SPECTRAL RESPONSE OF TWO HYPERSPECTRAL CAMERAS FOR UXO ENDMEMBER SELECTION

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There is currently no recommended procedure for acquiring endmembers in hyperspectral target detection when targets are larger than a single pixel. What is the best approach when multiple cameras are available for a dataset construction? This study examines the differences between hyperspectral cameras Specim IQ and Specim Imspector V9 that recorded the same surfaces under the same lighting conditions. A white balance card and a mortar mine are considered. As calibration procedures for cameras differ, raw data without processing are compared, and the same wavelength range is chosen. Clear differences are noticed between the spectra of the two cameras. Finally, guidelines for selecting statistically reliable endmembers and constructing an endmember dataset are provided based on the obtained results.

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SPEKTRALNI ODZIV DVEH HIPERSPEKTRALNIH KAMER ZA IZBOR KONČNIH ČLANOV UXO

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Ključne besede:
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Trenutno ni priporočenega postopka za pridobivanje končnih članov pri hiperspektralnem zaznavanju tarč, kadar so tarče večje od enega piksla. Kateri je najboljši pristop, ko je za konstruiranje nabora podatkov na voljo več kamer? Ta študija preučuje razlike med hiperspektralnima kamerama Specim IQ in Specim Imspector V9, ki sta posneli iste površine pod enakimi svetlobnimi pogoji. Upoštevana sta bela kalibracijska kartica in minometna mina. Ker se postopki umerjanja za kameri razlikujejo, se primerjajo neobdelani surovi podatki in izbere se enako območje valovnih dolžin. Opazne so jasne razlike med spektroma obeh kamer. Nazadnje na podlagi dobljenih rezultatov podajamo smernice za izbiro statistično zanesljivih končnih članov in izdelavo podatkovne zbirke končnih članov.

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1 Introduction

Hyperspectral image data comprises of a set of coherent images that represent intensities across different wavelength bands. These images consist of a set of pixels, also known as voxels, containing two-dimensional spatial details (with m rows and n columns) and spectral information across K wavelengths. Typically, they are referred to by various terms such as three-dimensional hyperspectral cube (shortly, hypercube), data cube, data volume, spectral cube, or spectral volume. Such data can provide insights into a tested material's physical and chemical properties. The information includes physical and geometric aspects like size, orientation, shape, colour, and texture. An unprocessed hyperspectral image consists of interconnected sub-images, each depicting the intensity and spatial arrangement of the examined object at a specific wavelength. These individual spatial images can be extracted from the hypercube at any wavelength within the entire spectral sensitivity range of the system. Consequently, a hyperspectral image denoted as I(x, y, l) can be understood either as an independent spatial image I(x, y) at each wavelength (l) or as a spectrum I(l) at every pixel (x, y). Each pixel in the hyperspectral image encapsulates a spectrum specific to its position, serving as a unique fingerprint for characterizing the composition of that pixel. Hyperspectral imaging captures spatially distributed spectral responses at the pixel level, allowing for a flexible selection of regions of interest on a target object with variable sizes and locations. For instance, extracting two pixels from distinct compositional locations in the hypercube would result in different spectral signatures, each showcasing unique fingerprints associated with their respective compositions. These resulting spectra act as fingerprints facilitating the characterization of the chemical composition at each pixel, thereby providing valuable insights into the material under examination (ElMasry & Sun, 2010). Many hyperspectral cameras are available in the market. Usually, there are no serious problems if endmembers and studied material are observed with the same camera. However, several questions arise if endmembers are collected with one camera and studied material with another.

Unexploded ordnances (UXO) are present in more than sixty countries around the world. For instance, UXO from World War I are still discovered when archaeological excavation or construction works are performed (National University of Public Service, Hungary & Ember, 2021)(Roberts & Williams, 1995). Consequences of explosions in ammunition storage areas, especially in densely populated regions, have had a significant humanitarian impact, leading to fatalities, injuries, environmental harm, displacement of communities, and disruption of livelihoods in more than 100 countries. Accidental detonations of ammunition warehouses rank among the most powerful explosions ever documented (Ammunition Storage Area Explosions – EOD Clearance, 2021). While UXOs buried in the ground are not suitable for hyperspectral detections, those on the surface can be very well detected (Bajić et al., 2013) (Bajić & Bajić, 2021).

