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Integrated use of aerial and ground-based close-range remote sensing techniques to support preventive archaeology: the case study of Ascoli Satriano (FG)

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***Abstract* – The present work aims to show the multi-sensor close-range remote sensing (RS) activities carried out in the municipality of Ascoli Satriano (FG; Apulia). The site is of great significance as it has been continuously occupied from the 8th century B.C. to the present day. The site is famous for the discovery of marble griffins dated to the 4th century B.C., probably inside a princely tomb. The study was conducted using a multispectral drone and a ground magnetometer. The results of the RS analysis showed a complex scenario, with features of buried remains related to roads, paleo-channel, and, above all, circular structures of considerable size. The latter, as confirmed by the targeted excavations conducted following the RS acquisitions, are referable to monumental *tumuli*. The integration of several sensors has made it possible to overcome the limits of single instrument observation and to provide useful data for practical preventive archaeological work.**

I. INTRODUCTION

The presence of structures of archaeological interest changes the physical, chemical and topographical characteristics of the soil. These can be detected non-invasively using active and passive sensors mounted on aerial, ground (geophysical), and satellite platforms. These technologies, through the use of appropriate data processing methods, make it possible to recognise indirect indicators of archaeological interest. These indirect indicators are linked to more or less intense spatial variations in moisture content, vegetation growth, magnetic field, and soil topography. In archaeology, such evidence is often referred to as proxy indicators of archaeological presence [1–7].

Since indicator proxies are the result of phenomena that the presence of buried remains produces in the vegetation, in the soil, or on the signal of certain instruments, the most effective approach as shown in the literature on the subject is to combine and integrate different remote sensing (RS) approaches and to work, if possible, with multiscale and multi-temporal approaches [8–13].

The present work aims to illustrate the results obtained within the framework of the operational agreement of scientific collaboration between the Soprintendenza Archeologia Belle Arti e Paesaggio of the Provinces of Barletta-Andria-Trani and Foggia and the Consiglio Nazionale delle Ricerche, Istituto di Scienze per il Patrimonio Culturale (CNR - ISPC) (DG ABAP 33245 of 20.12.2018 and consequent decree rep. 293 of 11.04.2019; prot. 10930 of 30.12.2019 prot. CNR/ISPC no. 25 of 07/01/2020). The work is the combined result of the use of various sensors from (i) UAS (Unmanned Aerial System) and (ii) on the ground, used between 2020 and 2021 in the area of archaeological interest of Ascoli Satriano (Apulia) near the area where the famous marble griffins were reported (figure 1).

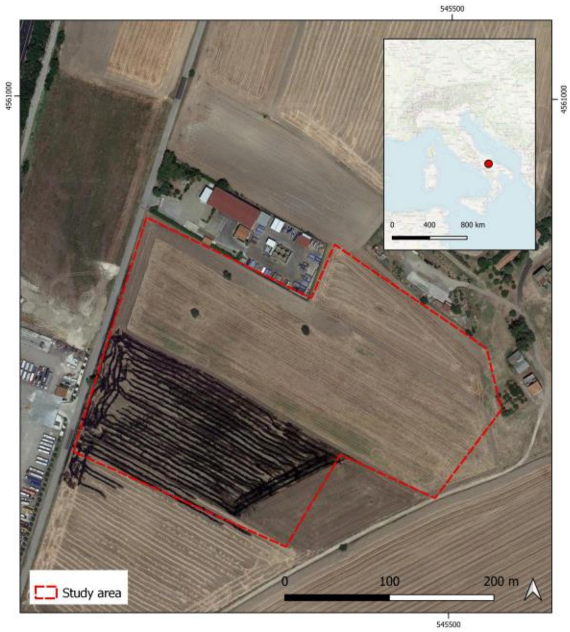

Fig. 1. Study area.

The area of Ascoli Satriano is of great interest to archaeologists.

Ascoli Satriano is located south-west of the city of Foggia, 410 m above sea level, in the Tavoliere delle Apulia, on a rise formed by three hills of the Dauno Sub-Apennine, at the foot of which flows the Carapelle, and which extends further south to divide the Carapelle valley from the valley of the Ofanto. From a geological point of view, the territory is characterised by Miocene deposits, on which are found the more recent Quaternary formations of a continental environment. The soil is composed by clays, pebbles, sands, and limestones [14].

