Developing a Ground Truth High Resolution Hyperspectral Imagery Database for Target and Natural Background EM Signatures Characterisation and Assessment

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***Abstract* — Modern camouflage techniques not only require an understanding of the asset (target) material, but also the sensor and platform used to detect a target.**

This paper discusses the need for a new approach to the design of camouflage materials and counter-surveillance measures and the tiered surveillance platform-sensor systems that are driving this need and describes the basic concepts employed within the 'Lelantos' program to deliver this new approach. Examples of field data collected as part of collaborative international programs are presented and described in terms of 'spectral fingerprinting' of targets in an operational environment.

Keywords—Hyperspectral imagery, ground truth, target and background signatures

I. INTRODUCTION

The application of persuasive military force has been a fundamental principle in human conflict for over two thousand years. Over this period of time, the development of systems intended to protect those who apply such force has evolved slowly with advances in technology. However, it has only been within the last century that camouflage techniques have been deliberately integrated into military assets to become a critical element of a protective system.

Camouflage techniques require an understanding of the sensor used to detect a target and more recently, the platforms that can carry these sensors. Recent developments in hyper-spectral sensing technologies and small unmanned vehicles able to carry target detecting sensors, has given rise to a category of threats that promises to change to nature of camouflage design, surveillance and counter-surveillance techniques.

Additionally, the rate of growth of computing speeds and miniaturisation of computing processors has increased the ability of sensing systems to process spectral data in real time. It is highly likely that within the next decade, small, task-able sensor-platform systems linked to tactical decision makers will be able to detect a potential target, recognise the spectral fingerprint of that object, identify it as a threat or not and communicate that information to a dismounted combatant on the ground in real time.

This will have a fundamental impact on the way in which surveillance and counter-surveillance solutions are designed and employed and it represents a significant challenge to scientists and engineers involved in this area of research.

Within the Land domain in particular, the vast number of sensor-platform systems that can be focussed on deployed forces, and the ranges over which those systems can be employed, creates a very complex and dynamic system of threats (Figure 1).

It is clear that conventional methods of camouflage design and analysis require a new approach that is able to measure, model and simulate the impact of surveillance and counter-surveillance techniques in a real time, dynamic and three dimensional environment.

DST has responded to this challenge by establishing a program to develop a virtual reality environment for the assessment of signatures from a number of sensor-platform systems that detect electromagnetic energy signatures across different spectral bands. The virtual environment will be generated by the Land signature modelling and simulation capability program known as ***Lelantos*[1]** and will fuse data from sensor-platform systems to generate a three dimensional, dynamic image that represents the signature of a target at various ranges across a broad spectrum of wavelengths. Figure 1 shows a 5 levels of tiered sensor-platform systems in relation to the signatures of land targets over different ranges and backgrounds.

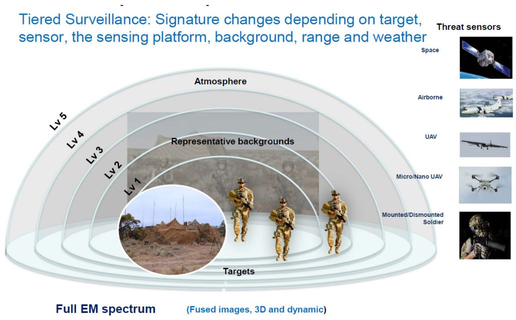

Figure 1. 5 levels tiered sensor-platform systems

This paper describes preliminary work to develop a hyperspectral imagery database framework and examines how the exploitation of such a database will inform decisions in the Land signature management domain.

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[1] ***Lelantos: Land Signature Modelling and Simulation Capability***
The Lelantos program aims to develop a fused, broad spectrum, dynamic imaging capability to provide a modelling and analysis capability for electromagnetic signature data. It seeks to generate a three dimensional virtual reality environment for the assessment of signatures from a number of sensor-platform systems that detect electromagnetic energy signatures across different spectral bands. [LELANTOS was the younger Titan god of air and the hunter's skill of stalking prey. His name was derived from the Greek words lêthô, lanthanô, and lelathon, meaning "to escape notice," "move unseen" or "go unobserved."]

