Cloud-computing procedures for the automated detection and monitoring of archaeological sites

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Introduction

The accurate detection, identification and monitoring of archaeological locations have been a principal driving aim for developing remote-based approaches to investigate past cultural landscapes. Since the inception of aerial photography throughout the early 20th century, archaeologists have manually photo-interpreted a myriad of remote datasets, ranging from airborne imagery to declassified satellite photographs and mid-to high-resolution satellite imagery as new global satellite missions became available. Standard approaches in archaeological remote sensing primarily rely on the observations made in limited satellite imagery collections, e.g. to detect prominent and well-preserved sites with a visible landscape imprint, or to evaluate change between narrow time series, i.e. showing *after* and *before* events. In many instances, however, the nature of archaeological phenomena and of the landscape around requires more considerable multi-temporal information to account for 1) the long-lasting spectral and spatial discernibility of surface and subsurface archaeological features, and 2) the short- to long-term land use and land cover trends that might obscure the archaeological imprint.

The consolidation of cloud-based platforms for the scientific analysis of global satellite missions offers a new scenario for archaeological landscape investigations. Platforms such as Google *Earth Engine* enormously facilitate the handling of big Earth Observation (EO) data, and expand our capabilities to efficiently operate with virtual constellations (Wulder et al. 2015, Agapiou et al. 2019). This concept embraces the synergistic integration of sensors, measurements, archives and data policies in EO-based research and innovation. The open data policies of the Copernicus Programme and the combined observations of multispectral and radar imagery is, perhaps, one of the most promising and interoperational constellations for archaeological research (e.g. Tapete et al. 2021). In parallel, the harmonious use of nano-satellites and drone-acquired imagery offers a complementary level of interoperability between sensor measurements that share the same principles (e.g. high-resolution optical sensors) but operate at slightly different spatial or spectral resolutions.

In this paper, we present a combined workflow for the remote detection and monitoring of archaeological landforms (e.g. mounds) and surface anomalies such as soil and crop marks as well as scattered surface materials, that primarily combines a) Copernicus data (Sentinel 1-2), b) high-resolution Planet Labs imagery, and c) new field data acquired from multi-sensor drones. Our methods make use of the multitemporal and multisource nature of these images. We draw on previously published procedures and ongoing research being conducted in distinct ecological and geographical settings, ranging from the monsoonal drylands in South Asia to the Mediterranean. Above and beyond the geographic or chronological scope, we focus on methodological-driven approaches that can be adapted to global archaeological landscapes, particularly in those regions where vulnerable sites such as earthen mounds or buried features are obscured by agricultural expansion and encroachment.

Methods and results

i. Automated site detection and monitoring

Our previous works (García-Molsosa et. al. 2019) explored the potential use of cloud-computing in Earth Engine to study historical morphodynamics using seasonal multi-temporal vegetation indexes (Orengo and Petrie 2017) and the application of multi-scale relief models (Orengo and Petrie 2018) to highlight subtle topographic landforms and vegetation trends in the rich archaeological landscapes of the Indus Civilisation in South Asia. More recently, we applied a machine-learning approach in Earth Engine for the large-scale detection of mound-like surfaces in the Cholistan Desert in Pakistan (Orengo et al. 2020). This research integrated multitemporal Synthetic-Aperture Radar (Sentinel 1) and multispectral bands (Sentinel 2) to explore spectral discernibility of known but partially eroded earth-mound locations. First, the implementation of explorative analysis such as linear discriminant analysis has proven useful to evaluate the distinctiveness of the mounds and their surroundings in terms of optical and radar values. Secondly, we trained a classifier (i.e. Random Forest) to produce highly accurate probability maps showing the distribution of mound-like surfaces that largely exceeded the previously known mounds in the region.

The mounds in the Cholistan Desert offer a unique opportunity to further investigate endangered archaeological locations by recent agricultural encroaching. This approach primarily benefits from the optimal temporal and spatial resolution of the Sentinel 2 imagery and the performance reliability of multi-spectral indexes for the remote assessment of vegetation phenology and seasonality. We move forward from standard change detection approaches by analysing multi-temporal and cumulative yearly vegetation changes that show agricultural expansion into mound-like surfaces (Fig. 1). Our Sentinel-2 vegetation time series are compared with new PlanetScope high-resolution satellite imagery to evaluate site conditions and preservations. Overall, new agricultural schemes have been put in place in desert lands between 2019-2021, largely expanding the agricultural boundary in the Cholistan Desert and affecting more than 40% of the previously detected archaeological mounds in the region.

