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Fusion and integration of heterogeneous close range remote sensing and geophysical data. The case of *Grumentum.*

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Abstract. This paper deals with the integration and fusion of UAV-based imagery, including Vis-NIR multispectral and infrared thermography data, with georadar and geomagnetic prospecting, applied on Grumentum, pre-Roman and Roman city, with an important phase dated to Late Antiquity, of the ancient Lucania, in Basilicata region. The data were processed individually and then integrated with each other in order to recover as much information as possible from the different signals. Due to the qualitative and quantitative approaches to the integration and fusion of the diverse data sets and features, it was possible to detect some urban blocks (insulae) reasonably referable to the Roman age, although obviously not datable, and other features spatially linked to the late antique/early medieval church. Grumentum's experience shows considerable potential as well as limits in the use of the image fusion-based approach for the enhancement of archaeological features, from which emerges the need to continue experimenting these approaches on a greater number of case studies.

1. Introduction

Human activity modifies the landscape through the building of monuments, the construction of cities, villages, roads, and hydraulic infrastructures which, after their abandonment, are over time reabsorbed by nature, and buried within variable thickness layers of soil.

The remains of this human activity of archaeological interest, modify the physical, chemical, and topographical characteristics of the soil, which can be detected in a non-invasive way by using active and passive sensors mounted on aerial, terrestrial (geophysics) and satellite platforms [1, 2].

These technologies, using appropriate data processing methods, enable to recognize proxy indicators of archaeological interest, thus facilitating the identification of buried walls, buildings, settlements.

These proxy indicators are linked to more or less intense spatial variations in moisture content, vegetation growth, magnetic field, soil nutrients, topographic surface, soil stratigraphy that can be identified by one or more prospecting techniques, with different results in terms of resolution of results, depending on the depth of the remains and the characteristics of the sensors .

Therefore, the most effective approach is based on the combination and integration of different remote sensing and geophysical techniques.

The heterogeneity of the measured parameters makes it necessary to use adequate tools for integrating and fusing the acquired data and the results obtained from the single techniques of prospecting and remote sensing, in order to extract information of archaeological interest (even automatically) taking full advantage of the rich and varied amount of data available.

To this aim it is necessary to devise ad hoc methods to be validated on case studies of which it is possible to know the characteristics of the expected archaeological features.

This paper deals with the integration and fusion of UAV-based imagery, including VNIR multispectral and infrared thermography data, with georadar and geomagnetic prospecting, applied on Grumentum, pre-Roman and Roman city, with an important phase dated to Late Antiquity, of the ancient Lucania, in Basilicata region [3].

The ancient city positioned in a raised area and defended on all four sides by slopes derived from the action of two rivers. The urban layout, dating back to the foundation of the third century BC, has an oval shape, articulated on three main parallel streets, the major (decumanus maximus) and the two lateral, intersected at right angles by cardines. The city was surrounded by walls with six gates, on a perimeter of about 3 km and occupied an area of about 25 hectares, of which only a tenth has been brought to light by archaeologists. Grumentum has been continuously frequented from the Republican age to the early Middle Ages as attested by transformation activities of the ancient topography, with archaeological layers dated back from VI th to VIIIth-IX th c. A.C. and by Christian buildings: S. Marco, S. Laverio and S. Maria Assunta [4,5].

The church of S. Maria Assunta has been recently investigated in the framework of the Project Chora-Archaeological Laboratories in Basilicata, under the direction of Francesca Sogliani, with the authorization of the SABAP, Ministry of Culture (DG-ABAP del MIC, n. 1011 del 20/09/2021). In the research area of the church, within the Project Chora, CNR performed the above-said investigations, based on the integration of geophysics and close-range remote sensing.

In 2006 Grumentum was object of some geophysical tests (georadar and geomagnetic) east of the Forum which made it possible to recognize a decuman with an approximately north-south axis, along whose eastern side a dozen almost modular quadrangular buildings are aligned [6].

New archaeological issues, matured in the context of the Chora Project, and regarding the north-eastern end of the urban fabric, near the aforementioned church of S. Maria Assunta, have suggested the need to carry out non-invasive investigations based on the integration of geophysical prospecting techniques (geomagnetic and georadar) and UAS-based imaging techniques (multispectral and thermal infrared).

The scope of the research project is twofold: i) scientific and methodological: that is to evaluate the effectiveness of an approach based on the integration of passive and active sensors in highlighting proxy indicators of archaeological interest; ii) archaeological: that is, exploring the subsoil of an area of interface between the Imperial Roman and early medieval phases.

2. Material and Methods

Acquisitions at the Grumentum site were carried out using different types of close-range remote sensing instrumentation and tools: (i) a DJI Matrice 210 Unmanned Aerial Vehicle (UAV) equipped with a Sentera AGX710 12-megapixel 5-band (blue, green, red, red-edge, and near-infrared) multispectral camera, a 20-megapixel RGB X5S camera, and a FLIR XT2 high-resolution (640x480) thermal imaging camera; (ii) Hi Mod georadar (IDS) consisting of a control unit and a dual 200-600MHz antenna, a Panasonic Computer; (iii) differential magnetometer Bartington-Grad601.