In the evaluation article of Behmann et al. (Behmann et al., 2018), the Specim IQ camera was compared to the Specim V10E. The conclusions from this study can help us understand what problems might arise if one camera is used to select the endmembers and another to detect the materials studied. However, the evaluation article's faulty assumption is that the IQ camera uses other principle for acquisition of images and not the 'push broom' technique. However, when we tested the IQ camera, we tried it handheld, but the obtained image (cube) was very distorted. A workflow that we were able to track on the IQ camera screen indicated that it is a line scanner in a box.

With the availability of similar two hyperspectral cameras as in Behmann's case, i.e., the Specim IQ and older Specim Imspector V9 cameras, we would like to highlight the problem of correct selection of endmembers in hyperspectral detection of targets larger than one pixel. It should be emphasized that the IQ delivers very fast and has a user-friendly workflow, which makes the limitations of technology unnoticeable. Thus, in our study, we will conduct a similar experiment as in the above evaluation article and, simultaneously, report gained experiences with both hyperspectral cameras.

2 Materials and methods

The first sensor used in our research is **Specim Imspector V9** (see Figure 1a). It is a hyperspectral prism-grating imaging spectrograph, which has a spectral range of 430-900 nm, with a spectral resolution of 7 nm, and possible 1024 channels. It is a very good instrument but require longer post processing for creation of hyperspectral cube. Raw data are collected in lines, Figure 1b, and, afterwards, data need to be calibrated (see Figure 1c).

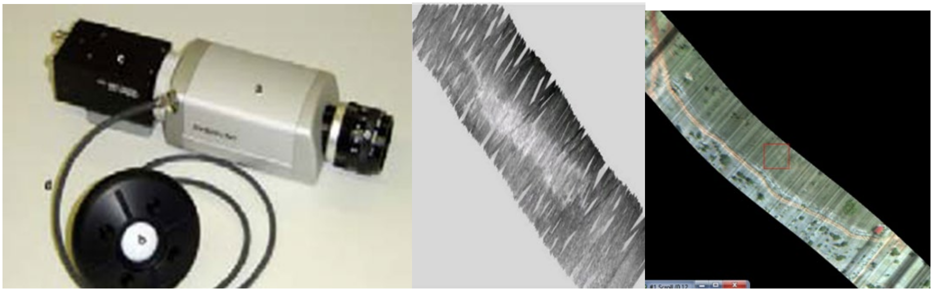

Figure 1: A hyperspectral push-broom sensor provides real hyperspectral data, while complex processing is needed to produce a calibrated hyperspectral cube. a) Hyperspectral line scanner, b) data are collected in scan lines, which need parametric geocoding, and c) hyperspectral cube needs calibration.
Source: own

Another sensor used in this study is **Specim IQ**. It is a portable carry-on hyperspectral camera that contains features needed for hyperspectral data capturing, data processing, and result visualization. It covers wavelengths between 400 and 1000 nm. It has 204 spectral bands. Image resolution is 512 x 512 pixels, while spectral resolution is 7 nm. Data output is stored in 12-bit format. A full Field Of View (FOV) is 31 x 31 degrees, whereat FOV at 1 m is 0.55 x 0.55 m. It supports WiFi and GPS. The camera has 32 GB SD memory card.

Figure 2: Handheld hyperspectral imaging camera Specim IQ.
Source: own

In our study, the Specim Imspector V9 and Specim IQ hyperspectral cameras are compared by measuring UXO on Friday 11th of February 2024. A white balance card and a mortar mine were chosen for measurements (see Figure 3). Raw values from the Specim Imspector V9 line scanner and Specim IQ are presented in all subsequent figures. Figure 4 depicts measurements for the white balance card. On y axis, there are sensor digital output values (digital numbers) that need to be calibrated to get standardized measures of radiance or reflectance. A wavelength is denoted on x axis. It should be stressed that a wavelength range of IQ camera is cut to match a range of V9 camera. Three squares in Figure 3 denote locations, where a material was sampled (measured). Black square denotes a location on the white balance card, while the red and blue squares denote locations on a green and grey part of the mortar mine (UXO). The values shown in the graphs were determined by averaging the pixels within the square at particular wavelength.

