Assessing the accuracy of 3D GPR results by comparing them to 3D laser scanner models: the case study of the archaeological site of Peluda Cave (Sierra de Atapuerca, Burgos, Spain).

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Introduction

The Sierra de Atapuerca sites are located in a hill near the town of Burgos (North of Spain). The area known as *Trinchera* consists of various caves filled with sediments that were sectioned by a XIXth Century railroad trench (image 4). This trench unveiled numerous archaeo-palaeoanthropological sites that have been studied for decades providing outstanding fossil remains (Bermúdez de Castro *et al.*, 1997; Carbonell *et al.*, 2008; Ortega *et al.*, 2014).

Peluda Cave is a subhorizontal karst conduit whose principal passage runs transversal to the direction of the railroad trench (images 1 and 2). As the ceiling of the cave can be found only 2 m below the flat surface of the trench, we have often used this site for testing the response of different geophysical techniques (Bermejo *et al.*, 2017; Ortega *et al.*, 2010).

The aim of this work is to compare the 3D model of the Peluda Cave (generated by a laser scanner) with the one created from a Ground Penetrating Radar (GPR) survey made over the cave, in order to assess the accuracy of the latter.

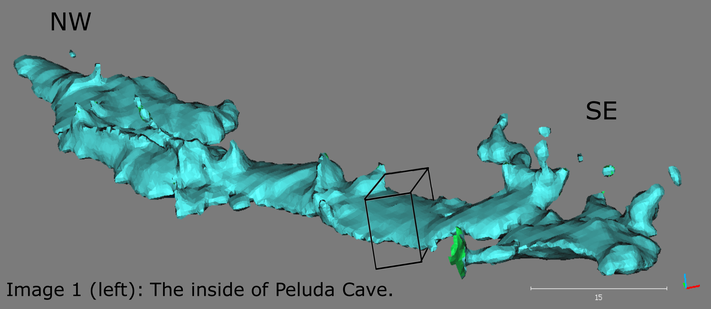

Image 1 (left): The inside of Peluda Cave.

Image 2 (right): Peluda Cave scanned model. The black box corresponds to the GPR surveyed area.

Laser scanner

We used a terrestrial laser scanner Faro Focus X330 to scan Peluda Cave (image 2). We carried out 93 scans at medium resolution (7-12 mm at 10 m), which were registered using the cloud-to-cloud method (mean error= 4 mm). The final point cloud was georeferenced using a GNSS LEICA GS15 and three b/w targets placed in the entrance of the cave. Georrerencing error was 13 mm. Finally, we used the 3DReshaper software to cut the portion of 3D model that corresponds to the GPR survey (image 5).

For these works we used the equipments of the laboratory of Digital Mapping and 3D Analysis (CENIEH).

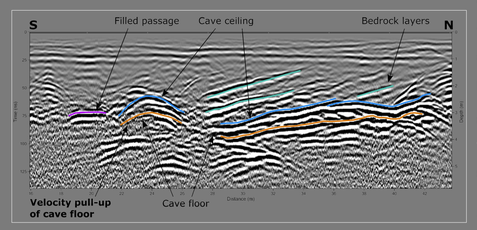

Image 3: GPR profile made over Peluda Cave.

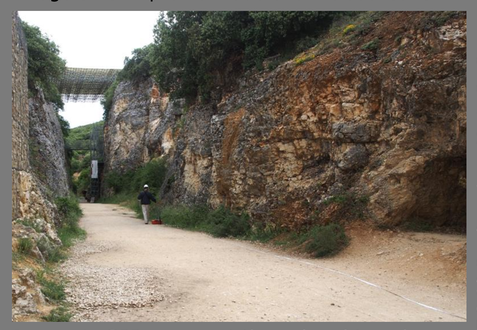

Image 4: GPR survey at the railroad trench.

GPR

We used 270 MHz antennas and a SIR-3000 system to create a 9 profile GPR grid over the part of Peluda Cave that crosses under the railroad trench (images 4).

GPR profiles show that the contrast between the void space of the cave and both the ceiling and the floor of the cave, generate high amplitude reflections (image3). However, the lower ones appear "pulled up" because the air in the void has increased the velocity of the radar wave, recording them earlier in time (Conyers, 2012).

To generate the 3D model of the GPR survey we first used the GPR-Process software to make horizontal slices of the profiles, choosing only the time window that corresponds to the cave (image 3). Then, we plotted these amplitude maps in the Surfer software and extracted this information in 2D images. Finally, we used the ImageJ software to create a 3D model from these images (image 6).