II. BACKGROUND

Airborne or space borne hyperspectral imaging has been widely used in agriculture, mineral exploration and other industries. With the rapid advancement in the hyperspectral sensing technology (and portable platforms such as UAS), and improved simplicity and accuracy of predictive models/algorithms through machine learning and deep learning from big data, there is a potential practical defence application of exploiting hyperspectral data cubes for tactical information collection in ground target Detection, Recognition and Identification (D.R.I.) for mounted or dismounted soldiers. It can also be used to design, develop and assess multi-spectral Camouflage, Concealment and Deception (CCD) counter-measures through measurement, modelling and simulation. Furthermore, it may benefit the development of simple Electromagnetic (EM) sensors for tactical information collection on different levels of UAV systems.

In the document "Shaping Defence Science and Technology in the Land Domain 2016-2036"[1], counter-surveillance across the hyperspectral visual, electromagnetic and audible spectrum has become one of the three priorities in force protection. To address this, there is a need to establish and characterise the EM signatures of land assets in representative operational environments [2], which could be further exploited to assess the EM sensor performance from different sensor-platform systems as shown in Figure 1.

One approach is through the development of a ground truth hyperspectral database to enable hyperspectral signature measurement, modelling and simulation.

This paper is intended to introduce the concept of developing a hyperspectral imagery (HSI) database framework and provide examples of the potential exploitation of such database in the land signature management domain.

III. HYPERSPECTRAL DATACUBE

A. *What is a ground truth HSI database?*

A ground based high resolution hyperspectral data-cube contains the 3D spatial and spectral complexity of a scene with embedded targets, which would enable the development, test and validation of algorithms for target classification and three dimensional, dynamic D.R.I.

A reference real world ground truth database containing high fidelity hyperspectral imaging data will have a number of hyperspectral data cubes over different solar illumination conditions (solar source position), weather conditions, and seasonal changes over a range of representative terrain backgrounds.

The database will enable the:

- Characterisation and assessment of land target asset signatures (spectral, spatial and temporal and fused imagery) from different sensor-platform systems;
- Exploitation of hyperspectral datacubes for camouflage design and development (counter-surveillance measures);
- Exploitation of hyperspectral datacubes for tactical D.R.I. algorithm development;
- Test and evaluation of target D.R.I. algorithms;

B. *Meta-data structure*

Spectral measurements need to be accurate and precise representations of the target material and background elements will be essential, but there are a variety of factors that affect the quality of spectral measurements. Critical issues for making in-situ spectral measurements have been actively considered elsewhere and in particular by the NATO CCD scientific community [3].

Factors that must be considered when collecting hyperspectral data cubes include, but are not limited to:

- Sensor position relative to the target (azimuth angle): Ground to ground, elevated ground to ground (aerial view in oblique angle);
- Solar illumination: solar spectra, time of day; solar zenith angle and altitude; presence of clouds;
- Aspect of the target orientation surface;
- Nature of surrounding vegetation; changes due to seasonal variation; and recent weather patterns, in particular, precipitation;
- Environmental conditions such as temperature, wind, presence of fog, smoke or haze.

Table 1: Non-exhaustive list of important Meta-data variables

Experimental design	• Timing of data collection (solar zenith angle; seasons) • Method of data collection i.e. 1) ground to ground, 2) elevate ground to ground; target range; target surface orientation • Sensor viewing angle (Oblique angle) (Not Nadir) • Equipment requirement list to collect the data • GPS coordinates of all sensor and target locations
Illumination	• Date • Time of the day • Solar position (altitude, azimuth) • Spectral profile of solar illumination at target location is also highly desirable
Environmental conditions	• Cloud cover • Temperature and humidity • Aerosol/smoke/haze • Weather records for days data collection and days preceding the measurements • Photographs (site set up, target and background, eastern sky, western sky
Hyperspectral sensor settings	• Type (reflective or emissive) and spectral bands • IFOV/FOV (Instant Field of View, Field of View)

Calibration reference	• Spectralon reflectance panels
	• Orientation
	  ○ Vertical
	  ○ 45 degree slope

Target	• Description and benchtop spectral measurement references • Species • Localised conditions • Texture (specular/diffuse) • Aspect of material surface orientation angle

Table 1 shows meta-data variables that should be linked to the HSI data cube. This non-exhaustive list of meta-data is important to the characterisation and assessment of the ground truth target signatures. When collecting ground truth hyperspectral data cubes, it should be collected along with HSI data cubes.

