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Multispectral satellite imagery processing to recognize the archaeological features: The NW part of Mount Etna (Sicily, Italy)

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We propose a new GIS-based procedure to retrieve archaeological elements using satellite remote sensing. The processing of multispectral satellite images consists in a preprocessing phase using the pansharpening technique to improve the spatial quality and in the exploitation of linear equations of the initial spectral bands with the aim of generating accurate and precise raster data that can be used as input for an object classification. The proposed methodology has been tested in an archaeological area located on the north-west flank of Etna volcano (Sicily, Italy).

KEYWORDS
archeology, classification, GIS, pansharpening, remote sensing

1 | INTRODUCTION

The use of remote sensing data for supporting archaeological research has been increased in the last decade due to the higher spatial resolution capabilities of the new satellite sensors [1-3] and the great availability of lower-cost satellite imagery. Satellite remote sensing is mainly used to identify crop marks, i.e. alterations of the vegetation, formed above buried archaeological remains that for their constructional characteristics tend to retain the soil moisture or around archaeological artifacts emerging from the surrounding area. This has been widely tested in environmental contexts that favor the characterization of archaeological artifacts with classical remote sensing techniques, for example in little cultivated areas or where archaeological artifacts emerge considerably from the ground.

Despite the innovative hardware and software techniques, the identification of crop marks is a challenging issue due to many difficulties related to weather conditions, the period of growth of crops, the characteristics of soil and vegetation, etc. In order to overcome these problems, satellite images acquired in spring and summer should be used in order to optimize the radiometric response of the sensor on board the satellite and therefore have images of excellent quality from a radiometric point of view. Moreover, it is necessary to improve the quality of satellite images using both pre-processing techniques and the combination of new spectral bands to emphasize the image content[4]. Crop marks can be then identified using vegetation indexes, with subsequent photo interpretation of images acquired in different periods.

Data fusion techniques to very high resolution satellite data have been used to improve the enhancement of archaeological marks and facilitate their detection (e.g.[4])

Semi-automatic approaches based on multiphase Active Contour Model (ACM) segmentation have been also proposed for the detection and extraction of linear archaeological traces. However, ACM consists in a region-based segmentation and does not utilize image gradients to identify object boundaries, but rather the statistical information inside and outside a contour line to control the region evolution[5].

In this work we propose a new procedure for the analysis and classification of archeological elements using Worldview-2 satellite images[6], which have a ground-based spatial resolution from 0.46 (panchromatic) to 1.85 (multispectral) meters at Nadir. The output of our procedure, which is a raster emphasizing natural and anthropic elements, can be used as input for the classification algorithm in order to recognize the archaeological elements of the study area. As case study, we used an archeological area in the north-western part of Mount Etna (Sicily, Italy), which is a difficult environmental context since the archaeological artifacts merge with the geology of the territory due to their manufacture (Figure 1). Moreover, the few ones that emerged from recent excavations attest a variety of geometries and dimensions that hardly lead to the visual identification of the artifact itself.

2 | MATERIAL AND METHODS

We search and classify buried or semi-outcropping archeological buildings using a Worldview-2 satellite images acquired in April 2013. To better identify crop and soil marks, we first selected the best date and time of image acquisition by considering the optimal lighting conditions and state of vegetation.

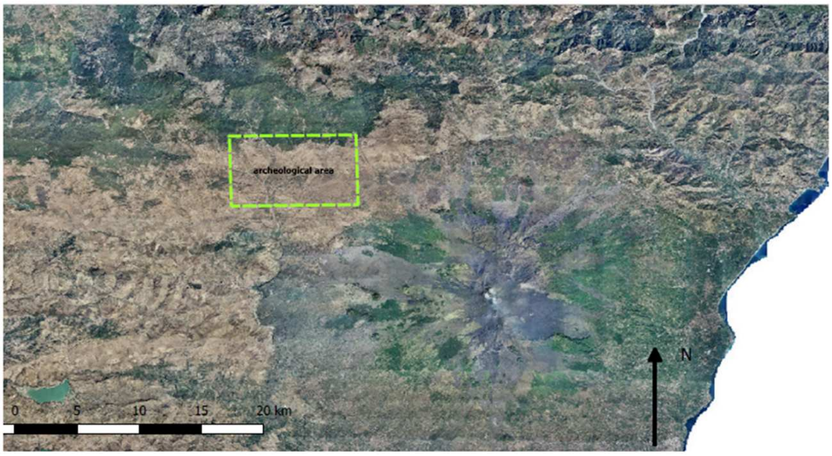

FIGURE 1 Worldview-2 image of the north-western part of Mount Etna. The archaeological area under study is highlighted in the green box [Colour figure can be viewed at wileyonlinelibrary.com]

