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Detection of buried archaeological remains with the combined use of satellite multispectral data and UAV data

Javier F. Calleja[a,*], Otilia Requejo Pagés[b], Nelson Díaz-Álvarez[a], Juanjo Peón[c], Natalia Gutiérrez[d], Esperanza Martín-Hernández[e], Alejandro Cebada Relea[f], David Rubio Melendi[f], Paulino Fernández Álvarez[f]

[a] RSApps Research Group, Department of Physics, Univeristy of Oviedo, Spain
[b] Department of Cultural Heritage, Principality of Asturias, Spain
[c] RSApps Research Group, Department of Mining Exploitation and Prospecting, University of Oviedo, Spain
[d] Foto Asturias S. L., Oviedo, Spain
[e] Dolabra Arqueológica, Oviedo, Spain
[f] Hydrogeophysics & NDT Modelling Group, University of Oviedo, Spain

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A B S T R A C T

Active and passive remote sensing sensors have been applied successfully in the detection of crop marks (vegetation with a different spectral reflectance compared to its surroundings) related with buried archaeological remains. However, the detection of such crop marks depends on the sensor used, the status of the cover and the algorithm applied on the data. Moreover, buried archaeological remains generally produce microrelief marks, which can be very difficult to detect. The purpose of this work is to demonstrate that the combined use of data from the multispectral orbital sensor WorldView-2 and RGB and near infrared cameras mounted on an Unmanned Aerial Vehicle (UAV) equipped with a Global Navigation Satellite System (GNSS) can be successfully applied to the detection of buried archaeological remains. Principal Component Analysis, the Normalized Difference Vegetation Index (NDVI) and a purposely proposed band combination were obtained from WorldView-2 data to detect crop marks. The cameras carried by the UAV provide a Real Color composite, the NDVI and a high precision Digital Surface Model. The methodology developed in this work consists of searching for locations that exhibit both crop and microrelief marks with a similar shape. The WorldView-2 NDVI and the normalized Digital Surface Model of the UAV are filtered. An Archaeological Binary Map is constructed, in which pixels with both NDVI and normalized elevation above corresponding threshold values are interpreted as susceptible of containing buried archaeological remains and are given the value of one, otherwise zero. One of the locations of the Archaeological Binary Map, with a very regular pattern, is subsequently surveyed with Ground Penetrating Radar to find a buried structure, the location and shape of which match perfectly those of the Archeological Binary Map.

1. Introduction

Discovering, locating and registering buried archaeological remains is crucial for the preservation of our cultural heritage. Because of this, urban sprawl and the development of neighbouring industrial sites demand a previous archaeological study of areas affected by the growing urbanization. Moreover, locating with high accuracy an archaeological site can contribute to an effective planning of the archaeological work. In this respect, remote sensing has found an interesting and promising niche of application in the detection of buried archaeological remains. Remote sensing techniques include, among others, the ones used in this work: aerial photography, multispectral satellite imagery and LiDAR data. Aerial photography has been one of the most important tools in archaeological survey(Bewley, 2003). Using oblique photography, earthworks can be detected as shadow-marks. Aerial photography is easy to execute and obtain airborne data.

Abbreviations: WV-2, World View 2; UAV, Unmanned Aerial Vehicle; NDVI, Normalized Difference Vegetation Index; PC, Principal Components

* Corresponding author at: Department of Physics, University of Oviedo, Federico García Lorca, 33007 Oviedo, Spain.
E-mail addresses: jfcalleja@uniovi.es (J.F. Calleja), gabiarq@las.es (O. Requejo Pagés), nelsonuniovi@gmail.com (N. Díaz-Álvarez), juanjopeon@gmail.com (J. Peón), natalia@fotoasturias.es (N. Gutiérrez), dolabra@gmail.com (E. Martín-Hernández), alejandro.cebada@hydrogeophysicsndt.com (A. Cebada Relea), david@hydrogeophysicsndt.com (D. Rubio Melendi), pauli@uniovi.es (P. Fernández Álvarez).

