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A MULTI-SCALE AND MULTI-TEMPORAL HYPERSPECTRAL TARGET DETECTION EXPERIMENT — FROM DESIGN TO FIRST RESULTS

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ABSTRACT

Hyperspectral target detection experiments under non-ideal conditions are scarce. An extensive multi-scale and multi-temporal field experiment was designed towards the goal of knowledge expansion under such circumstances. A range of camouflage materials and specific targets of interest were placed in a realistic natural environment with vegetation cover and varying illumination. In several experiments, aspects like changes in the sun position, variable moisture, and relocations of targets were analysed. Using an aircraft-based and a drone-based imaging spectrometer, the target scenarios were mapped at different daytimes. The data were radiometrically, atmospherically and geometrically processed to allow subsequent data analysis. First insights deliver promising results.

Index Terms— Hyperspectral, Target, Detection, Multi-Scale, Multi-Temporal, Experiment, Security, Defence

1. INTRODUCTION

The gain of new knowledge from hyperspectral data in the domain of security and defence requires better analysis techniques of multi-scale and multi-temporal spectral signatures. The value of such datasets was shown in previous studies, for instance in [1]. Similar studies [2, 3, 4, 5] evaluated camouflage and detection performances predominantly on homogeneous, natural backgrounds and under ideal illumination conditions. This provides a good basis for the comparison of different algorithms and leads to high detection rates. In reality, however, camouflage material is often used in combination with a certain amount of vegetation cover, seamlessly integrating into the natural environment. Furthermore, illumination plays

a crucial role for the camouflage and detection performance [6]. In order to analyse the impacts of vegetation cover and varying lighting conditions, an extensive field experiment was designed and realised.

2. EXPERIMENT DESIGN

The experiment took place in June 2019 in Greiding (Germany) under the guidance of the Remote Sensing Laboratories (RSL), University of Zurich (Switzerland) and the Fraunhofer IOSB - Institute of Optronics, System Technologies and Image Exploitation, Ettlingen (Germany).

2.1. Experiment Goals

In order to account for the issues raised in the introduction, the goals of the experiment were:

- multi-temporal scenarios, to include different illumination conditions and to provide a basis for change detection analyses;
- multi-scale acquisitions, to identify impacts of different sensor characteristics;
- realistic target placements, to gain insights into the influence of varying vegetation cover.

2.2. Experiment Setup

Four different scenarios from early in the morning until late in the afternoon were designed. They covered more than 30 targets from three categories: camouflaged targets, such as camouflage nets, camouflage tents or camouflage garages; vehicles, both civilian and military; and reference materials. The targets were placed in a realistic environment, for instance below varying degrees of vegetation cover (see Fig. 1). Between the scenarios, different target modifications (relocation, reconfiguration) took place.

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Fig. 1: Realistic placement of targets.

2.3. Study Site

The study site (see Fig. 2) consists of three distinct areas: a quarry in the south west, a shrub-dominated centre, and a meadow in the east. In the quarry different camouflage nets and camouflage cloths with stone textures were placed. The shrub-dominated centre was used for the placement of camouflage nets with varying vegetation cover and some special camouflage materials (ghillie, MANPADS, tents). In the meadow two different camouflage garages, equipped with alternating vehicles and differently coloured cotton fabrics, were set up. Additionally, military vehicles with camouflage paint and reference targets (cotton fabrics, camouflage nets) were placed at various locations.

Fig. 2: Target placement in the study site. Background: eBee orthomosaic (see Chapter 3.3).

3. INSTRUMENTATION AND PROCESSING

Three different sensor systems were used for the experiment: the APEX (Airborne Prism EXperiment) airborne

Table 1: Specifications of the hyperspectral systems.

	APEX	Headwall
Wavelength range [nm]	376 - 2505	400 - 2500
No. of bands	316	537
FWHM [nm]	3 - 14.5	6 - 8
Spatial pixels	1000	640
GSD [m] (m AGL)	1 (2400)	0.2 (80)

hyperspectral system mounted on a Cessna Grand Caravan aircraft, a Headwall Co-Aligned VNIR-SWIR hyperspectral sensor mounted on a DJI Matrice 600 Pro drone and an eBee Sensefly fixed-wing drone with an RGB camera.

3.1. APEX

APEX is an airborne imaging spectrometer [7], owned by the European Space Agency (ESA) and operated by RSL and the Flemish Institute for Technological Research (VITO). Table 1 provides an overview of some of the main system parameters. APEX was flown at an altitude of 2400 m above ground level, resulting in a ground sample distance (GSD) of approximately 1 m.

