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Terrestrial laser scanning for 3D archaeological documentation. The prehistoric Cave of Sa Miniera de Santu Josi (Sardinia, Italy)

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Abstract. Caves have a great archaeological importance: they were used as a dwelling, as a shelter of animals, as an occasional refuge both for funerary and religious purposes. A cave survey is the first step towards their exploration. This study describes the San Giorgio cave's survey that is the object of an archaeological research that concerns both the area above it and the underground environments. The cave, located in the north-west of Sardinia, has an extension of about 140 meters and has a maximum depth (surveyed) of -15 meters. Sixty-two TLS scans were carried out producing 1.5 milliard points. The Poisson surface reconstruction algorithm [3] is used to produce the 3D Model. A 3D model in low resolution can be adopted for aims of public archaeology; however archaeologists should take advantage of all the information available in the original point cloud.

1. Introduction

Caves represent an extraordinary and unique geological archive providing information about the climatic and geological evolution of the area. Furthermore, caves have also a great archaeological importance: they were used as a dwelling, as a shelter of animals, as an occasional refuge both for funerary and religious purposes. Since the 19th century the cave has become object of systematic archaeological exploration and scientific research. Sardinia has a very rich archaeological heritage, which includes numerous caves, frequented in prehistoric times. Many of them testify the frequentation of the Usini territory from the Neolithic to the post-medieval ages. Numerous national and international projects have come out with the aim to integrate archaeology, architecture, history, nature and the conservation of the cultural traditions. San Giorgio's cave, known in literature as "Sa Miniera de Santu Jolzi" or "Su Ru" in the regional speleological cadastre, is named by the local population "Sa Miniera de Santu Josi". It is located in the north-western area of the municipal territory of Usini, in the province of Sassari. The University of Sassari is involved in the project, "Usini. Rebuilding the past", that has the aim to study the use that has been made of the cave and its surrounding space during prehistoric times. The archaeological excavation of the external spaces started in 2019. Found materials inside the cave testify that the cave was already used during the third millennium cal. BC (cultural *facies* of Monte Claro). Its morphological characteristics, in particular the long descending and impervious corridor, suggest, at the current state of research, that it was used for funerary purposes [1]. Figure 1 shows the entrance of the cave and a view of the main gallery (Gallery a) and of the principal hall (Hall b). Figure 2 shows the secondary gallery (Gallery c). It has a high slope and very small spaces.

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Figure 1. Entrance of the cave (left), a view of the main gallery a (middle), the main hall b (right).

Figure 2. Gallery c: view (left); set up of a scan station (up right); entrance with very steep surface (bottom right)

A cave survey is the first step towards their exploration. The visual memory of speleologists was for a long time the only knowledge one had about the cavity. Later, several techniques, which evolved in line with technical progress, were established to represent caves: from freehand drawing to theodolite and total station, to photogrammetric applications, up to the use of terrestrial laser scanner (TLS). The TLS has revolutionized the cave's survey offering archaeologists a rich and complete description such as a 3D model of the area [2]. It produces with high precision and accuracy a 3D surface description [3] by means of a dense points cloud. Surface reconstruction from a point cloud is a well-studied problem in computer graphics, but cave reconstructions are very complex because of the high irregularity of the surfaces. Moreover, the better the 3D model fits the reality, the more computational problems arise due to hardware limitations.

2. Material and methods

The present study was possible thanks to the map made available by the Environmental Speleological Group of Sassari [4] which provided the map shown in figure 3. The map was used to obtain a first plan of the survey. The highly irregular surface required an accurate design of the scan stations on the field to avoid lack of data. A Faro Cam2 Focus 3D X130 was used and a total of 62 scans were taken. The survey lasted three working days: figure 3 shows the position of the scans and each colour corresponds at a different survey day. For safety reason the stay in the cave could never last more than 20 minutes and had to be alternated with another 15 minutes outdoors This resulted in stretching of the survey's duration. Moreover, all the movements of the terrestrial laser from one scan station to another and also from inside and outside were very difficult because of the poor lightning and because the very steep surfaces of the galleries were often covered by mud pools. The survey extends to all areas and places where we could enter with the instrumentation and work safely. Despite numerous attempts of using artificial light were done, we decided to work with reflectance value because it allowed a more uniform surface representation (Figure 4). It would have been very complex to reproduce the same illumination condition in every scan station.