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However, the detection of shadow marks can be a difficult task in rough areas, where they cannot be distinguished from the natural topographic elevation of the landscape and besides, their detection depends on the orientation of earthworks in relation to the sun. Furthermore, earthworks can be levelled by ploughing or soil management. For this reason, the next step was the detection of crop and soil marks induced by the archaeological remains underneath. The term crop/soil mark refers to sites with a radiometric response that differs from its surroundings. The radiometric response refers to the reflectance (in the case of passive sensors). Orbital sensors cover larger areas than airborne sensors and provide calibrated data with high spectral resolution. They include bands sensitive to vegetation and soil properties. A historical review of the evolution of orbital sensors applied to archaeology from low resolution sensors like Landsat 5 TM and ASTER to sensors with high spatial resolution like Ikonos, QuickBird and GeoEye-1 can be found in Fowler (2010) and a review of the application of optical orbital sensors in Archaeology in Lasaponara and Masini (2012). With the advent of orbital sensors with high spatial and/or spectral resolution, new algorithms began to be applied in the search of crop and soil marks. Data fusion, principal component analysis, vegetation indices calculation, spatial filtering and object classification were applied on ASTER, Landsat, Hyperion and Ikonos imagery (Alexakis et al., 2009) in the search of a predictive model of Neolithic settlements. The calculation of vegetation indices, alongside pansharpening, edge detection techniques and principal components analysis have been successfully applied to QuickBird imagery (Lasaponara and Masini, 2007); false color composites and pansharpening to Ikonos data (Beck et al., 2007) and an automatic algorithm has been developed to detect circle-shaped crop and soil marks using QuickBird data (Trier et al., 2009). A combination of bands especially devised for detecting crop marks has been proposed for several sensors including low resolution ASTER, Landsat 4 TM and Landsat 7 ETM and high resolution ones such as Ikonos, QuickBird, GeoEye-1 and WorldView-2 (Agapiou et al., 2013a). In the search of a fully automated data processing to detect archaeological remains, an object oriented approach has been proposed recently (Lasaponara et al., 2016) based on two steps (segmentation and classification), applied twice: first, globally at the whole image and, secondly, at the significant subsets identified by global analysis. The use of real color and near infrared cameras carried on an aircraft (Verhoeven, 2012) or on Unmanned Aerial Vehicles (UAVs) (Themistocleous et al., 2015) have joined to the conventional photography and the orbital sensors technologies. UAVs provide a cost-effective way of acquiring data with very high spatial and temporal resolutions. Moreover, when equipped with a Global Navigation Satellite System (GNSS), a georeferenced Digital Surface Model (DSM) can be calculated from the point cloud obtained with the data (Colomina and Molina, 2014; Puliti et al., 2015). UAVs have proven to be a powerful tool for archaeology, as demonstrated in documentation, in the generation of topographic outputs and in the detection of crop marks (Cowley et al., 2018). Regarding the spectral information, the NDVI obtained from a low-cost system identical to the one used in this work (a modified Canon Powershot S110 NIR camera mounted on the fixed wing UAV eBee from SenseFly) has been compared with that obtained from ground measurements using a spectroradiometer (Nebiker et al., 2016). The values of the NDVI of the camera are much lower than those obtained in the field, due to the spectral overlap of the bands of the camera. However, the authors conclude that the high resolution NDVI from the camera is suitable to carry out a qualitative monitoring of in-field variability.

Regarding active remote sensing technology, both LiDAR and Synthetic Aperture Radar (SAR) data have also been applied in archaeology. Aerial LiDAR allows the detection of upstanding relief features that can be associated with buried archaeological remains and it has provided valuable information when combined with multispectral data (Crutchley, 2006; Rowlands and Sarris, 2007). Aerial LiDAR has also been successfully applied in the detection of canopy biomass changes associated to buried archaeological remains (Stott et al., 2015).

It is worth mentioning that, in addition to the new sensors and platforms introduced in recent years, archived photography can still be used to detect elevation and crop marks, and it is a powerful technique capable of providing a complete interpretative map of a study area (Verhoeven and Vermeulen, 2016).

Recently, remote sensing techniques have been applied and assessed in the framework of landscape archaeology (Cowley et al., 2018; Traviglia and Torsello, 2017; Pournelle and Hritz, 2014; Verhoeven, 2017). In this context, the landscape is the framework that contains the traces of human activity and environmental processes, superposed over time. In Ref. Traviglia and Torsello (2017) the authors used black and white historical photographs, multispectral and hyperspectral airborne imagery and RGB high resolution aerial orthorectified images of different periods, targeting on similarly oriented objects that describe the landscape organization imposed by the Romans over two millennia ago. Other authors have explored the combined use of aerial photography and satellite remote sensing in the study of landscape archaeology in the Middle East (Pournelle and Hritz, 2014). In Ref. Verhoeven (2017) the sources of bias in landscape archaeology are examined and solutions to avoid them are proposed. Bias can be introduced by studying targeted locations (geographical bias), specific temporal data (time resolution bias) of by the use of complicated and purposely developed algorithms that can discourage other researchers to use them (processing complexity bias). In this work, we have tackled some of them. For instance, the geographical bias is minimized looking at a large area, and only focusing on specific targets after the results of several algorithms are examined. The temporal resolution issue was dealt with considering that the target area was chosen because the crop and elevation marks were detected by both WV2 and UAV data (spectral) and by Lidar and UAV data (elevation data) on different years and different seasons of the year. Finally, the use of widespread algorithms implemented in most proprietary and free-license software, diminishes the impact of the processing complexity bias.

In spite of all the efforts devoted to it, the detection of crop marks associated with buried archaeological remains is a difficult task, since it depends on the sensor used (Alexakis et al., 2009), the acquisition date (Agapiou et al., 2016), the algorithm applied on the data (Agapiou et al., 2012) and the status of the vegetation cover (Pan et al., 2017). The present work deals with algorithms and techniques to detect crop and microrelief marks that can be related with buried archaeological remains. The term microrelief mark is used to describe a site with an elevation pattern that stands out from its surroundings. The pattern can be regularly or irregularly shaped. The hypothesis of this work is that, if the upper soil layer of a study area has not been manipulated for years, crop marks produced by archaeological remains should remain detectable over time and they should be associated with microrelief marks. We will show that there is a correlation between some crop marks and microrelief marks. This can be used as a tool to distinguish crop marks associated with archaeological remains from those associated with man-manipulation of the soil or with the natural phenotype cycle of vegetation.

2. Materials and methods

2.1. Study area

The study area (Llanera, Principality of Asturias, Spain) is located in the central western part of the Cantabrian coast in the north of the Iberian Peninsula (Fig. 1). Due to its geographic situation it forms part of the Asturian depression bordering the sea, a horizontal band which runs from east to west across the Asturian territory and whose topographically is a sunken flattened surface in between two lines of low summits. The geomorphology mainly reflects the action of fluvial processes being the course of the Nora River, which stands out, both in length and extension, as one of the fluvial meadows which constitute the most significant element in the landscape of Llanera at its southern