The ancient Daunian center of Ascoli Satriano developed from the IX cent. BC on a series of hills (San Rocco, Pompei, Cimitero vechio, Serpente and Mezzana La Terra) along the valley of the Carapelle river. Most of these localities were archaeological excavated from the sixties and showed the typical Daunian settlement pattern with scattered nuclei with living areas and necropolises, these often located in close proximity to the dwellings. Archaeology has made it possible to reconstruct a landscape consisting of human settlements and burials, organized according to a criterion of 'widespread occupation' over an area of approximately 80 hectares. The burial areas were adjacent to residential areas with spaces left free for agriculture and animal husbandry. In particular a cult complex dated to the V sec. BC was investigated on the Serpente hill, closely related to the already known cemetery area. Most probably the Serpente hill was the reference point for local communities between the 5th and 4th century BC and was the seat of the houses of the aristocracy of that time.

In the territory of Ascoli Satriano, the clash between Pyrrhus, king of Epirus, and the Romans led by the consuls *Publius Decius Mure* and *Publius Sulpicius Saverriore* took place in 279 BC. during the war between Rome and Taranto (280-275 BC). Having definitively come under the influence of Rome, Ascoli did not lose the right to mint bronze coins in its name. During the Second Punic War (218-201 BC), which culminated in the Battle of Cannae, the city held firm in its alliance with Rome against Hannibal. Little is known about the city at the height of the Roman Age, both in terms of urban planning and institutions. An epigraph walled under the actual modern Clock Arch attests to the *duoviri Caius Statius* and *Quintus Castrius* and the tribe to which the municipality was inscribed, the Papiria, as *Aecae* and *Herdonia*. The city had a total area of 15 hectares.

In addition, Ascoli Satriano still preserves (i) traces of centuriazione related to the agrimensoria reorganisation of the Graccan era, and (ii) traces of the via Herdonitana. Both of these elements were identified through the use of aerial photographs. To date, Ascoli Satriano is famous for the discovery of the so-called marble griffins, currently housed in the city museum. The griffins date back to the 4th century BC and belonged to a Daunian princely tomb. The griffins were found between 1976 and 1977 through clandestine excavations [15].

II. MATERIALS AND METHODS

The study was conducted using several Close Range Remote Sensing techniques: (i) surveys from UAS with a multispectral camera; (ii) magnetometer (MAG) surveys; (iii) photogrammetric surveys with UAS. Surveys for points (i-ii) were conducted between September 2020 and November 2020, and survey (iii) in July 2021. In the latter case, the surveys were carried out after archaeological excavations had been conducted on some of the evidence revealed during the multispectral UAS and MAG surveys. The three survey campaigns were conducted in order to provide information to support the archaeological research before and after the excavation activities that were carried out between June and July 2021. In particular, campaigns (i) and (ii) were aimed at characterising the subsurface in order to assess the archaeological interest and, in particular, identify traces referable to buried cultural presences, with a view to carrying out the excavation campaign. While, the other investigation campaign (iii) was conducted in order to correlate the archaeological evidence of the excavation with the results of the geophysical surveys in order to assess the future prospects for archaeological research at the site.

The UAS multispectral camera survey was carried out using a DJI Phantom 4 Multispectral RTK drone. This drone allows images to be acquired in the blue (450 nm ± 16 nm), green (560 nm ± 16 nm), red (650 nm ± 16 nm), red-edge (730 nm ± 16 nm), and near-infrared (840 nm ± 26 nm) spectra. In the context of archaeological investigation, surveys with multispectral cameras, both satellite and drone, allow the identification of proxy indicators of archaeological presence such as crop-marks and soil-marks [9,16–22]. The acquisition was conducted with a nadiral camera and in automatic flight mode. The data thus acquired were subsequently processed using the Pix4D mapper software. This software makes it possible to obtain orthophotomosaics in the visible spectrum, as well as in the different bands.

In order to improve the visibility of indicators of archaeological presence, vegetation indices were produced, i.e. a mathematical combination of the individual bands (e.g. NDVI) [23–28].

Magnetic measurements were acquired with a Geometrics G-858 cesium vapour magnetometer. The magnetometric methodology is based on the measurement of variations in the earth's magnetic field (CMT) or its gradient, generated by phenomena of induced or remanent magnetism due to the presence of objects with different magnetic properties and placed underground. To summarise, anomalies due to induced magnetism are caused by secondary magnetisation phenomena in ferrous bodies. Due to the speed of investigation, the non-invasiveness of operations and its high sensitivity, the magnetometric method is the most widely used in archaeological research of a preventive nature. The survey carried out with the gradiometric configuration, which is used here, also makes it possible to operate independently of temporal variations in the earth's magnetic field and interference due to human activity [29–32].

