Semi-automatic identification of Cultural Heritage looting activities through Earth Observation

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ABSTRACT

The inability to prevent archaeological looting and trafficking is not confined to a specific failed-state environment or any part of the world; it is an issue faced by many EU Member States. Looting of cultural property is a significant global issue, yet the efforts to combat this criminal activity have not matched its severity. Criminals profit greatly from this illicit trade, while humanity is deprived of access to vital archaeological information and artefacts that form our shared heritage. Challenges faced by authorities and Law Enforcement Agencies (LEA) in monitoring and protecting archaeological sites include their abundance, remote locations, limited protection resources, and inadequate funding. Satellite technology has shown great potential for analysing archaeological looting through various academic studies worldwide. While space-based earth observations cannot directly prevent illegal activities on the ground, they play a crucial role in identifying new looted areas that may be unknown to local stakeholders, thus raising awareness about potential illegal trafficking and increasing local ability to introduce new site-level protections in vulnerable locations. This study focuses on the development of a semi-automated satellite imagery brokering procedure for data mining and enhanced processing workflow for early and accurate identification of threats, determining the most effective remote sensing methods.

Keywords: Illegal Archaeological Excavations, Remote Sensing, Earth Observations, Cultural Property Protection.

1. INTRODUCTION

Archaeological looting and trafficking, often exacerbated by conflicts, present significant challenges for many EU Member States. These challenges include protecting widely dispersed and remote heritage sites with limited resources in terms of equipment and specialized personnel, and funding. Recognized first at an international level in 1954 with The Hague Convention [1], the gravity of cultural property crimes has since been emphasized by UNESCO in 1970 [2] and 2001 [3], and the Council of Europe in 2017 [4]. Yet, these crimes persist, harming global heritage.

Satellite technology has shown great potential for analyzing archaeological looting through various academic studies worldwide [5, 6, 7]. To achieve more reliable and accurate results, semi-automated detection processes have been developed, focusing on multitemporal site monitoring, which traditionally required laborious and error-prone manual comparisons of satellite imagery. Despite these advancements, managing the increasing volume of information can be challenging for final users who may not fully leverage the benefits of the space segments' operations.

In the framework of the ENIGMA Project [8], a remote sensing toolkit for endangered site monitoring is currently being developed using Earth Observation (EO) data, which will be able to provide early warnings to relevant authorities. It will exploit optical and radar satellite images using various processing techniques, such as interferometric SAR (InSAR), and Change Detection (CD).

The current study focuses on the description of the EO toolkit with a particular emphasis on the overall architecture and the preliminary results of the Change Detection processing optical data. The developed pipeline is presented together with the achieved results and current limitations.

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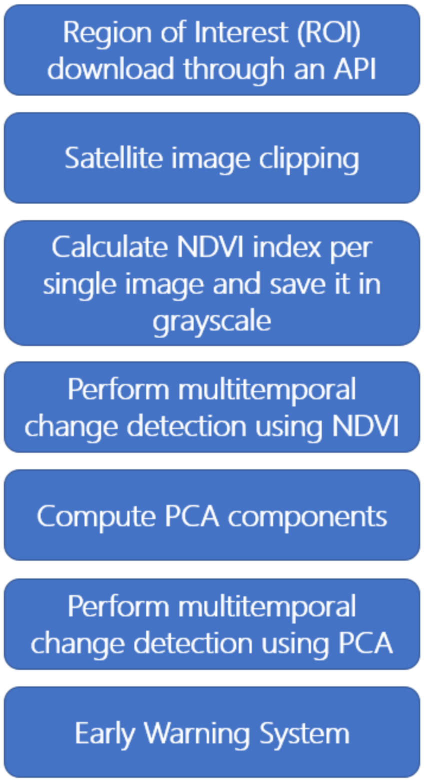

Figure 1. EO toolbox architecture

2. METHODOLOGY

Looting pits represent a typology of ground anomaly that is extremely difficult to detect using remote sensing techniques due to their size and variability in geometry and texture. In this context, the resolution of satellite images, particularly for optical satellite data, is crucial. Low-resolution data, with a magnitude of ≥ 5 meters, may not be indeed sufficient to detect illicit archaeological excavations. For this reason, the current study has utilized the Planetscope dataset [9], which offers a resolution of 3 meters per pixel (resampled) with an average temporal resolution on 1 day. The methodology employed for generating Change Detection maps is concisely outlined in Figure 1.
The functionalities of the Earth Observation toolkit were developed using the Python programming language and leveraged the capabilities of GDAL libraries.

