3D rock thickness extraction by combining Point Clouds of different origin. Case Study: The roof of Koutouki Cave Peania, Greece

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The purpose of this research is to combine two state-of-the-art technologies in surveying for extracting the rock thickness above a cavity. By combining Lidar technology for indoor surveying and photogrammetric processing of Unmanned Aerial Systems (UAS – drones) data, we managed to calculate and project with high accuracy the rock thickness of the roof of the underground environment of Koutouki Cave (Peania, Greece).

Usually, cave systems are complex and unique because of their distinctive geometry and compound geomorphology along with natural harsh conditions such as constrained accessibility, limited light, high humidity and possible existence of water. Such environments make mapping difficult and further complicated (Kershaw, 2012). Nowadays, the state-of-the-art in surveying of open surface is based on LiDAR technology. Lately, similar technology has started to be used for indoor surveying and consequently in cave mapping, especially where the underground space allows it.

Our research was based on the use of a recently released piece of equipment introducing a lightweight mobile handheld laser scanning system (GeoSLAM ZEB – REVO) that has the ability to produce a quite dense point cloud within an underground cavity. The x, y, z point cloud is generated while the operator walks through the cave (Zlot and Bosse, 2014). The specifications of this equipment include a 360° rotation, a (class 1 eye safe) 100Hz laser – making 100 rotations per second with the collection of 43,200 points per second. The maximum effective range is around 25-30m for indoor environment and data over 30m are usually excluded.

Scanning the Cave

The testing was held at "Koutouki" cave which is situated on the north – eastern side of Hymittos mountain in Athens and stretches at an altitude of 510m, within the Jurassic thick bedded marbles of Attica Geotectonic Unit (Lekkas and Lozios, 2000). It is the biggest and most popular show cave of Attica (*37°56,8'N, 23°49,7'E*).

Wearing a backpack and holding the Zeb - Revo device the scanning process of Koutouki Cave was established in less than 25 minutes, following the main corridor – touristic route. Even in narrow spaces outside the main route where larger systems require a survey tripod, the mobile device was still effective. The entire cave contains many geomorphological features such as speleothems which are included in the scan. The technical entrance, as well as the outdoor space in the surrounding area were also scanned, requisite for the later geo-referencing procedure. The physical entrance of the cave is a 38m cavern where the range of the handheld laser scanner (maximum indoor range 30m) can't reach. The final point cloud contained more than 80 million of points representing the entire show cave, including the shaded areas and chambers, which are not visible or able to be visited by any guest walking on the visitor's aisle.

Open Surface surveying with UAS

The open to the air surface of the area of interest was extracted with the implementation of a rotor-wing UAS during the field surveys. It was used to collect high-resolution natural colour images with its built-in camera (with 3.61 mm focal length) bundled on a two-axis gimbal.

The UAS platform is equipped with a Geodetic Navigation Satellite System (GNSS) antenna which provides quite good precision especially for the horizontal positions of which may be used for the alignment of the images captured during the survey (Fonstad *et al.*, 2013). Despite this we used 8 ground control points (GCPs) the coordinates of which were measured with high precision equipment (Real Time Kinematics GNSS) for maximizing the accuracy of the products, since the main objective was the combination of these outcomes with the previously mentioned under surface point clouds (Fugazza *et al.*, 2018). The flight was programmed at an average flight elevation of 120 m and a total of 36 aerial photographs were acquired for the photogrammetric processing afterwards, based on the Structure-from-Motion photogrammetric methodology (Westoby *et al.*, 2012; Granshaw, 2018).

Processing and Results

After the collection of the data we had to geo-reference the point clouds, in order to transform the registered point clouds from their local coordinate system to the Hellenic Geodetic Reference System (GGRS'87) (Mugnier, 2002). The reliability of the methodology is accomplished by measuring the geodetic coordinates of at least three non-collinear signalized markers outside the cavity system using Global Navigation Satellite Systems (Galley et al., 2015). The post processing of the data follows the registration and point cloud geo-referencing. The initial step in the post processing is to generate a triangular 3D – mesh by using the CloudCompare v2.10.2 software (Girardeau-Montaut, 2011) (Figure 1).