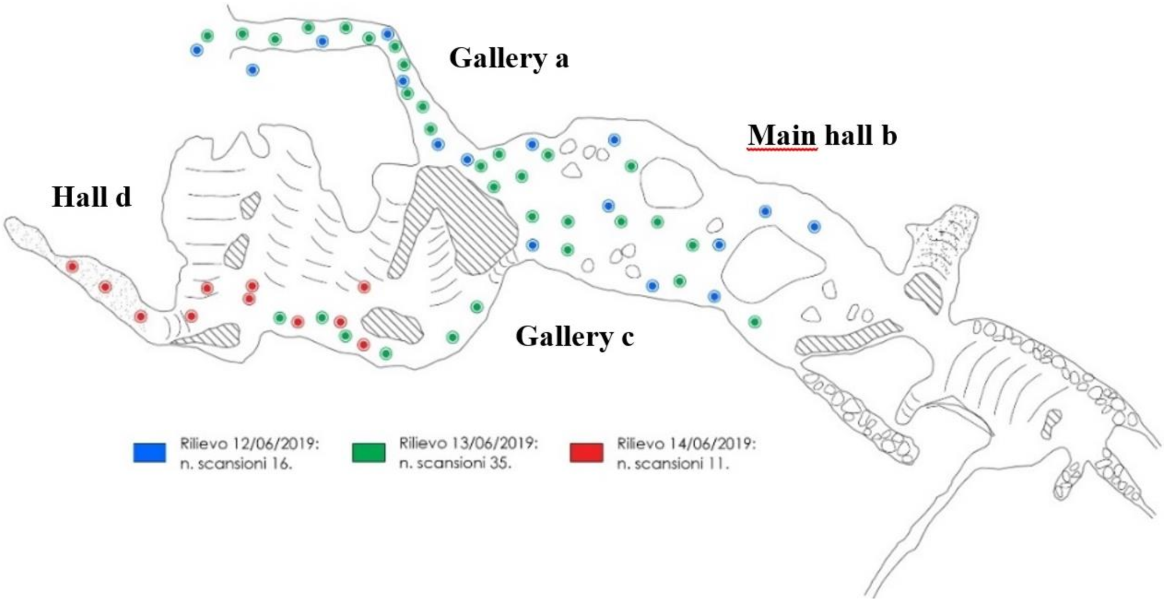

Figure 3. Map produced by Environmental Speleological Group of Sassari [4]. Scan station position on the speleological map: each colour corresponds to a different survey days.

We worked with a resolution of 1/5 and 3x measurements, points density is of 7.67mm/10m obtaining a point cloud of about 1,6 milliards of points. 44 black-white targets were used to align the scans inside the cave.

Figure 4. Equirectangular view of a scan.

The three external scans were georeferenced by means of five Ground Control Point (GCP) measured using a GNSS-RTK survey. Mean residual was 4.7 cm with a maximum value of 7.4cm and a standard deviation of 1.9cm. The TLS point cloud was aligned to a digital surface model produced by a photogrammetric UAV survey. All the scans were aligned using the software Scene of Faro and a mean accuracy of 1.8mm with a maxim error of 4.8mm was achieved (Figure 5).

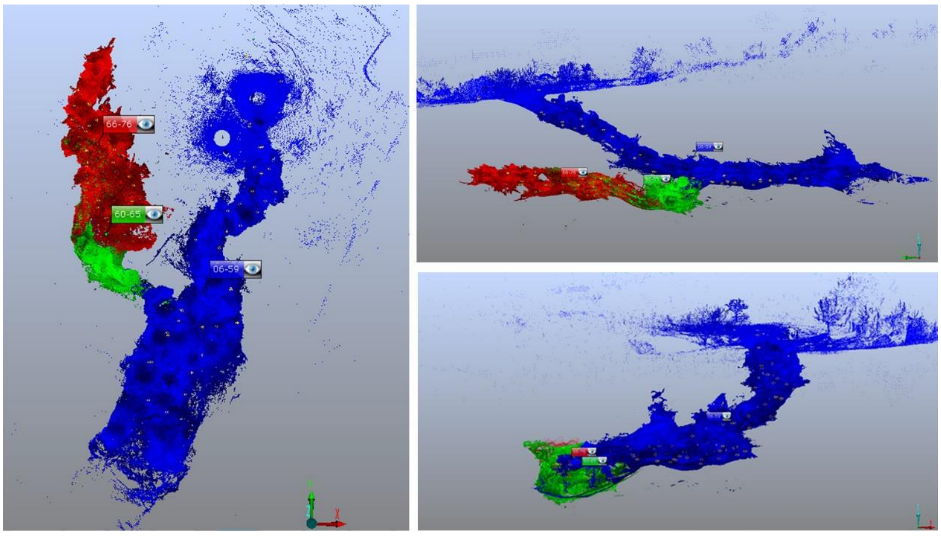

Figure 5. Subdivision in three groups of the whole point cloud. Each colour represents a group.