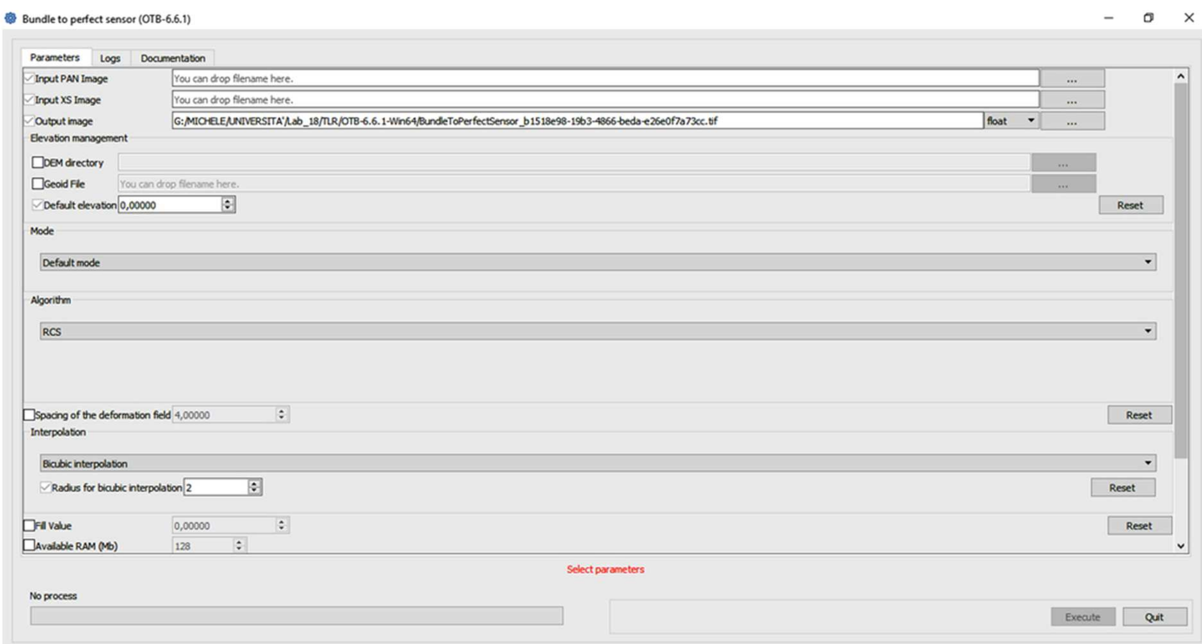

FIGURE 2 Orfeo Toolbox for the pansharpening [Colour figure can be viewed at wileyonlinelibrary.com]

DigitalGlobe's WorldView-2 satellite sensor, launched October 8, 2009, provides a high resolution panchromatic band (450–800 nm) at 0.46 m and eight multispectral bands (Coastal: 400–450 nm; Blue: 450–510 nm; Green: 510–580 nm; Yellow: 585–625 nm; Red: 630–690 nm; Red Edge: 705–745 nm; Near-IR1: 770–895 nm; Near-IR2: 860–1040 nm) at 1.85 m. WorldView-2 has an average revisit time of 1.1 days and is capable of collecting up to 1 million km^2 of 8-band imagery per day.

Wordview-2 images are supplied orthorectified, i.e. radiometrically correct, and georeferenced, according to the reference system WGS 84/UTM zone 33 N (EPSG: 32633). Therefore they can be directly managed in any GIS environment.

The procedure we developed to process Wordview-2 images consists of different steps, including:

- Preprocessing of images;
- Combinations of bands to enhance the elements of the territory;
- Segmentation and object classification of the study area.

Each step is described hereafter in detail. At the very end of the workflow, once the data processing phase was completed, the proxy indicators or archaeological features detected were validated through surface surveys, GPS surveys and aerial shots. In fact, it is worth remembering that false traces are numerous and very common in such complex environments.