Drone acquisitions were carried out in several flights. The acquired images were then processed within the Agisoft Metashape software in order to create orthophotomosaics in the visible wavelengths (X5S), in separate bands from blue to near infrared (Sentera AGX710), and in thermal infrared (XT2) [7–12].

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The orthophotomosaics produced by the multispectral camera were also spectrally enhanced by producing different indices (mathematical operations between bands) to improve the visibility of any proxy indicators and archaeological features.

The processing and interpretation phase of the georadar data is mainly based on the identification of reflectors, the calculation of their position in depth and their size. The processing phase was very complex and involved several steps: (i) removal of the average trace; (ii) amplitude normalisation (declipping); (iii) migration; and (iv) low-pass filtering [13–17].

The magnetometric method consists of measuring the intensity of the earth's magnetic field and then analysing its variations or anomalies. By analyzing these anomalies in the soil layers closest to the surface, it is possible to identify the presence of buried archaeological features. The gradiometric survey was carried out according to pre-set grids (40 m per side) and profiles at 1 m [18–20].

The data set was processed and subsequently loaded within a GIS platform. The data were evaluated individually and as a whole, trying to gain as much information as possible from each piece of data (fig. 1).

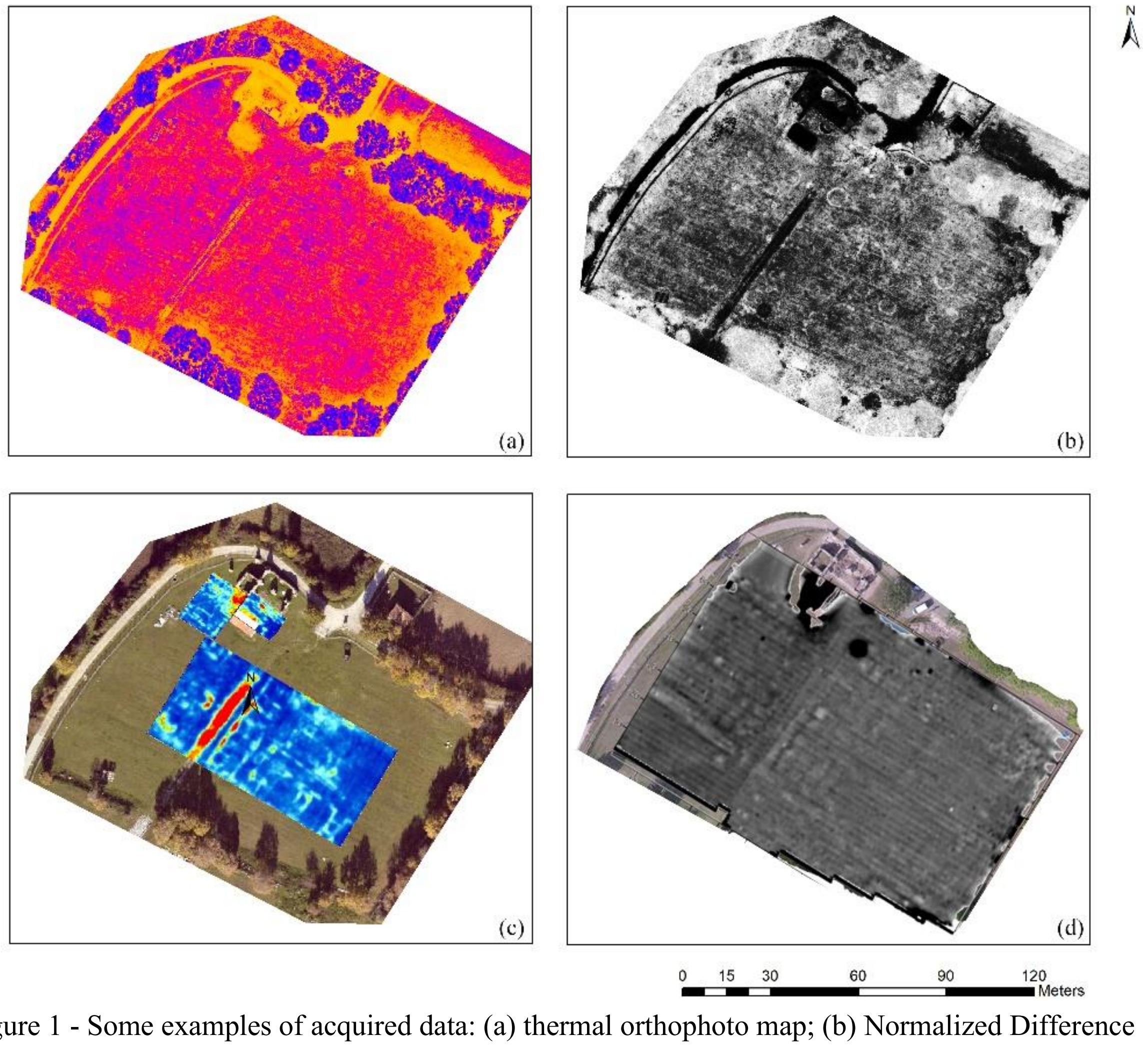

Figure 1 - Some examples of acquired data: (a) thermal orthophoto map; (b) Normalized Difference Vegetation Index (NDVI); (c) georadar (GPR) maps; (d) magnetic map.

