CAN AIRBORNE HYPERSPECTRAL IMAGING DETECT HIDDEN GRAVES?

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ABSTRACT

This paper investigates the use of hyperspectral imaging as a non-invasive method to locate buried remains in open fields. Airborne HySpex data were acquired over two fields containing buried pig carcasses, considered as proxies for human bodies. The objective was to identify local spectral anomalies above the burial sites, indicative of decomposition processes locally enhancing vegetation health. The Red Edge Inflection Point (REIP) proved to be a particularly sensitive indicator, revealing spectral anomalies aligned with burial sites. A comparison with ground-based spectrometer data, based on absorption integrals in the 660–780 nm range, supported this analysis, despite the acquisitions being performed nearly one year apart. This suggests that airborne hyperspectral imaging could provide law enforcement with a scalable, non-invasive tool for locating graves in unsolved cases, complementing traditional ground-based methods.

***Index Terms*—** Forensic Science, Vegetation Indices, Crop Marks, Red Edge

1. INTRODUCTION

The search for buried human remains is a critical and often challenging task for law enforcement. Traditional search methods, such as ground-penetrating radar, cadaver dogs, or manual excavation, are often time-consuming, labor-intensive, and limited to smaller search areas [1]. The need for a more efficient and large-scale method has led to the exploration of remote sensing technologies, particularly those that can detect subtle changes in the environment caused by buried objects [2, 3]. The decomposition of a buried body, whether human or animal, creates localized changes in soil chemistry, enriching the soil with nutrients and fluids that fertilize the vegetation above the burial site. Healthy, stressed, or disturbed vegetation exhibits distinct spectral characteristics in the visible and near-infrared (NIR) ranges of the electromagnetic spectrum. Hyperspectral imaging is well-suited to detect these subtle changes in this context [4]. By analyzing the spectral signature of the vegetation, it is possible to identify vegetation anomalies potentially linked to buried remains [5].

This paper presents the results of an airborne hyperspectral remote sensing campaign conducted in cooperation with the German Federal Criminal Police Office (BKA). We focused on detecting buried pig carcasses in an agricultural field. The primary method of analysis was the use of the Red Edge Inflection Point (REIP), a key vegetation index sensitive to chlorophyll content and plant health. In addition, the absorption integral in a range centered around the vegetation red edge provided additional insights into vegetation health and was used to consider also spectrometer data acquired in situ. The aim is to investigate the potential of airborne hyperspectral imaging for forensic applications in this frame, specifically as a proxy for the non-invasive detection of buried human remains.

2. DATA ACQUISITION AND PROCESSING

As a preliminary step to the airborne campaign, on 5 and 6 September 2024 measurements were carried out at two test sites in Rhine-Main Metropolitan Region, Germany, each containing four graves with the same number of buried pig carcasses, with the exception of an empty grave in Field 2. Fig. 1 shows the available photos captured in Field 1, related to three targets. A ground-based field spectrometer of type HR-1024i manufactured by Spectra Vista Corporation (hereinafter referred to as SVC) was used on both days. The aim of these measurements was to measure the reflectance of the land surface in order to determine the spectral variability around the burial sites. The study was conducted at two separate test sites with different conditions: while in Field 1 vegetation was relatively sparse, making the sites' locations visible to the naked eye, in Field 2 vegetation was quite dense and uneven. In the first field, a transect was measured for all burial sites. In the second one, a mobile tripod was used to collect over 100 spectra along straight lines containing the known locations of the sites (Fig. 2).

On 29 April 2025 an airborne campaign was conducted using a pushbroom HySpex hyperspectral sensor, which col-

Fig. 1. Test area: burial of carcasses in Field 1, corresponding to targets 1, 2, and 3. Buried pigs from left to right: directly buried, in a plastic sack, rolled in a carpet.

Fig. 2. In situ data acquisition campaign (Field 2).

lected imagery in both the visible/near-infrared (VNIR) and short-wave infrared (SWIR) spectral regions. The flights were carried out over both test fields in the Rhine-Main region. For this study, the average of two HySpex strips was used, as this combination provided the most consistent data.

The raw hyperspectral data was pre-processed in DLR for radiometric calibration, geometric correction, and atmospheric correction. The primary spectral index used in this study was the Red Edge Inflection Point (REIP), which is an estimation of the point on the vegetation reflectance curve in the steep red-to-near-infrared transition region, where the second derivative goes to zero. A shift in this point is a reliable indicator of local changes in vegetation health, such as those caused by nutrient stress or enhancement. Healthy vegetation has a pronounced ”red edge” and a higher REIP value, while stressed vegetation has a less defined red edge and a lower REIP value. The fertilizing effect from the buried remains was hypothesized to increase the health of the overlying vegetation, resulting in a positive REIP anomaly.

3. RESULTS

This section illustrates the use of REIP for the identification of the buried targets, and compares vegetation features derived by HySpex and SVC data. In addition to REIP, around 30 relevant spectral indices were tested, providing comparable or less defined results.

