SATELLITE BASED INVESTIGATION FOR DETECTION OF ANCIENT TOMBS' LOOTING IN CYPRUS

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Περίληψη/Abstract

Η παρούσα εργασία πραγματεύεται την ανάλυση πολυφασματικών δορυφορικών εικόνων και αεροφωτογραφιών υψηλής χωρικής ανάλυσης (WorldView-2) και RGB εικόνων από το Google Earth©, με σκοπό τη χαρτογράφηση και διαχρονική παρακολούθηση περιοχών, οι οποίες υπόκεινται σε συστηματική σύληση από τυμβωρύχους. Η έρευνα επικεντρώνεται στην ευρύτερη περιοχή της αρχαιολογικής θέσης «Άγιος Μνάσωνας» στο χωριό Πολιτικό της επαρχίας Λευκωσίας, όπου έχουν εντοπιστεί πέραν των δέκα συλημένων αρχαίων τάφων. Οι παράνομες αρχαιοκαπηλικές δραστηριότητες στην περιοχή πραγματοποιήθηκαν σε διαφορετικές χρονικές περιόδους με τις εισόδους των τάφων να εντοπίζονται σε βάθος περίπου τριών μέτρων από την επιφάνεια του εδάφους. Οι αναλύσεις των δορυφορικών εικόνων σε συνδυασμό με επιτόπια έρευνα έχουν δείξει ότι το φαινόμενο αυτό δεν είναι μεμονωμένο περιστατικό, αφού και άλλες περιοχές δυτικότερα της θέσης που εξετάζεται στην παρούσα εργασία, παρουσιάζουν ίχνη διατάραξης. Η προτεινόμενη μεθοδολογική προσέγγιση αποδεικνύει ότι η ανάλυση εικόνων και η επεξεργασία πολυφασματικών δορυφορικών δεδομένων υψηλής χωρικής ανάλυσης, προσφέρει τη δυνατότητα συστηματικής παρακολούθησης περιοχών αρχαιολογικού ενδιαφέροντος, με σκοπό την προστασία και διαφύλαξη της πολιτιστικής κληρονομιάς από παράνομες δραστηριότητες.

This study aims to present the results from the analysis of high resolution multispectral satellite and aerial images (WorldView-2) and RGB images from Google Earth© engine in order to map and diachronically monitor sites of archaeological interest that are endangered from looting. The research concerns the archaeological landscape of *Ayios Mnason* in Politico village, located in Nicosia district, where more than ten looted tombs have been identified. Some of these tombs have been disturbed in the past, while others by more recent illegal activities, detected in depth of more than three meters below ground surface. Image processing and *in situ* investigations evidenced that this phenomenon is not isolated, since other areas in the western part of the case study under examination in this paper, have been also disturbed. Overall, it is evident that image analysis and processing of high resolution multispectral satellite datasets, can be used for systematic monitoring of areas with archaeological interest, in order to protect and safeguard cultural heritage against illegal archaeological activities.

Keywords: archaeological looting, remote sensing, aerial images, satellite images, Cyprus, WorldView-2, Google Earth©

Introduction

Illegal archaeological activity consists one of the major anthropogenic hazards of cultural heritage threatening several important archaeological sites of Cyprus. While illicit trafficking has been secured under various international treaties (e.g. The Hague Convention 1954, UNESCO general Conference 1964, European Convention 1969 etc.), the local law and its subsequent amendments, still the illicit archaeological excavation and particularly tomb looting, as far as Cyprus concerns, is even today a serious infestation threatening the history and archaeology of the island. It is therefore evident that a robust and systematic tool is needed in assisting legal and local authorities and stakeholders.

To this end remote sensing technologies, including space observation and ground non-contact techniques, can be of a great support for mapping and monitoring both the archaeological sites and the natural and anthropogenic hazards threatening them. Through remote sensing technologies current threats could be detected, mapped and thus observed and monitored, while in some cases prediction of threats could be achieved. The *a priori* consideration of potential threats of 'sensitive' archaeological areas could consist of a strategic tool towards their prevention.