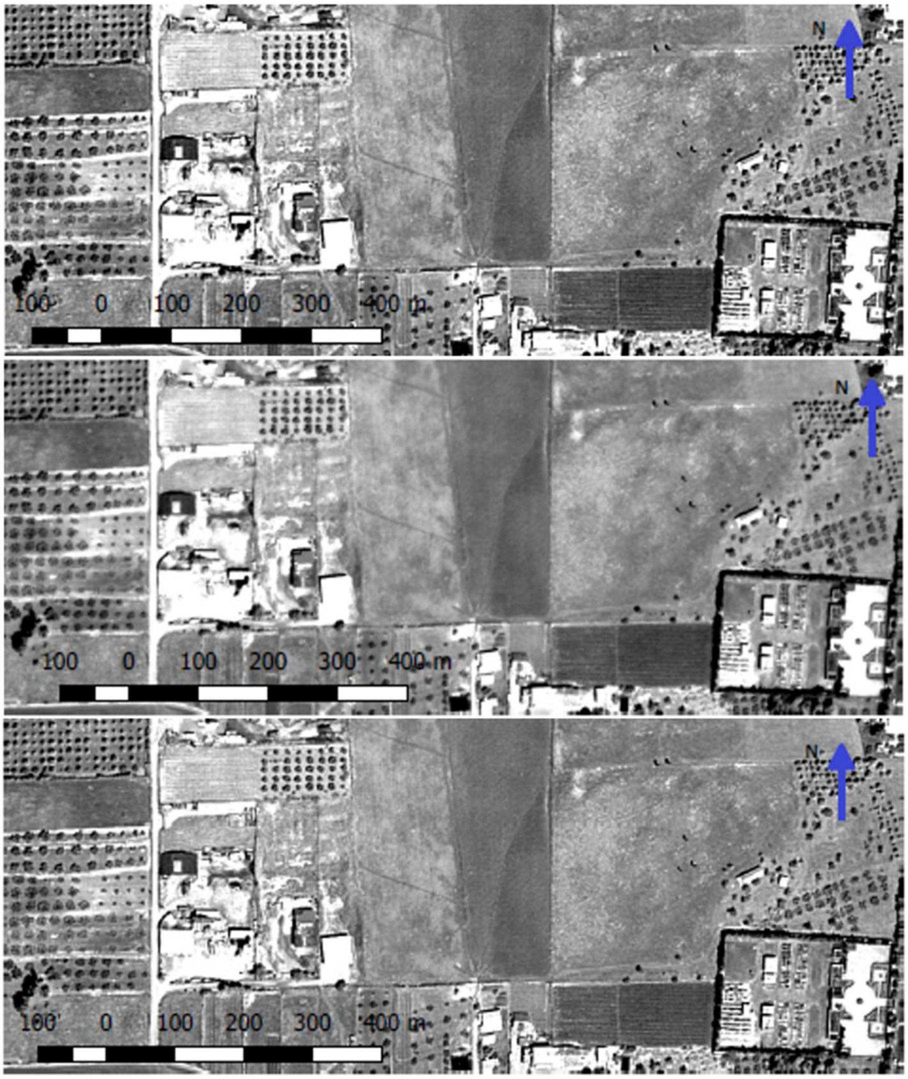

FIGURE 3 Results of the pansharpening performed with the three algorithms available in the Orfeo Toolbox: Relative Component Substitution (top), Local Mean and Variance Matching (middle), and Bayesian Data Fusion (bottom) [Colour figure can be viewed at wileyonlinelibrary.com]

3 | PREPROCESSING OF IMAGES

The first phase of image processing was the Pansharpening. This technique is based on “data fusion”, i.e. merging and integrating the information content associated with two or more data sources. In particular, in the case of panchromatic and multispectral satellite images, the data fusion algorithms are used to integrate the high spatial resolution of the image acquired in the panchromatic with the spectral information acquired in the various bands, having lower spatial resolution[1]. The use of this technique allows to obtain multispectral images having a spatial resolution comparable to that of the panchromatic image.

Regarding the use of this technique for identifying archaeological features, there are particular studies in literature[7,8] in which high resolution multispectral satellite images are processed and the results obtained are compared by applying different algorithms, such as the Zhang algorithm[9] or the Brovey transform. From these studies it emerges that the use of data fusion algorithms is of fundamental importance for the valorization of spatial and spectral features related to the presence of underground archaeological artefacts (such as buildings, but also ancient roads, terrestrial divisions, etc.).

In fact, the data fusion allows to greatly improve the spatial characteristics of the multispectral image, allowing to emphasize and facilitate the recognition of archaeological features. In particular, the use of this technique is particularly important in all archaeological sites located in agricultural areas where mechanized agriculture can destroy archaeological markings. In this context, in fact, the archaeological signs can be more difficult to identify using only panchromatic aerial images.

In our work, pansharpening was performed using the open-source Orfeo Toolbox (OTB), which is a C++ library for remote sensing image processing using a user-friendly software interface (Figure 2). OTB provides different plugins for accessing, reading and processing most remote sensing image formats using GDAL, meta-data access etc.. All of OTB's algorithms are accessible from QGIS allowing to manage vector data in shape format, and to use specific tools for remote sensing, such as calculation of vegetation indices, filters, etc. Here we used OTB-6.6.1 provided by the Monteverdi software[10].