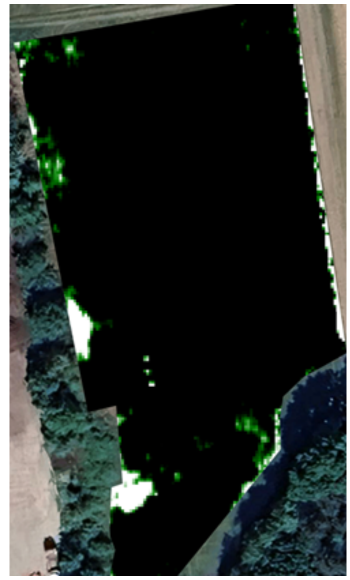

Fig. 3. Pseudo-color REIP map for field 1. Three graves are clearly visible as localized anomalies (bright patches). Background for context © Google, Airbus, Maxar Technologies 2025.

3.1. REIP Analysis

We used as a specific method for REIP calculation the three-point linear interpolation, which estimates the inflection point based on fixed wavelengths [6]:

$$REIP = 700 + 40\frac{\frac{(R_{670}+R_{780})}{2} - R_{700}}{R_{740} - R_{700}}$$

where R_λ is the reflectance at frequency λ.

Potential grave sites were identified using an unsupervised approach, thresholding REIP values to isolate pixels with anomalously high values. This method was chosen to simulate a real-world scenario where the precise location of buried objects is unknown, relying on the data themselves to reveal anomalies, rather than selecting training pixels in a supervised classification method. The threshold was manually selected to highlight areas where the vegetation showed the strongest indication of enhanced health, which in turn corresponded to the known locations of the buried carcasses.

In Fig. 3, the REIP map of the field shows a false-color representation of the calculated REIP values. Areas corresponding to the known burial sites appear with a visibly higher REIP value, indicating a positive spectral shift associated with more vigorous vegetation growth. These areas appear as distinct, localized patches against the more homogeneous background of the surrounding field.

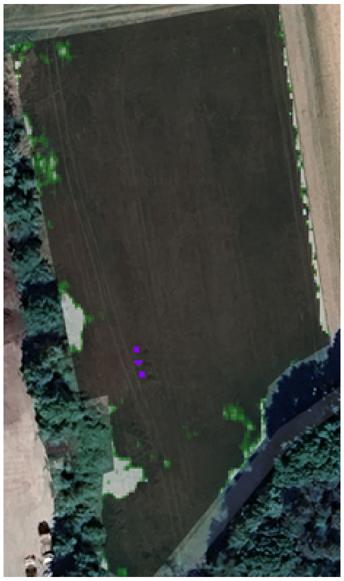

Fig. 4. Spatially filtered REIP map in Fig. 3 with purple markers indicating the three detected burial sites. A partially transparent image shows the background for context (© Google, Airbus, Maxar Technologies 2025).

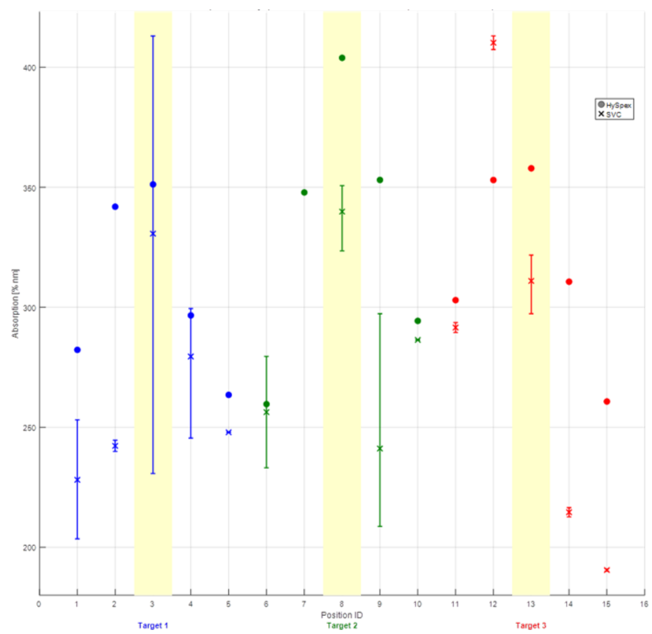

Fig. 5. Vegetation red edge absorption values computed on HySpex and SVC spectra (Field 1). The center of the targets are located in correspondence of the positions highlighted in yellow.

In Fig. 4, the grave sites were detected based on REIP results. In order to isolate them, two thresholds were applied to the REIP values, creating a simplified map that delineates the three burial sites as spatial anomalies. In the specific, the assumption was made that burial sites exhibit higher REIP values but have reduced dimensions with respect to vegetation clusters. Therefore, the first threshold identified high REIP values, while the second kept only pixels with a significant difference from values in a local neighbourhood, approximated by the median value in a 3×3 window. The output of this classification successfully identified all three targets with no false alarms, demonstrating that the methodology is capable of locating clandestine graves without prior knowledge of their exact position. The strong correlation between the classified areas and the known locations of the carcasses motivates the use of the REIP index as an indicator for this application. While the visual evidence of the burial sites in the visible spectrum is more subtle, the use of hyperspectral data and a targeted spectral index can provide clearer detections.

