Miniaturized electro-optical sensors for archaeological prospecting

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ABSTRACT

Advanced technologies, such as coring, geophysical methods, and remote sensing, are successfully applied to subsurface prospecting. In particular, modern electro-optical sensors are sturdy enough to meet the requirements of an archaeological survey. In the framework of the project ARCHEO, funded by the Italian Ministry for Universities and Scientific and Technological Research, we have developed GEOSCOPE, an innovative instrument equipped with miniaturized electro-optical sensors for archaeological prospecting. GEOSCOPE consists of a coring machine and a probe: the coring machine bores the soil while recording the drilling parameters, the probe performs visual inspections and data acquisitions in the hole. A user-friendly computer interface allows the archaeologist to acquire, record, and display measurements and images.

Keywords: archaeological prospecting, visual inspection, electro-optical sensors.

1. INTRODUCTION

In the last decades, archaeological prospecting has been revolutionized by the introduction of new techniques\textsuperscript{1}. The usefulness of aerial photography for the detection of buried structures has been recognized in the years following World War One. After World War Two, geophysical methods – at first used in mining research – have been applied to archaeology. In particular, ground penetrating radar (GPR) has been introduced in the seventies.

Among the modern procedures used for archaeological prospecting\textsuperscript{2}, we can mention coring (often followed by probe insertion in the hole), geophysical methods (seismic sounding, gravimetry, resistivity method, magnetometry, metal detector, GPR) and remote sensing (aerial photography, thermocamera, satellite remote sensing).

Such procedures offer many advantages:
- they are fast and non destructive;
- they allow one to investigate sites where excavations are not possible (areas under historical buildings);
- they indicate the excavation priorities;
- they provide a comprehensive view of the zone within days or weeks (the excavations could require decades to reach the same result).

Often, a site exploration needs the application of more than one procedure. A typical operative sequence could be outlined as follows: at first satellite remote sensing and image photointerpretation are executed, in order to locate the interesting zone (low resolution, large scale); then, aerial reconnaissance of that zone is effected (medium resolution, medium scale); finally, core samples are extracted from remarkable points (high resolution, small scale).

In the framework of the development of new techniques for archaeological prospecting, MURST (Italian Ministry for Universities and Scientific and Technological Research) entrusted CORISTA (Consortium for Research on Advanced Remote Sensing Systems) with the three-year project ARCHEO (Advanced Devices and Techniques for Detection and Recovery of Archaeological Zones)\textsuperscript{3}. ARCHEO is subdivided in three research lines:
1. development of airborne and ground GPRs for archaeological surveys;
2. realization of a Mobile Unit equipped with hardware and software tools for data acquisition and recording before, during and after excavations;
3. development of a knowledge-based system to assist design, execution, and maintenance of excavations in difficult conditions (e.g. urban areas).

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The Mobile Unit includes five subsystems. OMERO is a software able to guide the archaeologist in the choice of the more appropriate technique in the search for buried remains. SIRIA is a system conceived for the positioning and the photographic recording of finds. GEOSCOPE — object of this paper — consists of a coring machine and a probe: the coring machine bores the soil while recording the drilling parameters, the probe performs visual inspections and data acquisitions in the hole. GEOLIDAR is a laser range-finder conceived for the volumetric characterization of buried cavities by motor driven three-dimensional scan. SIAI is a database for the cataloguing of the information acquired and processed by the other subsystems.

![Diagram of coring machine and probe]

**Fig. 1.** GEOSCOPE scheme. The coring machine and the probe are equipped with sensors. The rack contains computer and electronics.

### 2. GEOSCOPE

According to the needs of the archaeologists and the suggestions of the experts in soil mechanics, we decided to improve the traditional coring reducing the drilling diameter and conceiving an innovative instrument. In fact GEOSCOPE, besides extracting the core samples, has been designed to visually inspect the bored holes and possible underground cavities while providing information useful for the determination of the ground stratification and the evaluation of the preservation state of the buried remains. All the data are accurately georeferenced, also thanks to the devices of SIRIA: global positioning system (GPS), high-resolution digital camera, and total station. Once circumscribed the archaeological site by airborne GPR and located an interesting point by ground GPR, the coring machine (fig. 2) executes a non-invasive drilling. In case the soil tends to collapse, a transparent tube can be installed before extracting the auger in order to support the hole. An inclinometer indicates the bit angle and three sensors measure, with accuracy of 0.5%, penetration, draught-push and torque pressures. A data logger records on a movable board the drilling parameters (advancing speed, time taken to cross 1 cm, and draught-push and torque pressures) as a function of the penetration. A special device reads the data recorded on the movable board and transfers them to the computer through RS232 interface.
The graph of fig. 3 gives an idea of the information on the ground stratification retrievable from the drilling parameters. The coring has been started cautiously (moderate pressures) in the superficial zone of low consistency. Near 0.2 m the pressures have been increased, without obtaining a corresponding augmentation of the speed due to a more compact layer. As soon as 0.5 m have been exceeded, a particularly soft layer has been encountered: this is highlighted by the speed peak and the decrease of the pressures (a similar phenomenon happens also at about 3.75, 5.75, and 9.5 m). Around 3.1 m an increment of the speed has been obtained thanks to the augmentation of the torque pressure. The fairly high pressures and the low speed before 4.5 m indicate a layer harder than the average. Nevertheless, the more demanding zone lies between 8.25 and 8.75 m: the speed remains limited notwithstanding the pressures are maximum. The operator attributed this resistance to a chert layer because the fragments coming from that region were of this rock. Similarly, the archaeologist, on the basis of the graph of the drilling parameters, can draw some conclusions on presence and location of anthropic structures (walls, floors, and roads) without examining the core sample or visually inspecting the hole.