Both point clouds of the cave and the open surface above the cave were processed to produce several Digital Surface Models (DSMs) in order to make quantification analysis of the terrain by using a GIS platform. The point cloud data of

Koutouki cave were partitioned into the ceiling (roof), including the stalactites and the floor (ground), including the stalagmites and columns of the cave. In addition, the point cloud was filtered by erasing the noise, including the points generated by the human presence, the technical entrance of the cave, the commercial route containing the stairs, the railings and the concrete, along with noise generated by the equipment.

Once the point cloud was cleaned, both ground and ceiling points clouds were used to create two separate DSMs with spatial analysis of 0.05m using the natural neighbor triangulation method. Additionally, after the photogrammetric processing of the aerial photographs we created a dense 3D point cloud which led to a Digital Surface Model (DSM) with spatial analysis of 0.06 m.

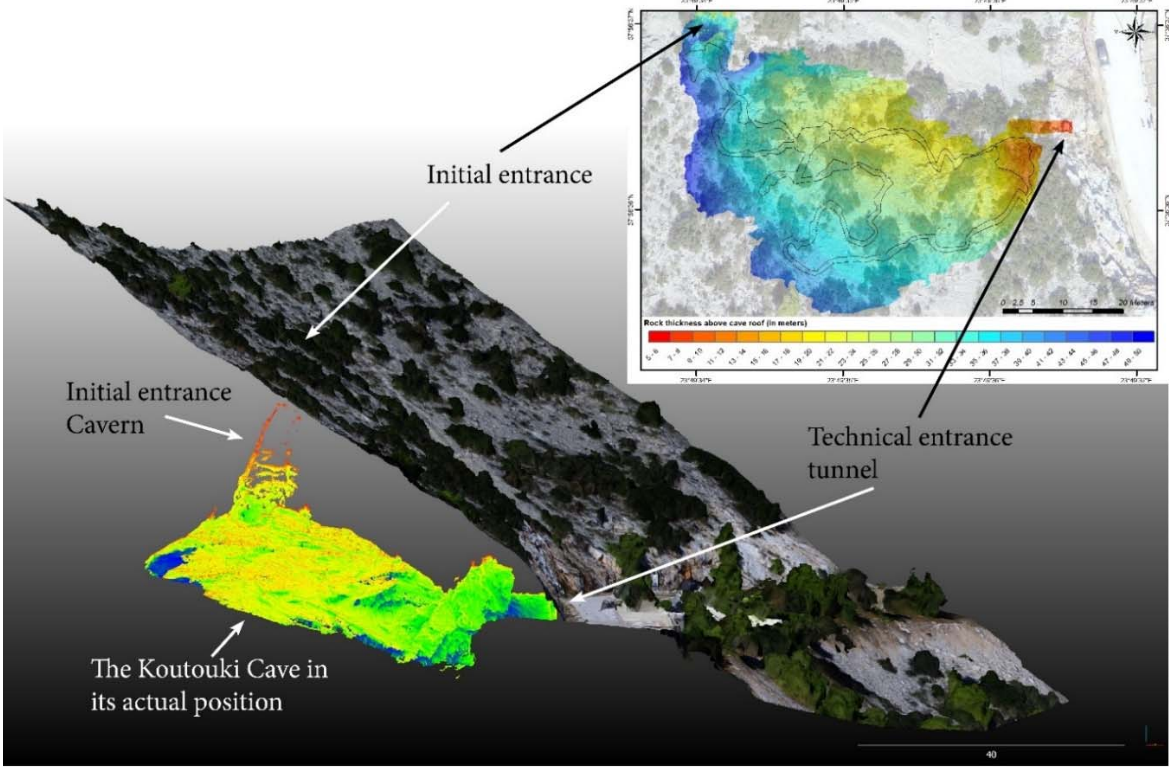

Figure 1. 3D visualization of the combined data of the underground triangular mesh of Koutouki Cave and the open-to-the-air surface relief. The inset is a map view of the cave showing the rock thickness distribution above the cave roof.

The information that was derived by the DSMs is sufficient to proceed to the generation of the rock thickness above the roof of Koutouki Cave by using GIS map algebra and subtracting the DSM of the ceiling from the open surface DSM. The result of this procedure led to the calculation of the rock thickness above the roof of Koutouki Cave with very high accuracy and resolution, which varies from 5.38 m (at the technical entrance, to the east) to 48.57 m (at the westernmost parts of the cave) with a mean rock thickness of 30 m.

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