A fourth grave in Field 1 was not detected, likely due to local vegetation differences, though the exact cause remains unclear. This suggests the need for further investigation into the specific factors that influence the visibility of the effects caused by the burial sites.

3.2. Ground-Based and Airborne Data Comparison

To validate the airborne HySpex measurements, a comparison was performed with the ground-based SVC data collected over the same test area one year before. We considered a sequence of five HySpex pixels for each target, from South to North with the target location at the center, acquired in similar spots as previously measured in the ground-based SVC data.

A method close to the Chlorophyll Absorption Integral (CAI) [7], which links leaf chlorophyll absorption to the area under the reflectance curve divided by the envelope between 600 and 735 nm, was applied to estimate local vegetation health in this case. We considered here a spectral range approximately of the same size, but centered on typical red edge frequencies (720 nm), in the specific 660 to 780 nm, similarly to the interval proposed in [8]. This absorption feature will be further tested and described in future works.

Figure 5 presents the described absorption integral values from both datasets, with the known burial sites highlighted as Target 1, Target 2, and Target 3. The atmospheric conditions during the acquisition of SVC spectra were changing considerably and rapidly. Therefore, we report the minimum and maximum values computed on the measurements from each spot, along with the mean one. For the same reason, we observe some discrepancies, especially for Target 3. In spite of the measurements being performed approximately one year apart and in different seasons, the general agreement between the two sensors, particularly in the absorption peaks corresponding to the target locations, confirms that the spectral anomalies observed from the airborne platform are consistent with the ground-based measurements.

On the other hand, analysis on the second investigated field, where vegetation was much denser, was inconclusive.

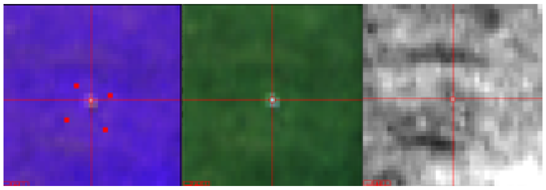

Fig. 6. Field 2, where analysis of HySpex data was inconclusive. From left to right: infrared combination with graves locations marked as red squares; RGB combination; REIP values. The crosshair marks the same spot in all images as reference.

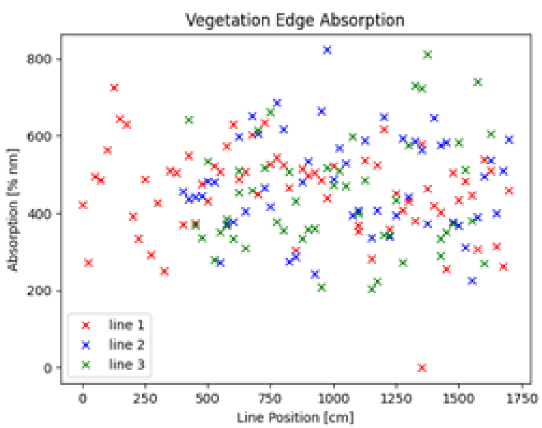

Fig. 7. Vegetation red edge absorption values computed for SVC spectra on Field 2. There is no clear detection for the buried carcasses here, as in the HySpex image in Fig. 6.

Figs. 5 and 6 report the second case of study.

4. DISCUSSION

The goal of this research is to validate the effectiveness of hyperspectral data for locating clandestine graves and to develop a rapid, non-invasive method for police investigations. The results from the Rhine-Main test fields confirm that burial sites can be detected and mapped from an aerial platform by analyzing the spectral response of vegetation [4, 2]. The detection based on the REIP index, in contrast to the less clear visual evidence from RGB imagery, highlights the value of hyperspectral technology in these scenarios. The successful detection of all three buried targets using simple and unsupervised detection workflows indicates that this approach is practical for large-area searches.

However, a key limitation of the methodology was observed at a second field where the surrounding vegetation was thicker and healthier. In this area, subtle spectral features were masked by dense vegetation, preventing detection. A total of 30 additional vegetation indices were investigated, but provided no clear outcome. This suggests that the effectiveness of the REIP method is highly dependent on the background environment, and it may be less effective in areas with robust, homogeneous vegetation that does not show a significant contrast with the vegetation over the burial sites.

Further research is needed to understand the temporal aspects of the changes in vegetation health, as the spectral signature may vary depending on the time since burial and seasonal changes. Our findings also underscore the importance of selecting the appropriate spectral indices for a given application, as they can reveal crucial information not visible to the naked eye. This work lays the groundwork for developing a standardized protocol for law enforcement agencies seeking to leverage remote sensing in their investigations [1].

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