Algorithms available in the Orfeo Toolbox for the pansharpening are: Relative Component Substitution (RCS), Local Mean and Variance Matching (LMVM), and Bayesian Data Fusion (BDF).

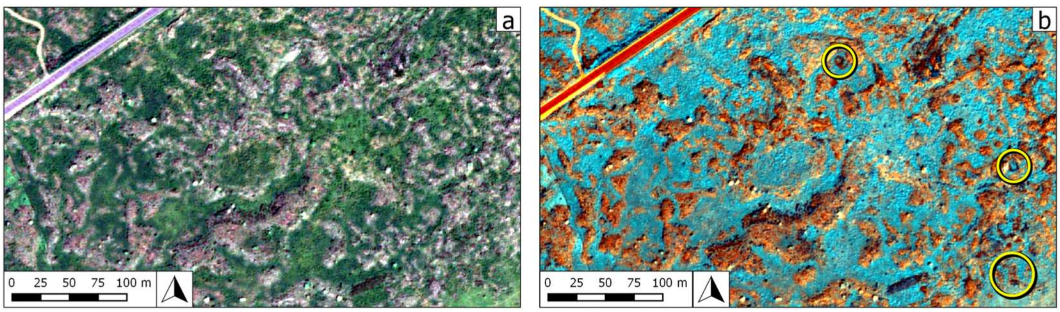

FIGURE 4 RGB composite with bands B5, B3 and B2 (a) and our combinations of spectral bands (b) of the Worldview-2 image. The archeological features detected are highlighted in the yellow circles [Colour figure can be viewed at wileyonlinelibrary.com]

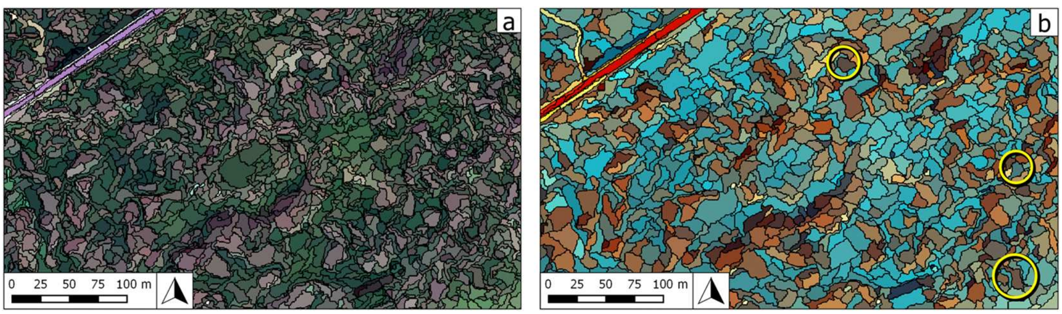

FIGURE 5 Segmentation of the RGB composite (a) and our linear combination of bands (b) of the Worldview-2 image shown in Figure 4a. The archeological features detected are highlighted in the yellow circles [Colour figure can be viewed at wileyonlinelibrary.com]

Even all three algorithms were tested (Figure 3), the one providing the best results for our multispectral images was the Bayesian Data Fusion.

The application of the pansharpening algorithm allowed a noticeable improvement of the image quality in terms of spatial resolution. In particular, starting from the 8-band multispectral image with ground sample distance (GSD) equal to 2 m, we obtained the analogous multispectral image having GSD equal to 0.50 m.

4 | COMBINATIONS OF BANDS TO ENHANCE THE ELEMENTS OF THE TERRITORY

Different works have proved that the optimal values for wavelength that allow recognizing archaeological features range between 700 and 800 nm[4,6]. The wavelengths for each Worldview-2 multispectral band are: B1 (Coastal Blue) [400–450 nm], B2 (Blue) [450–510 nm], B3 (Green) [510–580 nm], B4 (Yellow) [585–625 nm], B5 (Red) [630–690 nm], B6 (Red-Edge) [705–745 nm], B7 (NIR1) [770–895 nm], B8 (NIR2) [860–1040 nm]. Indeed the Worldview-2 closest spectral bands are B6, B7, B8 and the panchromatic [450–800 nm]. However, given the difficult environmental context where the archaeological artefacts are set and the lava stones that characterize the site, these bands used as raster input for the segmentation give a low-quality result (Figure 4a).