3. Results and conclusion

From the analysis of the results obtained, several surface anomalies emerge. First of all, the most evident feature is connected to the pre-existing outcropping road that presents a SSW-NNE direction, in fact in a perpendicular direction it is evident the presence of a thistle that crosses the road in a W-

NW E-SE direction. In addition, secondary structures are present in the quadrants to the east and west of the macaw divided by the pre-existing road. These secondary anomalies identify reticulated surface structures, probably attributable to a regular construction pattern. These anomalies are found especially from the remains of the church to the previously mentioned hidden thistle.

The extreme magnetic response, and good response from thermal, multispectral analysis, in the investigated area, is a symptom of the superficial nature of buried structures.

These data are also confirmed by the analysis of the georadar maps and radargrams (fig. 2).

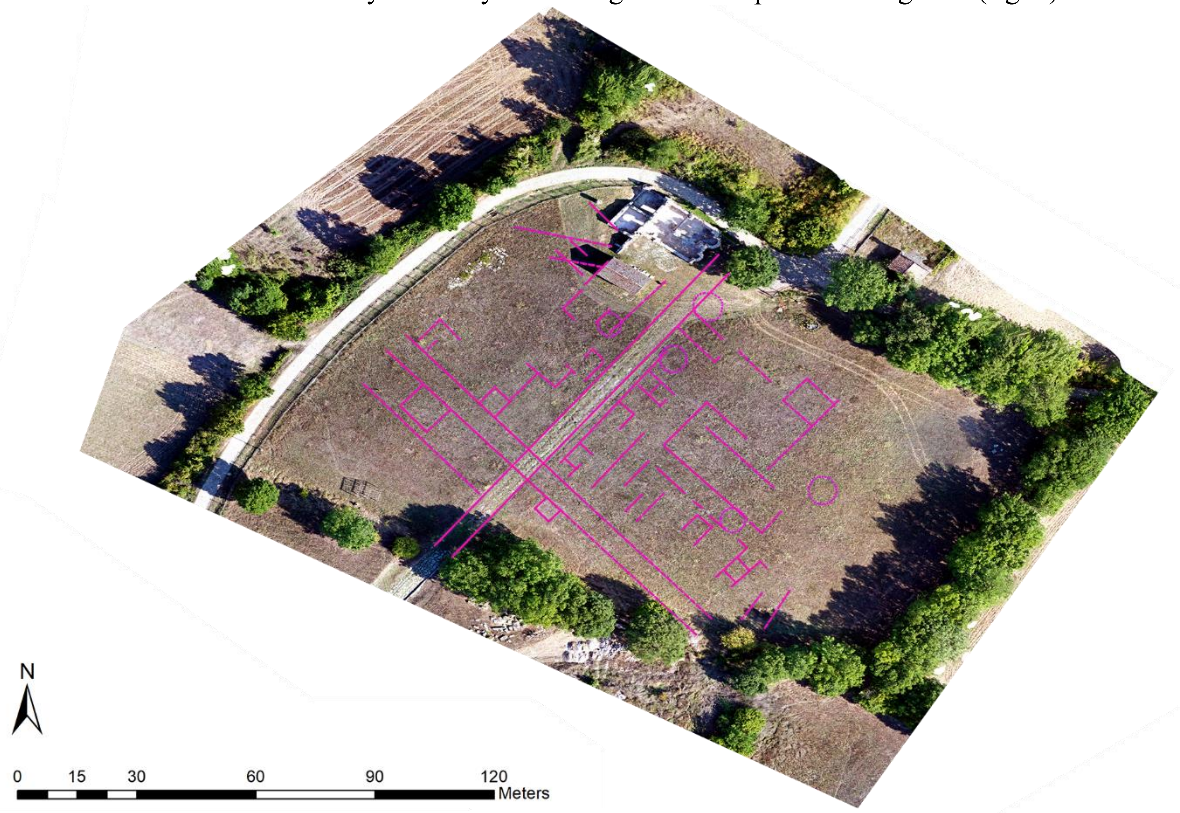

Figure 2 - Summary map of identified archaeological features.

Due to the qualitative and quantitative approaches to the integration and fusion of the diverse data sets and features, it was possible to detect some urban blocks (insulae) reasonably referable to the Roman age, although obviously not datable, and other features spatially linked to the late antique/early medieval church. Grumentum's experience shows considerable potential as well as limits in the use of the image fusion based approach for the enhancement of archaeological features, from which emerges the need to continue experimenting these approaches on a greater number of case studies.

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