The APEX data were processed from raw data to at-sensor radiance in the APEX Processing and Archiving Facility [8]. The radiometric gains and offsets were based on laboratory calibration data obtained in spring 2019 and extracted within the APEX Calibration Information System [9]. Spectral shifts were detected using the smile module of the ATCOR-4 [10] package in order to correct for changes in radiometry caused by the beam splitter between VNIR and SWIR channels. The APEX images were then atmospherically corrected and processed to reflectance values using the ATCOR-4 environment. In addition to a standard atmospheric correction, a so-called in-flight calibration (IFCALI) was applied in ATCOR-4 to calibrate the radiometry. IFCALI exploits ground reflectance spectra for a simulation of at-sensor radiance and a subsequent tuning of the measured radiance. After the atmospheric correction, a geometric correction was carried out in PARGE [11] (see Fig. 3).

3.2. Headwall Hyperspec

The Hyperspec Co-Aligned VNIR-SWIR is a hyperspectral sensor produced by the American company Headwall. Its technical specifications are summarised in Table 1. Only weighing 2.83 kg, the sensor is well suited for UAV applications [12]. The geolocation and image geocoding are achieved with GPS and an integrated IMU by an Applanix APX-15 UAV. An operating altitude of 80 m

Fig. 3: Fully atmospherically and geometrically corrected (level 2) APEX strip.

above ground level resulted in a GSD of approximately 0.21 m per pixel.

Dependent on weather conditions like wind and temperature and the overall take-off weight of 14 kg, one battery pack lasted for a flight of 12 min to 18 min. During this period, an area of about 4.2 ha was covered in an autonomous flight mode. The GPS and IMU data processing was performed using POSPac UAV 8.3. Headwall's SpectralView software was used for subsequent geometric, radiometric, and atmospheric correction. Inputs for the geometric correction were the processed GPS and IMU files and a high precision elevation model based on the eBee data (see section 3.3) [13]. The radiometric correction was executed by applying the dark current measurements and sensor calibration files provided by Headwall. Two different approaches of atmospheric correction were tested. First, an empirical line calibration of a white reference blanket placed in the field was calculated. This model is based on three components: ASD FieldSpec data recorded during the field campaign, extracted spectra from the Hyperspec images, and calibration files provided by Headwall. The second approach contained the single-use of extracted Hyperspec spectra and calibration files. A quality validation between the two approaches will be performed next to the data analysis.

3.3. senseFly eBee

The eBee by senseFly is a Swiss fixed-wing drone system. During the campaign it was equipped with an off-the-shelf Sony DSC-WX220 digital RGB camera. The drone acquired images at an altitude of 90 m above ground level, with a lateral overlap of 60 % and a longitudinal overlap of 75 %, yielding a GSD of roughly 2.5 cm.

Using Pix4Dmapper, the eBee acquisitions were processed to orthomosaics and digital elevation models (DEM) with a pixel spacing of 3 cm. The products have proven to be well georeferenced internally. Externally, however, some horizontal shifts were observed, which

required an additional georeferencing to the dGPS survey using a Helmert transformation in QGIS.

3.4. Auxiliary Measurements

Different ground-based measurements accompanied the airborne data takes. Using an Analytical Spectral Devices (ASD) field spectrometer, the targets' spectra between 350 nm and 2500 nm were measured. The ASD spectral data were ingested by the SPECCHIO spectral information system [14] and annotated with metadata to enable streamlined data analysis. Moreover, all targets were surveyed precisely using a Trimble dGPS system resulting in horizontal accuracies of 0.9 cm to 1.8 cm in most parts of the study site and < 10 cm in the quarry area due to a weaker connection to the dGPS reference station.

4. PRELIMINARY RESULTS

First applications of the Adaptive Coherence Estimator (ACE) algorithm [15] in combination with APEX data delivered promising target detection results (see rule map in Fig. 4). The input for the algorithm was a spectral signature of a specific type of camouflage net. Using an optimal decision threshold, almost all nets of this type, including some vegetation-covered, were detected, while all other camouflage objects were successfully excluded.

Fig. 4: APEX ACE rule map with a specific camouflage net type as target signature. Red outlines denote target camouflage nets of this type, blue outlines denote other camouflage net types and objects.

5. CONCLUSIONS AND OUTLOOK

With the realisation of multi-scale acquisitions of multi-temporal scenarios involving military targets in a realistic, natural environment, the experiment could successfully be accomplished as planned.

In the near future, we plan to fully exploit the wealth of information gathered during the experiment. With selected algorithms we plan to compare both sensors' detection rates of different targets depending on varying illumination conditions and vegetation cover. Since the two hyperspectral systems are spectrally comparable, we particularly expect to get insights into the role of the spatial resolution in the detection performance. Furthermore, we intend to repeat a distinctly smaller version of the experiment in 2020 on a day with more cloud cover.

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