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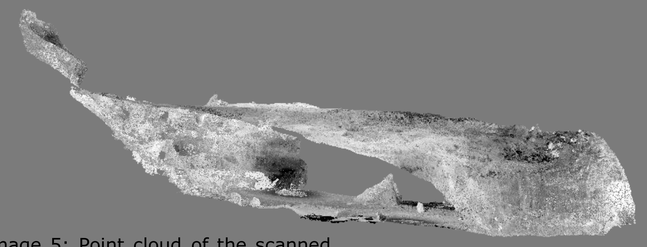

Image 5: Point cloud of the scanned model section of Peluda Cave.

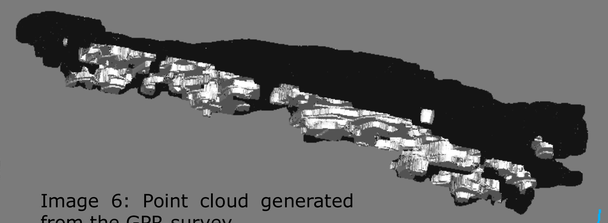

Image 6: Point cloud generated from the GPR survey.

Comparing models

We used the Cloud-Compare software to align the point clouds of the two 3D models according to their coordinates (images 5, 6 and 7) and to compare them. The results are shown in a logarithmic scale of colors that represent the absolute distance between clouds (images 8 and 9).

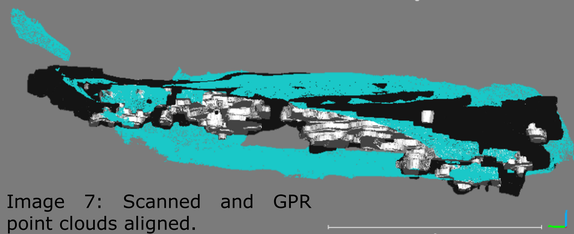

Image 7: Scanned and GPR point clouds aligned.

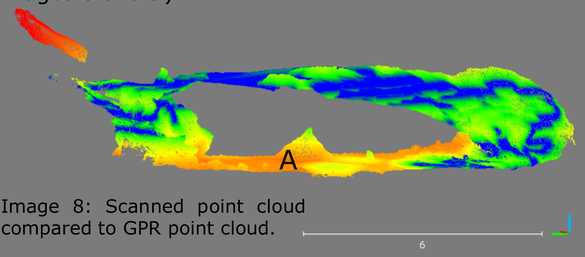

Image 8: Scanned point cloud compared to GPR point cloud.

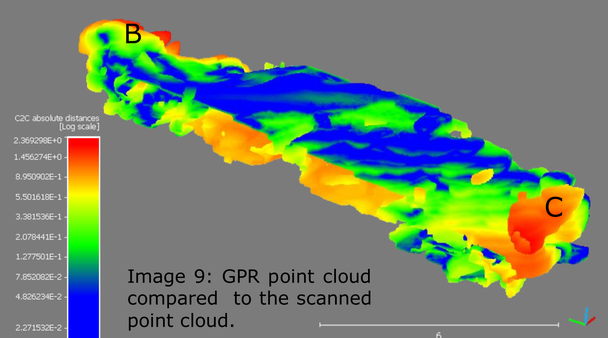

Image 9: GPR point cloud compared to the scanned point cloud.

Results and discussion

The results show many coincidences in the length and surface of the ceiling of the cave.

However, three major points of difference can be found:

A: In the deepest part of the cave, the GPR model results to be smaller than the scanned one (images 7 and 8) because of the aforementioned velocity pull up (image 3).In the shallower part of the cave, instead, both models match.

B: There is an area in the GPR model, located to the east of Peluda's main passage (image 9), which is missing in the scanned model. This could correspond to a void space or a chimney of the cave, inaccessible at present. Some small conduits visible in this side of the cave wall could support this theory.

C: There are some high amplitude reflections overlaying the scanned model (image 9) that could correspond to one of the multiple chimneys present in the cave but maybe unreachable to the laser scanner.

Conclusion

We can conclude that the GPR results are reliable, as there are many similarities between the GPR and the scanned models. In fact, the main differences are due to the velocity pull up of the radar wave or to the limitations of the laser scanner.

Moreover, the Cloud-Compare software has revealed itself to be a useful and visual tool to analyze GPR results.

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