Within the last years remote sensing has been systematically employed to support various aspects of archaeological research (Agapiou & Lysandrou 2015) and cultural heritage sector (Tapete *et al.* 2016). More recently, greater attention was given towards the exploitation of earth observation techniques concerning the destructions made in war conflicted areas, including amongst others, the documentation of looted sites (Tapete *et al.* 2016). The investigation and monitoring of illicit archeological activity from space has been also studied in vast areas of archaeological interest upon limited surveillance means (Lasaponara *et al.* 2012; Lasaponara *et al.* 2014).

Even though remote sensing cannot stop looters, it can positively impact to the distant monitoring of large scale sensitive areas, providing fruitful information to stakeholders in order to identify looting signs, as well as to distantly and efficiently record and monitor these sites, also preventing further destructions of this kind.

For the aims of this study, multi-temporal aerial images taken during 1993, 2008 and 2014, as well as a multispectral high resolution WorldView-2 image and RGB images from Google Earth© engine were used. The multi-temporal analysis of the various data-sources included the creation of pseudo colour composites, the use of vegetation indices and Principal Component Analysis. The preliminary results from the image analysis of the above datasets are hereunder presented.

1. Case study area and methodology

The area under investigation is located in the south western part of the modern village of Politico, in Nicosia District. In this area, looted tombs have been identified in the past as well as in more recent years. The tombs are hewn out of the natural bedrock. Undisturbed tombs are difficult to be detected by means of aerial and/or satellite techniques due the fact that they are underground, in an approximate depth of 3 meters below surface. In contrast, signs of looted tombs are more likely to be observed and recognised in that way (Fig. 1).

The wider area of the Politico village consists of an intense archaeological territory, very important for the history of Cyprus, linked to the ancient city-kingdom of Tamassos. While several archaeological excavations took place in the past or are still taking place in the area of Politico (Politiko-Kokkinorotsos 2007: La Trobe University, Melbourne under Dr. David Frankel and Dr. Jenny Webb, Politiko-Troullia 2016: University of West Carolina Charlotte, USA under Dr. Steven Falconer and Dr. Patricia Fall), the necropolis under investigation here has never been excavated or studied. Even though this area has been declared as an ancient monument (Scheduled B' monument) and is protected by law, the looting not only has not ceased, but as will be shown hereunder, it has been augmented through the years.

Figure 1 Looted tomb. Looting has been achieved using mechanical equipment (depth more than three meters below ground surface).

The archaeological importance of the site is also documented in the first topographic map of Cyprus, drawn in the last quarter of the 19th century (Fig. 2).

Figure 2 Case study area as indicated in the Kitchener's map, drawn in the last quarter of the 19th century.

For the specific case study, three high resolution aerial datasets have been exploited: (a) a grayscale orthophoto aerial image taken in 1993 with 0.50 m pixel resolution; (b) an RGB orthophoto aerial image taken in 2008 with similar pixel resolution and (c) an RGB orthophoto aerial image taken in 2014 with pixel resolution of 20 cm. Further enhancement of the results obtained by the analysis of the abovementioned aerial datasets, was given through processing a high resolution WorldView-2 satellite image taken at 11th of June 2009 and examining the historical record of the Google Earth© engine.

2. Results

Initially, a critical interpretation of the aerial images has been accomplished (Fig. 3a-c). Subsequently, the datasets were overlaid and several colour composites have been created (Fig. 3d-f). For instance, Figure 3d presents a pseudo colour composite before looting events have taken place and therefore no anomalies are detected contrary to the rest of the composites (Fig. 3e-3f).

In addition, Principal Components Analysis (PCA) was applied to the aerial datasets. Figures 3g -3h present the first two Principal Components (PCs) while Figure 3i presents a pseudo colour from the first three PCs. In the latter, the looted areas are easily recognized.