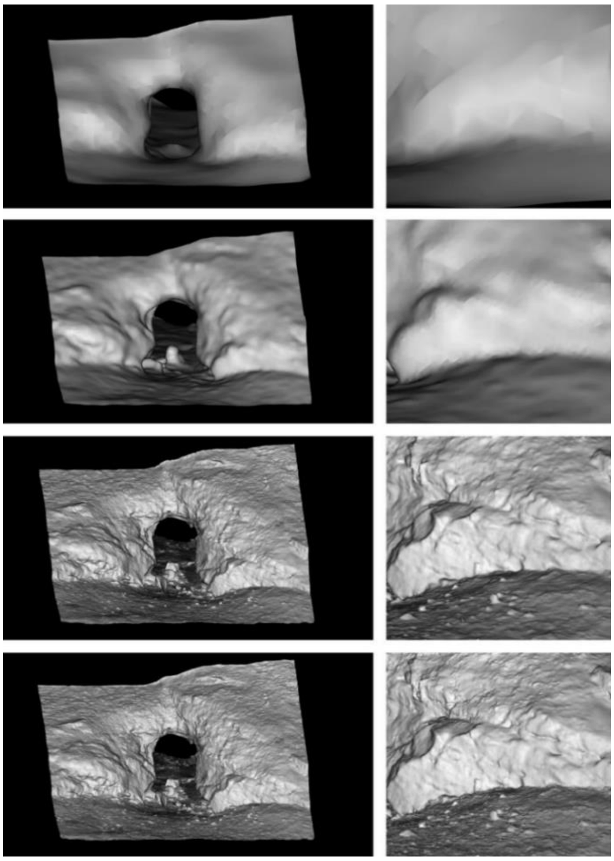

Figure 6. Surface reconstruction of cave entrance. Starting from top the following octree depth were used: 6, 8, 10 and 15. Dirichlet boundary function.

Data management of the aligned, georeferenced points cloud is performed by means of CloudCompare, the open source software which is a valid instrument for point cloud processing [5]. More specifically, we have used the plugin of Poisson surface reconstruction [6][7] to test its application to a complex environment such as a cave. It has a useful density output that allows easily to reduce the extents of the output mesh to fit as much as possible the input point cloud. We have considered the effects of the maximum octree depth on the reconstructed surface. Figure 6 shows the reconstruction results for a portion of the cave (the entrance) at octree depths of 6, 8, 10 and 15. As the tree depth is increased, the reconstructions capture finer detail. Memory and time requirements are roughly quadratic in the resolution. Increasing the octree depth, the running time, the memory overhead, and the number of output triangles increases too.

3. Results

With the available computers, (processor CPU Intel i9-9900K and 64GB di RAM) we were able to process up to a maximum depth of the tree that will be used for surface reconstruction equal to 15. The points cloud was processed separately, dividing the cave in four parts. A surface reconstruction of the whole cave was achieved using Dirichlet boundary.