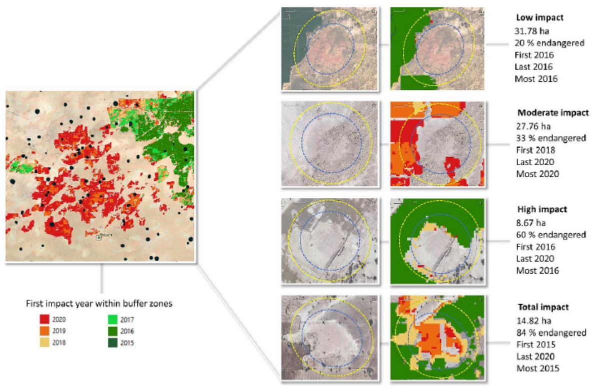

Fig. 1. Performance of our Earth Engine approach showing yearly agricultural expansion in drylands and the automated extraction of land-use information and other spatial indicators for the systematic monitoring of endangered archaeological mounds at large scales.

ii. Automated site detection and monitoring UAV-based surveys: from optimal flight windows to automated feature extraction

Following a downscaling approach, using *Earth Engine* we can further explore land use trends that inform field site conditions to further plan on site field surveys. For example, crop growth monitoring has been used to identify the seasonal early boot stage of common Mediterranean crops (e.g. wheat, barley in the fields of the island of Mallorca). The boot stage is a particular and relatively short plant stage that has been identified in the literature as the optimal time window for the formation of archaeological crop marks in Mediterranean agricultural context (e.g. Cyprus, see Agapiou et al. 2013). This is critical temporal information to develop drone-based campaigns aiming at revealing soil and vegetation anomalies produced by surface or subsurface remains. Technological advances in drone platforms, miniaturised sensors and GNSS positioning systems have certainly contributed to the consolidation of drone-based studies beyond experimental projects, and nowadays this available specialised toolkit is indispensable to archaeologists as shovels and trowels. In particular, we highlight four current trends in drone-based automatisation procedures:

a) The generation and co-registration of multi-sensor and multi-source high-resolution drone orthomosaics and DEMs using public and freely available aerial data archives (see Angelats et.al, 2018);
b) The automated delineation and vectorisation of visible archaeological remains from such orthophotos (Fig. 2);
c) The synergistic exploitation of multispectral and thermal bands to identify subsurface archaeological remain;
d) The development of intelligent drone surveys using low-altitude flights and machine and deep learning methods to identify subcentimetric archaeological remains, such as scattered potsherds (see Orengo and García Molsosa 2019, and Orengo et al. 2021).

Conclusions and future prospects

This research workflow offers a set of open and freely available tools that can be used for effective and reliable documentation, site management and decision-making for future surveys and explorations, with an additional focus on data sharing and product dissemination to both scientific and non-expert audiences. Likewise, these approaches have close ties with the development of precision agriculture not only because it draws on past and present patterns of land activities, but also because archaeological interpretations can have the potential to inform on specific agricultural practices. Finally, new and more efficient algorithms, coupled with reproducible processing chains and available code, can dramatically reduce the computational costs invested in data acquisition and processing, thus leaving more time and resources for data interpretation and compared studies.

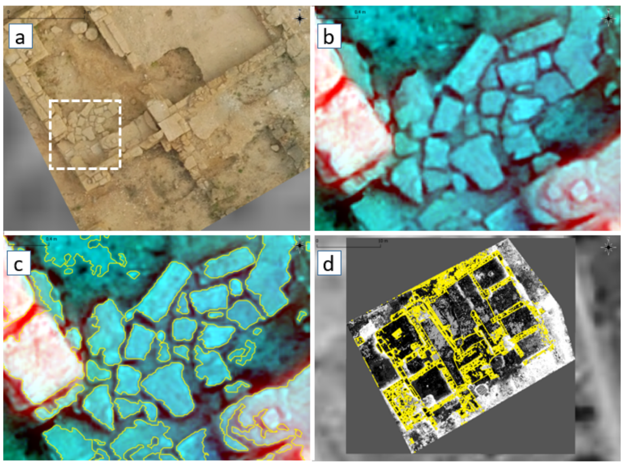

Fig. 2. Segmentation-based classification and automated extraction of visible structural remains using Orfeo ToolBox libraries.

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