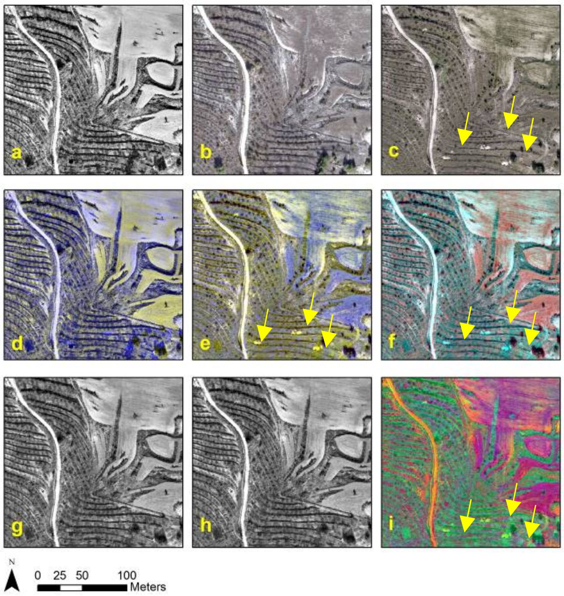

Figure 3 Grayscale orthophoto aerial image taken in 1993 with 0.50 m pixel resolution (a); RGB orthophoto aerial image taken in 2008 with similar pixel resolution (b); RGB orthophoto aerial image taken in 2014 with pixel resolution of 20 cm (c). Different colour composites have been created from these datasets (d-f), while (g-h) present the first two Principal Components (PCs) and (i) a pseudo colour from the first 3 PCs.

From the exploitation of the satellite datasets employed for this study, signs of looting have been identified in different periods covering a time span from 2008 until today (2016). Compared to the results of the aerial data, the satellite images have both identified even more looted tombs and provided information in relation to the looting period (Fig. 4).

Figure 4 shows the results from the image interpretation of WorldView-2 and Google Earth© images. Circles indicate areas looted at different times, demonstrating the expansion of looting from 2008 to 2016. Yellow circles are referring to the looted tombs that have also been identified in situ by the authors, while red circle defines a disturbed area detected only by satellite investigation.

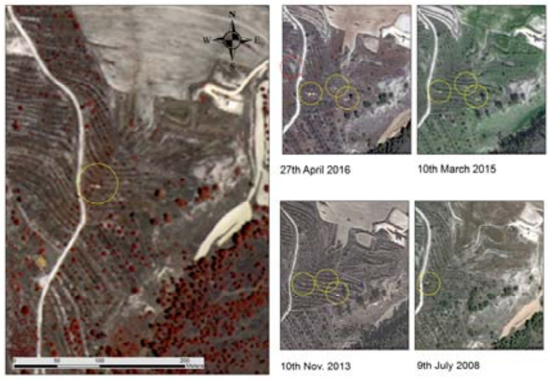

Figure 4 Left: Worldview-2 pseudo colour composite of 2009 indicating one looted tomb in circle. Right: screenshots from Google Earth© engine indicating looted tombs of the same area between 2008 and 2016.

Moreover, other algorithms have been tested at the WordView-2 dataset (see Figure 5) including several vegetation indices (such as the Normalised Difference Vegetation Index – NDVI; Difference Vegetation Index – DVI; Atmospheric Resistance Vegetation Index – ARVI etc.) and other indices like the Sum Green Index and Build Up Index as well as the orthogonal linear equations (Agapiou 2017). The latest techniques allow to the enhancement of the satellite image by creating a new 3D spectral space, which is linearly correlated to the initial spectral bands of the sensors, namely soil, vegetation and crop marks.

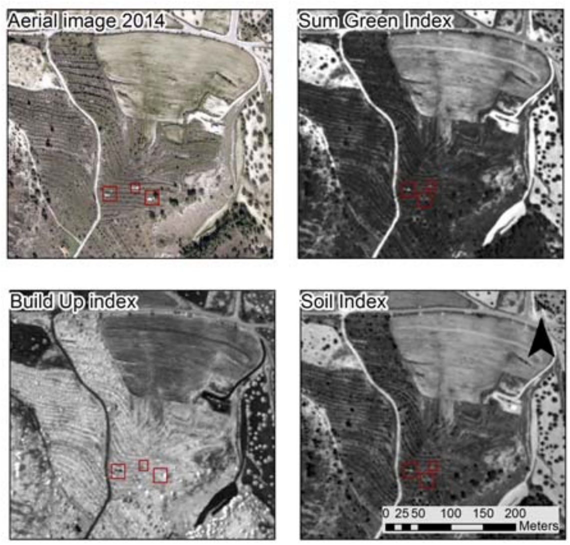

Figure 5 Aerial image indicating the looted areas in red squares (top left). The rest figures show the post-processing of the Worldview-2 image using different vegetation and other indices (such as Sum Green Index; Build Up Index) and linear orthogonal equations (soil component).