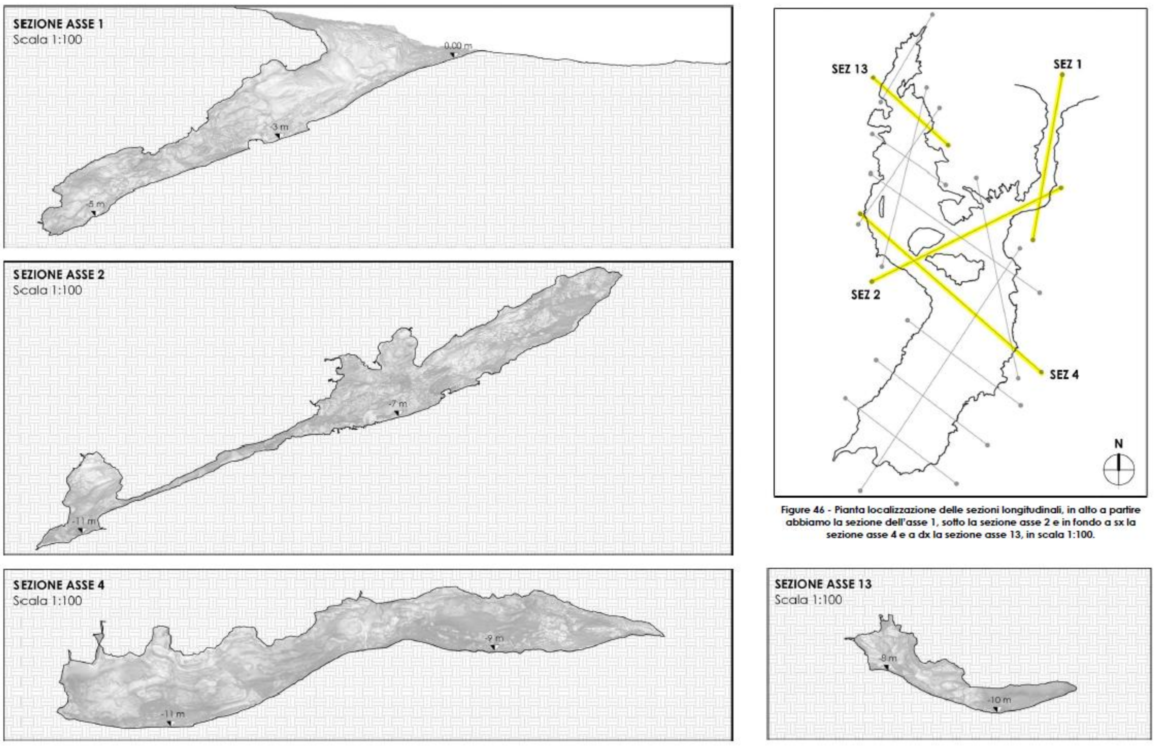

Figure 7. Sections according to the cave alignment. Top left: map with the axes of the section. Bottom left and right: the four corresponding sections.

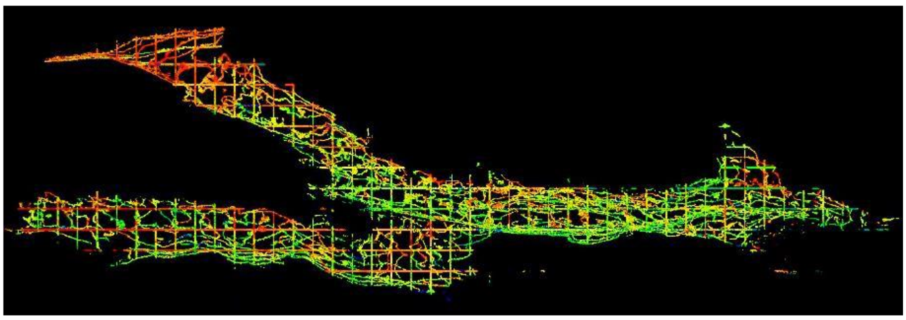

Figure 8. Sections provided along the three axes: easting, northing and elevation, at a distance of 5 meters.

A video was framed for advertising purposes. It is clear that even with higher octree depth, the 3D model reduces details of the cave. For archeologist it is important to take advantage of all the information that a TLS survey can give. The 3D point cloud gives the opportunities to reproduce all the required plans and sections in a more flexible way then by mean of traditional techniques. Figure 7 shows the section along the principal directions of the cave according to what the archeologist required. Figure 8 shows all the sections produced at a distance of 5 meters along all three axes (easting, northing, elevation). These results want to be the input for future research in which the management of a 3D underground GIS will be analyzed and which allow a direct access to the original point cloud to select just smaller segments of 25square meters. This will give archaeologists an instrument for a faster and easier way to access to the original point cloud.

4. Conclusion

The survey of San Giorgio Cave in Usini is part of a larger research project which involves several aspects with the purpose of reconstructing the environmental and socio-economic framework of the prehistoric communities that frequented the territory. It also aims to deepen the knowledge of the cultural heritage in order to promote and valorise it. Regarding the survey of caves, we can state that TLS is a very important tool. The irregularity of all the surfaces and the total lack of illumination makes it the most appropriate instrument. Its main disadvantage was the dimension which limited its use in reduced space. A future development will be dedicated to its integration with portable scanner 3D carried out by a drone in all the space not accessible for human.

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