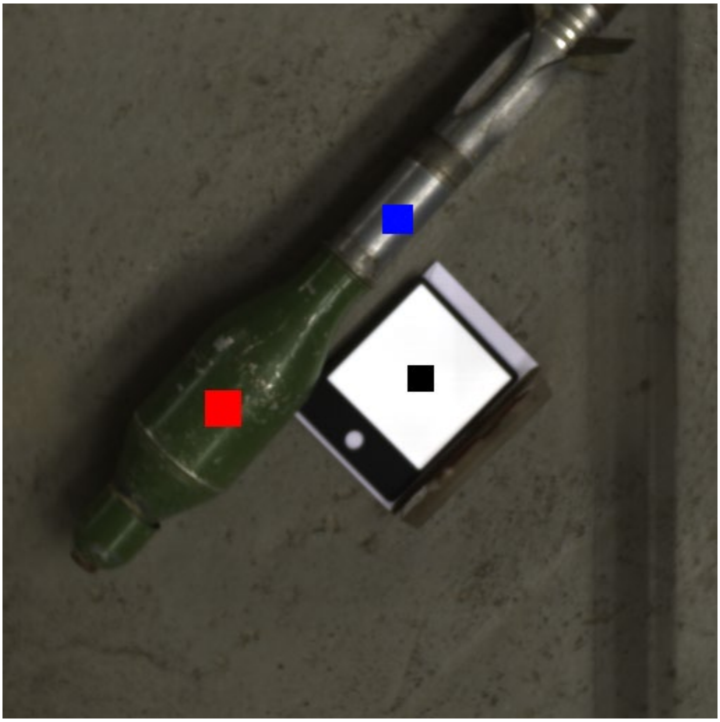

Figure 3: Mortar mine and white balance card. A red rectangle denotes a green part, while a blue rectangle denotes a grey part of mortar mine. Three squares (red, blue and black) denote an approximate location, where a material was measured.

Source: own

We used white balance card delivered with Specim IQ camera to test spectral response of both sensors. Lighting conditions were the same for both cameras. Sensor output values by the same wavelengths differ, of course, because an exposure time is not the equal for both cameras (see Figure 4). Stronger amplitudes are always noticed by V9 camera. The range of wavelengths between 530 nm and 630 nm is very interesting, because the V9 output stays almost constant. Higher amplitudes are noticed for wavelengths between 730 nm and 830 nm by V9 compared to IQ camera as well.

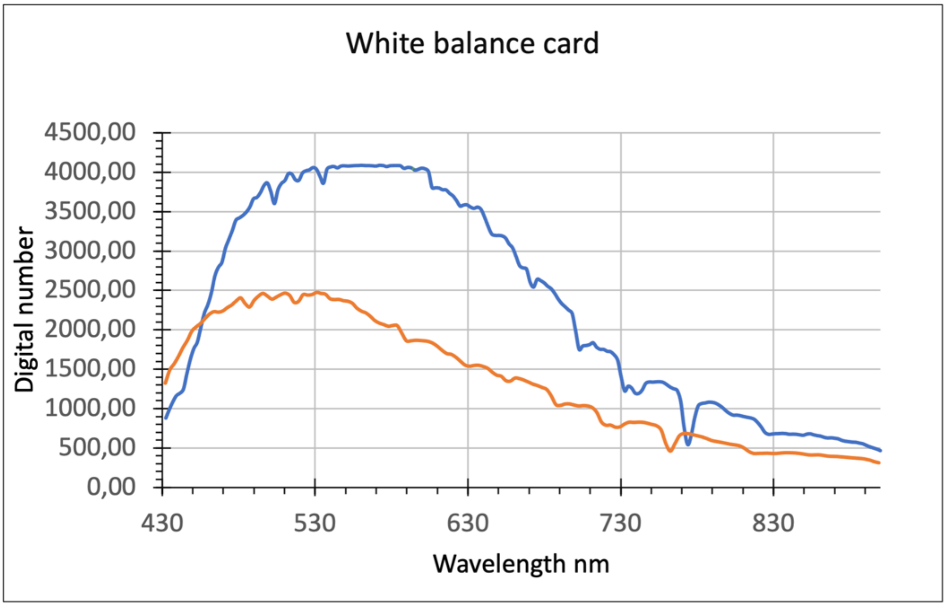

Figure 4: Uncalibrated outputs of Specim IQ (orange) and Specim Imspector V9 (blue) hyperspectral cameras by measuring the white balance card.