In addition, semi-automatic segmentation and classification techniques have been applied in both aerial and satellite data to evaluate their performance for the identification of looted areas. The semi-automatic segmentation was performed within the ENVI software using rule-based and object-oriented approach (Figures 6 and 7). Various parameters regarding the scale and the colour have been tested. Supervised and un-supervised classification of the image was also carried out within the same software. Un-supervised classification was performed using the ISODATA algorithm while supervised classifiers such as Mahalanobis distance and Support Vector Machine (SVM) have been applied. The classification was employed in order to examine whether the spectral properties of the looted areas could be detected from the multi-spectral sensor.

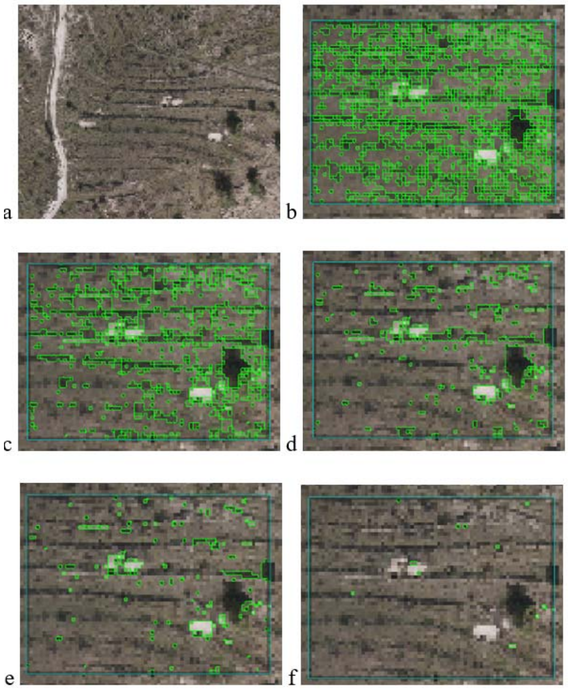

Figure 6 (a) Aerial image of 2014 (RGB) over the looted tombs; (b) Segmentation with 50 scale factor; (c) Segmentation with 60 scale factor; (d) Segmentation with 70 scale factor; (e) Segmentation with 75 scale factor and (f) Segmentation with 80 scale factor.

Figure 7: Simple rule base threshold values applied to the RGB bands of the orthophoto image acquired in 2014.

The overall results of the methodology for the specific case indicate that remote sensing techniques can be of great support to the authorities for monitoring tomb looting in vast archaeological landscapes, hard to be investigated systematically by other means.

Conclusions

The aim of the present paper was to evaluate the potential use of aerial and satellite datasets (object oriented classification compared to other classifiers, etc.) for monitoring tomb looting.

As demonstrated in this case study, protection and monitoring of sites and monuments (either known or still un-known) is feasible using remote sensing data and methodologies. While tomb looting identification was successfully achieved in the present research, this methodology could be useful (and further exploited) to identify other types of changes occurring in an archaeological landscape.

Remote sensing datasets can provide helpful information for stakeholders to monitor cultural heritage sites and landscapes. The piling of aerial and satellite data resulted in the identification of even more disturbed areas, upon different periods of time. The results clearly indicate that archaeological areas and landscapes can be monitored on a systematic basis to track and eventually prevent similar activities in the future, assisting local authorities to identify areas of high risk in relation to looting.

From an archaeological point of view, it is of great importance that this specific area, obviously a vast ancient cemetery laying to the west of Politico village has never been excavated and/or studied. The recurring loss of archaeological information and material from looting provokes an irreversible destruction to the archaeological layers and should be considered catastrophic for Cypriot archaeology.

It is important to highlight that the authors have accomplished in situ investigation prior and after image analysis, providing ground truth validation of the remote sensing results, thus permitting the evaluation of the techniques employed.

Acknowledgements

The present communication is under the “ATHENA” project H2020-TWINN2015 of European Commission. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691936.

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