IV. HSI FIELD TRIAL DATA COLLECTION

Under DST's Land Division "Lelantos" program, which aims at measurement, modelling and simulation of EM signatures of land assets, we have conducted a number of field trials collecting ground truth hyperspectral imagery of terrain backgrounds and representative land targets in a number of representative operational environments in collaboration with Defense Research and Development Canada (DRDC) and NATO SCI 295 task group [3].

A. Puckapunyal training area (PTA)

We conducted a hyperspectral field trial data collection at PTA in early December 2017. Resonon Pika XC2 (400-1000nm) and Pika NIR (900-1700nm) hyperspectral sensors were employed to collect the hyperspectral data cubes. Figures 2(a-c) show examples of HSI (400-1700nm) of target and terrain background environment at PTA.

Figure 2a HSI - ground to ground (400-1000nm)

Figure 2b HSI -ground to ground (900-1700nm) – grey level

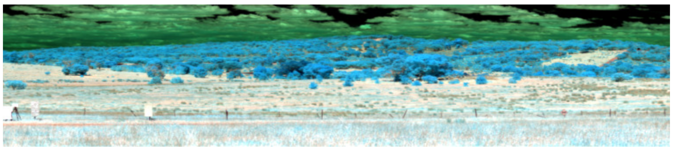

Figure 2c HSI-ground to ground (NIR 900-1700nm) – false colour fused image

B. Extracting background hyperspectral profiles from datacubes

Hyperspectral imagery provides hundreds of spectral channels (Figure 2a: - 450 spectral bands; Figure 2b: – 156 spectral bands) in each pixel over a single scene. As different substances have different reflection spectra, each material will have its own unique spectral fingerprint which could be extracted for D.R.I purposes. However, due to influential factors discussed earlier, HSI requires robust and accurate classification techniques to extract the relevant features from the image.

Using spectra extraction tools, the spatial coverage and spectral profiles of background elements and targets can be extracted and assessed. Generally speaking, spectra captured in laboratory measurements will display deterministic spectra (a spectrum uniquely specifies a material), whilst in scene measurements, they will show spectral profile variation due to in situ influential factors [4].

Figure 3a illustrates an example where the spectra reflectance profile of the foliage top is extracted from the datacube. Through sampling a small section of the foliage, the tool was able to highlight, in red, every part of the image scene that is foliage with a similar spectra profile. Similarly, using the same method, all of the areas that are grassed are highlighted in red in Fig 3b. The spectra profiles for both foliage and grassed ground are shown in Figure 3c.

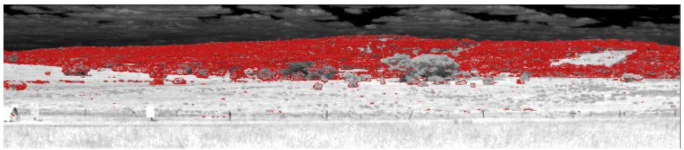

Figure 3a: Mask of similar spectral characteristics of foliage top (in red)

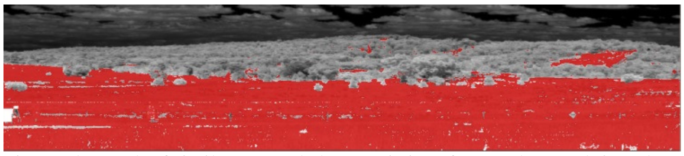

Figure 3b: Mask of similar spectral characteristics of grassed ground (in red)

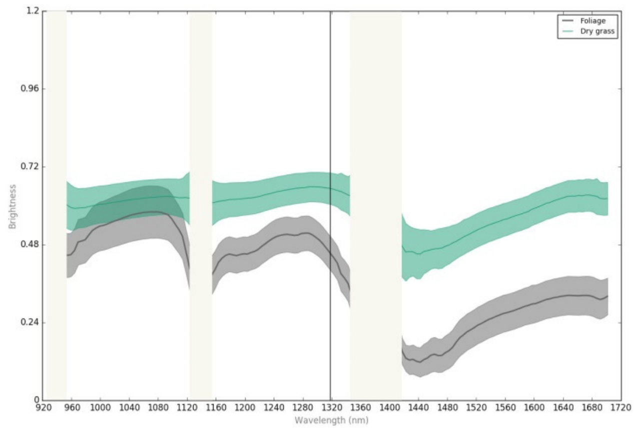

Figure 3c In scene spectral profile and variability of foliage top (grey) and grassed ground (green)

There is a degree of variation in the reflectance curves for each field element due to their 3D nature of foliage and grassed ground. Each curve represents a particular type of vegetation in the scene. When the two spectra are compared, it can be seen that foliage top has higher reflectance levels over the spectrum 900-1700nm in comparison with the grassed ground.

