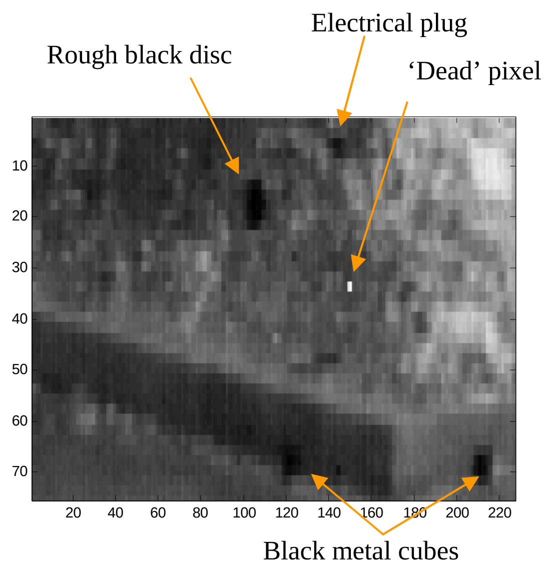

Figure 6 – Image for Demonstration of Improved Detection Performance

A region of interest in an image containing a small number of potentially target like objects (Figure 6) had anomaly detection applied to different combinations of the available data.

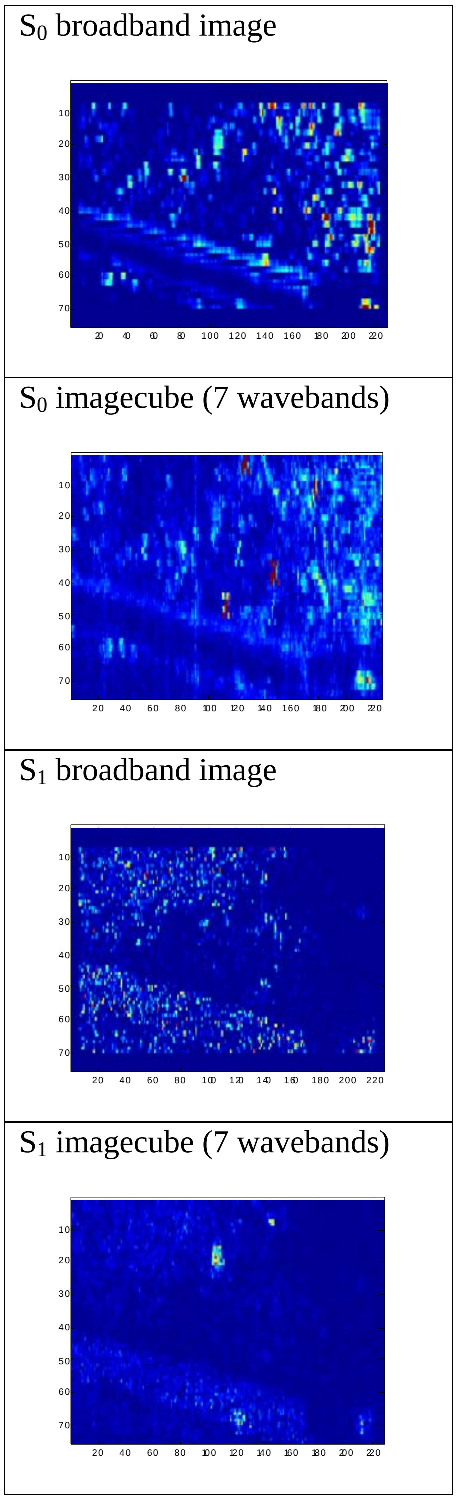

Figure 7 – Anomaly Detection Results

The results in Figure 7 are plotted using a 'jet' colormap (i.e. red for highest values and blue for lower values). They show that purely spectral data has had highest response to the dead pixels in the image, which are shown to be the most anomalous points in that data. The purely polarimetric data has given a noisy result around the dimmer regions in the image. Whereas the spectral-polarimetric data has given generally higher values at the objects placed in the scene to represent potential objects of interest.

Conclusions

The notable achievement in this year of the project is to automate data collection and interface it with an Image Processing and Display application (IPAD) developed in this year of the project, and enables the data for seven wavebands to be collected, processed and displayed at a user interface at a rate greater than 1 frame a minute. The IPAD suite of algorithms, able to compare and contrast results from individual processes, has been developed for the SWIR Multispectral-Polarimetric sensor which by offering complimentary information provides a user with the flexibility to select and adjust the results from image processing and so aids detection performance.

Atmospheric transmission in this waveband is dominated by water absorption bands at 1.14 and 1.4 microns. Spectral processing has been included in the IPAD processing including an RX Anomaly Detection algorithm, and a spectral Change Detection algorithm. Visualisations are also provided in IPAD of collected data and linear Stoke's parameters S_0 and S_1 at each waveband, in addition to results from overlaying polarisation data on an intensity image (PolO).

It has been demonstrated in this work that better discrimination between some objects of interest and background materials is enhanced when detection image processing is completed with spectral data combined with polarimetric data, compared to each set of data individually.

References

1 G.Bishop and A.Killey "Final Report on RCSC18 Sensor Technologies for Future Tactical UAVs Research Study". TES100935 Sept. 2006

2 D Jordan, G Innes and D Hayter "Polarimetric Imaging". Journal of Defence Science, Vol. 10, No. 3, R166-172 (2005)

3 W Hubbard et al. "Multispectral-Polarimetric Sensing for Detection of Difficult Targets". 5th EMRS DTC Technical Conference 2008.

4 I.S.Reed and X.Yu "Adaptive Multi-band CFAR Detection of an Optical Pattern Unkown Spectral Distribution". IEEE Trans. Acoustics, Speech, Signal Processing, Vol. 38, pp.1760-1770, Oct. 1990

Acknowledgements

The work reported in this paper was funded by the Electro-magnetic Remote Sensing (EMRS) Defence Technology Centre, established by the UK Ministry of Defence and run by a consortium of SELEX Galileo, Thales UK and Roke Manor Research.