The last drone acquisition was instead conducted using a drone with a camera in the visible spectrum, only to document by means of three-dimensional photogrammetry the results of the archaeological excavations conducted as a result of the preliminary analyses mentioned above.

III. RESULTS

The results obtained at the site made it possible to identify some interesting anomalies presumably associated with large-scale archaeological structures (e.g. roads, ditches, paths). Furthermore, the reflectance maps, as well as the vegetation indices, and magnetic maps are characterised by anomalies that can be associated with less extensive, but no less interesting structures.

In particular, figure 2 shows the results of analyses conducted with a magnetometer (a) and a multispectral drone (b). The magnetometric analysis (figure 2, a) revealed the presence of anthropogenic traces (e.g. roads and canals) that are characterised as linear and sub-linear features (light blue and red dotted lines and red arrows in figure 2, a). In addition, circular traces are present, shown in figure 2 (a, b) with the letters A1-A5. The magnetometric analysis also revealed an abundance of small sub-circular evidence (light blue arrows in figure 2, a). Similar evidence was also found in the multispectral maps obtained by UAS (Figure 2, b).

The circular features, clearly visible in the magnetic maps and multispectral data, on the other hand, are referable to structures (e.g. large circular tombs in figure 2, a-d). Confirming the findings of the close-range remote sensing investigations, the excavation conducted after the analyses revealed a large circular tomb structure (figure 2, c, d), which was subsequently surveyed using three-dimensional photogrammetry. Similar anomalies are also found in other areas investigated in at least three locations and may have been generated by similar, but presumably smaller structures.

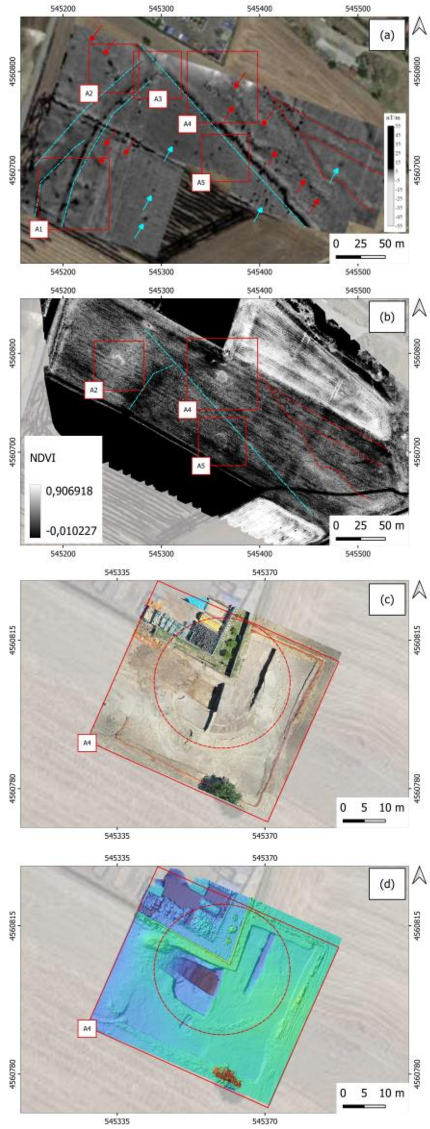

Fig. 2. (a) magnetic map; (b) NDVI (Normalized Difference Vegetation Index) from UAS; (c) orthophoto of the excavated (A4) area where the monumental tomb was found; (d)Digital Elevation Model of the excavated (A4) area where the monumental tomb was found.

IV. CONCLUSIONS

The integrated multisensor approach with aerial (multispectral drone) and ground-based (MAG) technologies enabled the identification of several features of archaeological interest. In particular, as highlighted by the maps produced, the nature of the anomalies greatly facilitates the interpretation of the results, i.e.: (i) large linear features pertaining to roads; (ii) irregular linear features such as paleo-channel or rills; (iii) circular structures (tombs). If for the large circular features it is possible to give a fairly certain characterisation, thanks to the excavation conducted and reported in the orthophoto in figure 2 (c), the anomalies of smaller size and circular, sub-circular, and sub-polygonal shape still remain to be clearly interpreted and defined. The present study has once again demonstrated how an integrated, non-invasive, and expeditious approach can be of fundamental importance and aid to preventive archaeological work as it provides information on the type of features that can be expected during archaeological excavation. Using such technologies it is in fact possible to establish in advance where to operate, saving time, money, and land consumption, as well as hypothetically reconstructing an archaeological scenario without necessarily excavating it in its entirety, but confirming hypotheses and ideas with targeted excavation tests.

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