C. Spectral “fingerprints” of target

The spectral properties of material for camouflage are also collected in the field trial. Figures 4a and 4b show an example of material measured in the field and the measured target spectral reflectance profile (spectral fingerprint).

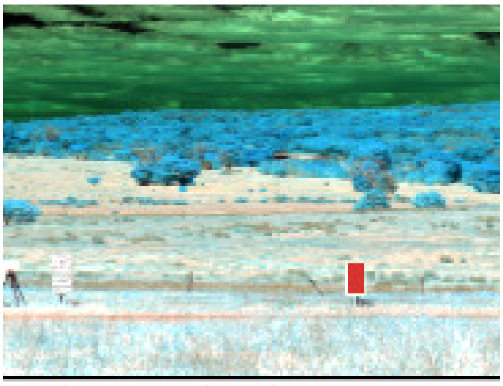

Figure 4a Mask of target fabric sample (in red)

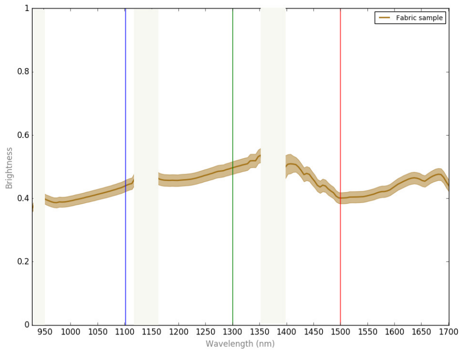

Figure 4b In scene spectral profile of fabric sample

These extracted spectral profiles of background elements and target materials can be used to assess the target camouflage effectiveness, and assist with design of improved camouflage patterns and counter-measures.

The spectral profile of materials in a scene can also be used to compare with the deterministic spectral fingerprint library using benchtop hyperspectral reflectance measurements (Figure 5) to assess the fidelity of the material spectral library.

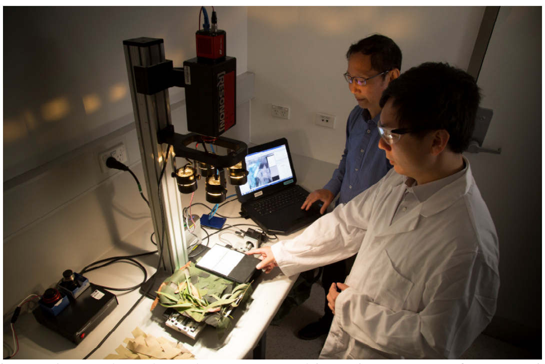

Figure 5 DST benchtop hyperspectral imaging camera for material reflectance property measurements

Whilst the hyperspectral datacubes can be directly exploited for the characterisation and assessment of land asset signatures, the data is also invaluable for modelling and simulation of target signatures across a broader range of environmental field conditions than that already collected. These datacubes and its corresponding meta-data can be used as inputs and as validation results from physics based models. For example, the benchtop measurements of a new candidate material will be modelled to determine its signature in the field and with the confidence that the model itself is already validated using field measurements. The output of this modelling will feed into the broader signature modelling and assessment work program that is ‘Lelantos’.

Other areas using the hypercube undertaken within Land Division include the development of algorithm and predictive models for D.R.I. using convolutional neural networks (deep learning) and multiple feature learning.

Further hyperspectral data collection field trials are planned in different seasons to build a comprehensive database for PTA.

SUMMARY

Hyperspectral imagery data cube contains huge amount of spatial and spectral data. A hyperspectral database for ground-truth of platforms, equipment, materials and environmental elements could be exploited for target DRI and camouflage technique and counter-measurement development.

A comprehensive hyperspectral imagery data base on a representative operational environment (i.e. PTA) will allow the design, development, assessment of land target signatures through modelling, simulation and accuracy validation, and new sensor technology development and performance evaluation.

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