Region of Interest (ROI) download through an API

Defining the Region of Interest (ROI) involves specifying the precise geographic coordinates or boundaries of the investigated area. Once the ROI is defined, the Planetscope API requests and downloads the relevant imagery data. This process requires authentication and the setting of specific parameters, including the date range and cloud cover to ensure the data meets the task needs. After submitting the API request, the selected satellite images are retrieved and downloaded, making them ready for further processing.

Satellite image clipping

Satellite image clipping is used to isolate the specific portion of a satellite image that corresponds to the predefined Region of Interest (ROI). To begin, the full satellite image dataset is loaded, revealing the full satellite image footprint. Next, the clipping boundaries are defined using the geographic coordinates of the ROI, setting precise limits around the desired area. With these boundaries established, the image data within the ROI is extracted, effectively cropping the satellite image to focus exclusively on the area of interest. This process allows to perform the change detection analysis on specific areas defined by the users where illegal excavations are suspected to happen

Calculate Normalized Difference Vegetation Index (NDVI) per single image and save it in grayscale

NDVI is used to identify looting because it might effectively highlight changes in vegetation [10]. The latter indeed can be indicative of ground disturbances such as those caused by archaeological looting. To save the NDVI index of a multiband image in grayscale, a series of steps is followed. First, per each clipped image, the NDVI is computed for each pixel in the image using the formula (NIR - Red) / (NIR + Red), which compares the near-infrared and red-band reflectance. Once the NDVI values are calculated, they are normalized to fit the grayscale color space by scaling them to a range of 0 to 255. Finally, the scaled NDVI values are converted into a grayscale image, where each pixel's intensity accurately represents the corresponding NDVI value (Figure 2, left). This grayscale image visually illustrates the vegetation index, facilitating further analysis and interpretation.

Perform multitemporal change detection using NDVI

Multitemporal change detection involves comparing satellite images taken at different times to identify changes in vegetation or land cover. The NDVI clipped images are pre-processed, in order to ensure that they are properly aligned. This process computes a disparity map between the two images. It is intended for the case where small misregistration between images has to be estimated and fixed. The algorithm uses an iterative approach to determine the best match between local patches, and the final output image contains X and Y offsets, as well as the metric value, with sub-pixel accuracy. By then comparing the NDVI values over time of the co-registered images, areas where changes in vegetation have occurred can be identified. This method allows to effectively monitor and detect man-made or natural soil and degradation (Figure 2, right).

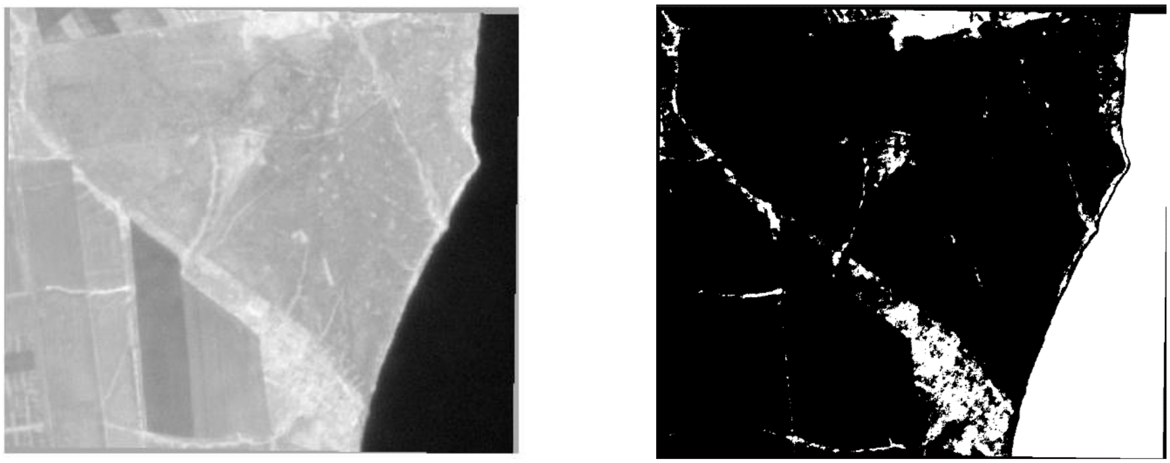

Figure 2. NDVI Map (left), and NDVI Multitemporal Change Detection Map (Right)