We therefore looked for a combination of bands that can give a better emphasis of the archeological features. From empirical studies, and we found the following three linear combinations of spectral bands to enhance the anthropic elements in study area:

- Combination 1: B1 + B2 + B3 + B4 + B5 + B7
- Combination 2: B5 + B6 + B7 + B8
- Combination 3: B4 + B5

From these three band combinations and applying a contrast stretching in the QGIS environment, we obtained a high-quality raster (Figure 4b).

5 | SEGMENTATION AND OBJECT CLASSIFICATION OF THE STUDY AREA

The last step of our procedure was the segmentation of the image generated with the new combination of bands and the subsequent classification.

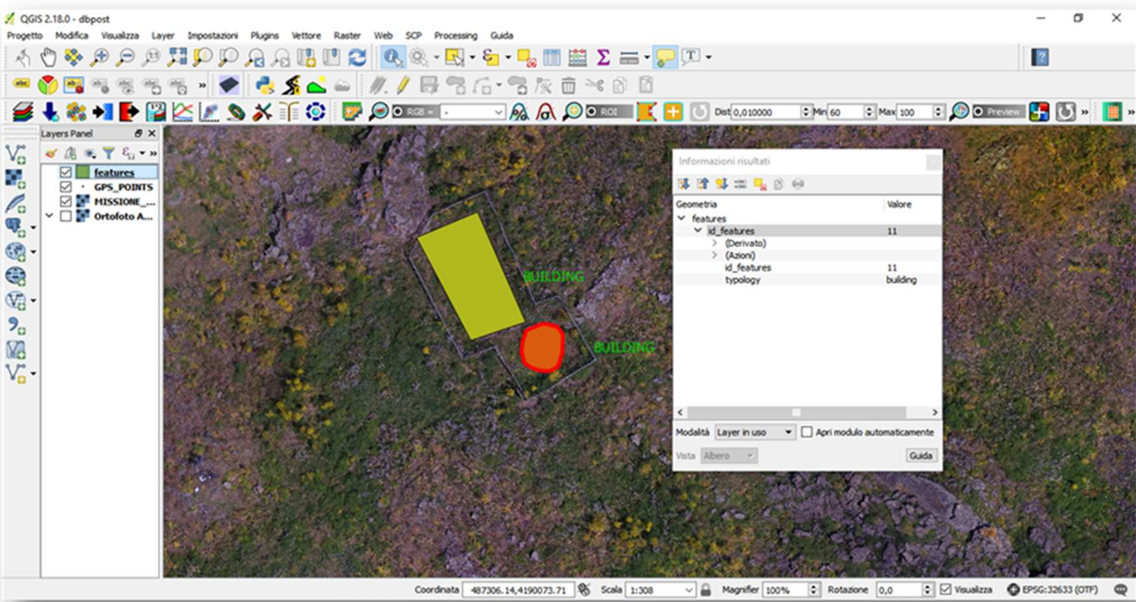

FIGURE 6 Archaeological features digitized in the GIS platform [Colour figure can be viewed at wileyonlinelibrary.com]

For this processing phase, we used the trial version of the eCognition Developed platform (http://www.ecognition.com/suite/ecognition-developer)[11]. In particular, we used the Multi Resolution Segmentation setting the input parameters as follows:

- Scale: 25
- Color/Shape: 0.85
- Smoothness/Compactness: 0.25.

As shown in Figure 5, the segmentation obtained using the bands B6, B7 and B8 (Figure 5a) is undoubtedly less performing than the one obtained using our new combination of bands (Figure 5b). Indeed, our combination allows to better distinguish the elements present in the area, such as the road at the top left of image.

In order to manage the archaeological artifacts in the GIS platform, a relational database was created using an external Data Base management system, i.e. the postgreSQL platform with the PostGis extension[12] .The database is characterized by three entities and two relationships. Finally, the archaeological artifacts detected on the basis of the relational data structure were digitized in the GIS platform (Figure 6).

6 | CONCLUSIONS

The aim of this work is to determine linear combinations of bands from multispectral satellite images for the segmentation and classification of archaeological features.

Our results obtained in the archeological area in the north-western part of Etna volcano provide evidence to the best combinations of bands founding to generate a raster support for the segmentation and classification of archaeological features. The procedure we proposed is particularly useful in sites where the construction material of the archaeological structures are confused with the characteristics of the territory.

Obviously, the use of pansherpering has improved the result of the processing related to segmentation and classification thanks to the improved input image compared to the image acquired by the satellite.

Furthermore, the GIS environment has been proven to be an excellent technology to computerize the features obtained from the classification in order to have a real geo-referenced distribution of the territory and insert the relative information that includes the features found.

Future work will include the improvement of results by implementing and testing new algorithms for the segmentation and classifications, such as neural networks and fuzzy logic.

7 | CONCLUSIONS

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