compass and inclinometers
hygrometer and thermometers
led
camera

displacement transducer

Fig. 2. The coring machine in the SAT limestone quarry (Guardiagrele CH, Italy).

Fig. 3. Graph of the drilling parameters as a function of the penetration (Guardiagrele CH, Italy, 24/06/1999). Black thick line: draught-push pressure [bar]. Grey thick line: torque pressure [bar]. Black thin line: advancing speed [dam/h]. Grey thin line: time taken to cross 1 cm [s].

Fig. 4. The probe. The lid, where the diverging lenses and the protective window are fastened, has been removed.
Fig. 5. Example of display of the data acquired by the probe. The profiles as a function of the penetration are shown on the top right. Moving the cursor the operator gets images (left) and values (bottom right) corresponding to any point of the hole.

<table>
<thead>
<tr>
<th>element</th>
<th>parameter</th>
<th>value</th>
</tr>
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<tbody>
<tr>
<td>coring machine</td>
<td>maximum torque</td>
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<tr>
<td></td>
<td>maximum draught-push</td>
<td>2000 kg</td>
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<tr>
<td></td>
<td>hole maximum length</td>
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<td></td>
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<td>camera</td>
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<td></td>
<td>f number</td>
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</tr>
<tr>
<td></td>
<td>depth of field</td>
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<td></td>
<td>field of view (diagonal)</td>
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</tr>
<tr>
<td></td>
<td>number of pixels</td>
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<tr>
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<td>thermometer (Pt100)</td>
<td>accuracy</td>
<td>0.5 K</td>
</tr>
<tr>
<td>thermometer (infra)</td>
<td>accuracy</td>
<td>2 K</td>
</tr>
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<td>accuracy</td>
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<tr>
<td>inclinometers</td>
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</tr>
<tr>
<td>compass</td>
<td>accuracy</td>
<td>2.5°</td>
</tr>
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</table>

Table 1. GEOSCOPE specifications.
Even if the drilling parameters give valuable indications, the visual inspection is irreplaceable for a precise characterization of the buried remains. For this reason, after extraction of the bit, the probe (fig. 4), equipped with a color camera, is inserted in the drilling. The optical axis of the lens is parallel to the hole, but a right-angle mirror can be mounted for side view. The lighting is ensured by twelve white leds arranged in a ring bordering the camera. In front of each led a diverging lens has been placed to spread more uniformly the light.

The measurements of humidity and temperature allow the archaeologist to evaluate the preservation state of the buried remains. For this reason, the probe has been equipped with a hygrometer and two thermometers: the first – based on a P100 resistor – is precise, the second – observing the infrared emission – is fast.

A displacement transducer and two inclinometers guarantee the probe positioning. An electronic compass indicates the camera vision direction in case the right-angle mirror has been mounted.

Fig. 5 is an example of display of the data acquired by the probe. The hole has been simulated with a cardboard tube of the same diameter. A side of the wall has been covered with a grid made of perpendicular lines (thickness: 0.1 mm, spacing: 1 mm). The surface granularity and the impurities of the mixture are clearly perceptible. This demonstrates that very close color tones appear distinct (note that the real case is better because the camera shows the colors). The grid image gives an idea of the fineness of the discernible details. The diverging lenses ensure the lighting of a considerable part of the walls without saturating the camera. The vignetting is due to the mount of a protective window but, thanks to the circular geometry of the observed object, darkens an unimportant fraction of the field of view. Moreover, the tests prove that the transparent tube does not affect at all the vision.

GEOSCOPE specifications are summarized in table 1.

3. CONCLUSIONS

This paper has described GEOSCOPE, an innovative probe developed in the framework of the research project ARCHEO, funded by MURST for the development of new techniques for archaeological prospecting. After having outlined the rationale that guided us in conceiving the aforementioned system, its first measurements have been discussed. In conclusion, GEOSCOPE provides the archaeologist with remarkable amount of accurate measurements, particularly valuable before excavations: ground stratification, humidity and temperature profiles, and visual inspections in non-invasive drillings.

In the near future, GEOSCOPE will be used in an artificial site at CIRA (Italian Aerospace Research Center), specially designed for ARCHEO, and in an important archaeological area (the ancient Roman town of Caesius). In our opinion, the usefulness of GEOSCOPE is not limited to archaeology because it could find interesting applications in many other fields such as geology (territory assessment), civil engineering (structural inspection), and remote sensing in hazardous area (nuclear power plants).

4. ACKNOWLEDGEMENTS

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5. REFERENCES