Compute PCA components

Principal Component Analysis (PCA) algorithm is a statistical procedure used in several domains and developed to transform a set of correlated variables into a new set of uncorrelated variables considering the principal directions in which the data are spread in space [11]. The process begins by stacking the image bands, combining the various spectral bands into a single multi-dimensional array. This comprehensive dataset is then standardized, normalizing the pixel values across all bands to have zero mean and unit variance. With the data prepared, PCA is performed, transforming the dataset into a set of orthogonal components, each representing a direction of maximum variance. Finally, these transformed data are extracted as PCA components, which can be saved and further analyzed to reveal underlying patterns and features that may not be immediately apparent in the original spectral bands (Figure 3, left).

Perform multitemporal change detection using PCA

Following the same approach described above for NDVI image co-registration, PCA is performed on the combined dataset. The resulting components are analyzed to identify changes, with an emphasis on significant shifts in the principal component values over time. Finally, these detected changes are highlighted by generating change maps, which visually represent areas with notable alterations, providing a clear and detailed view of temporal variations (Figure 3, right).

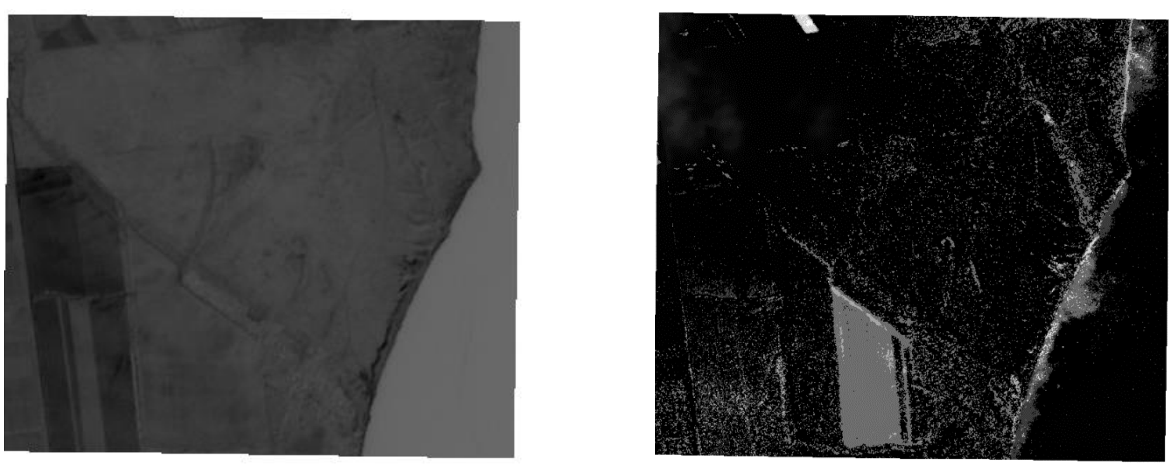

Figure 3. PCA Map (left), and PCA Multitemporal Change Detection Map (Right)

Early Warning System

Once the analysis is complete, the script is equipped with a function to activate an early warning system if it detects a significant change, specifically any variation exceeding 10% in pixel values. Should this threshold be exceeded, the system automatically triggers an alert mechanism. An email notification, including the location and an attachment, is then sent directly to the relevant authorities. This automated response ensures timely communication and enables prompt action to address potential threats to archaeological sites. This feature is key for maintaining surveillance over critical areas and responding swiftly to illegal archaeological excavations.

3. CONCLUSIONS

The Earth Observation toolkit is designed to automate the identification of illegal archaeological excavations using remote sensing techniques. The workflow utilizes the Python programming language, GDAL libraries, image processing techniques, and Change Detection algorithms. These components work together to trigger an alarm system, enabling authorities to quickly intervene and mitigate the risks associated with illegal activities. The increasing revisit capabilities of various satellite providers enhance the system's potential to improve responses to threats and protect archaeological sites. However, it is important to note that the resolution of the input data is critical for accurately identifying ground anomalies associated with illegal excavations and looting. Additionally, factors such as cloud coverage or water proximity can hinder the accurate interpretation of detected changes, potentially impacting the effectiveness of the system in real-world scenarios.

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