Source: own

We measured the mortar mine in the next experiments. First, the green part of the mortar mine was selected. This is a pretty realistic scenario, described also in (Ammunition Storage Area Explosions – EOD Clearance, 2021) about ammunition depot explosions. One can expect to find all kind of UXOs in grass or other green surroundings. Thus, it important to see whether we would be able to separate the mine from the environment characterized by vegetational jump around wavelength 700 nm. Figure 5 depicts outputs for both tested hyperspectral cameras.

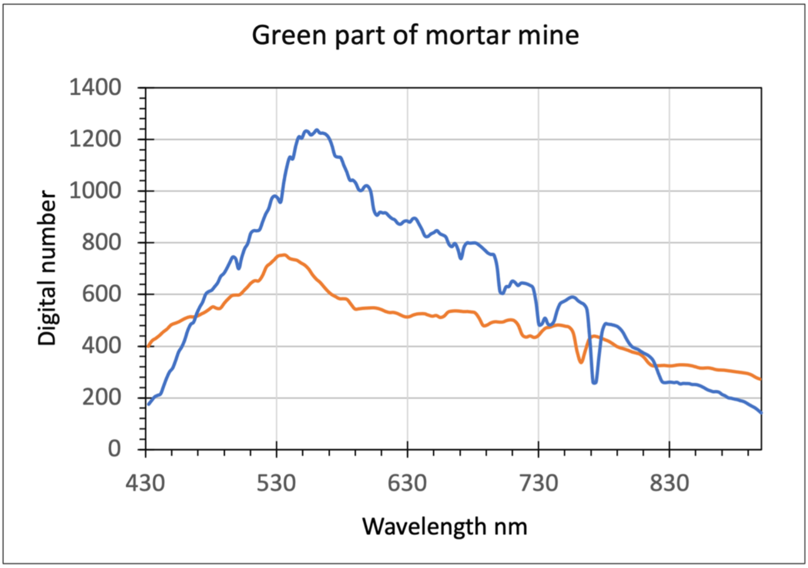

Figure 5: Uncalibrated outputs of Specim IQ (orange) and Specim Imspector V9 (blue) hyperspectral cameras by measuring the green part of the mortar mine.
Source: own

Figure 6: Uncalibrated outputs of Specim IQ (orange) and Specim Imspector V9 (blue) hyperspectral cameras by measuring the grey part of the mortar mine
Source: own

Hyperspectral sensors are passive devices, relying on spectral response rather than on chemical properties of the materials. Thus, it is important by endmembers selection to inspect also colour variations within the same object. Our test subject (mine) was new, with no traces of use or rust. Therefore, we wanted to check if sensors' responses are different for grey part of the mortar mine compared to the responses for the green part. Figure 6 depicts graphs for both studied sensors.

3 Discussion and conclusion

In a fundamental work by Manolakis, (Manolakis, 2005), endmember selection is very clearly defined. If there are two spectra from the same target, one should find mean vector of the existing spectra or use other endmembers selection technique. Very important consideration is also that the number of used pixels should be larger than the number of spectral channels used, with recommendation to use from 10 up to 100 times more pixels than channels to obtain statistically reliable estimate of the covariance matrix. It is worth to mention that these suggestions are from a remote sensing domain, based on satellite imagery and a high inter-pixel variability.

With our experiments we wanted to inspect a spectral response of both sensors for the white balance card and the UXO. Results are as expected. The size of our targets is approximately 10,000 pixels when viewed from a distance of 1 metre from the ground. At the altitude of detection procedures, which is around 30 metres above the ground, the size is at least 10 pixels depending on the target. If the target is smaller than one pixel or mixed with spectra from other materials, our recommendations for endmember selection may not be applicable or may need to be adjusted. Authors in (Behmann et al., 2018) for comparison of IQ and V10E cameras used 400 pixels and, afterwards, calculated mean reflectance, standard deviation, and the mean and maximum spectral distance. To the best of our knowledge, there are no clear suggestions in the literature on how many pixels to consider by statistical analysis, taking into account a variability of the terrain and a size of the target. Especially, when performing hyperspectral detections on targets with their size on the image between 1 pixel and 10 to 100 times of number of channels. The conclusions presented in this sequel are based on our measurements and knowledge. When constructing a statistically reliable endmembers dataset, it is important to adhere to the following principles:

- Different parts of the target must be included,
- Sample area should be of sufficient size,
- When reducing data dimensionality, it is important to exercise caution when using principal component analysis for wavelength selection,
- Consider including a spectral graph of the endmembers to visually confirm similarities, even if there is a shift in wavelength.

Viri in literature

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