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# Handheld Mobile Laser Scanners Zeb-1 and Zeb-Revo to map an underground quarry and its above-ground surroundings

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Underground quarries are typically difficult environments for 3D mapping. They are dark, wet, dusty, have limited lines of sight and are full of hidden corners behind pillars. These properties call for a dense succession of active measurement (using some kind of light) stations with hardened materials. Once mapped, the next obvious question creeps up, how does this cavity relate to the above-ground world? The Zebedee range of handheld mobile laser scanner was designed to address just these questions by CSIRO. We have tested a Zebedee-1 (Zeb-1) and a Zebedee-Revo (Zeb-Revo) in an abandoned underground quarry. The initial purpose of the work was to assess the equipment in mapping a sector of a quarry and its above-ground surroundings. In a second phase, we examined how the full 3D dataset was to be processed to retrieve pertinent metrics for geotechnical purposes.

The investigated site is located in the abandoned limestone quarry at Saint-Maximin (Oise, Northern France), where INERIS, within the framework of the R&D part of the “Plan National Cavités”, french program dedicated to cavity risk assessment, managed by the French Ministry in charge of Environment, created an underground experiment and demonstration unit. This laboratory site is dedicated to investigate underground cavity risks and operated in collaboration with Saint-Maximin town council, owners, and the “Maison de la Pierre”, manager of the site.

The Zebedee range of handheld mobile laser scanners exists as Zeb-1 and the recent Zeb-Revo. Both are time-of-flight line scanning lidar bundled with an inertial mapping unit so as to locate the moving lidar head in space and time. The scanning plane freely oscillates on a spring (Zeb-1) or rotates around a horizontal axis in order to scan a sphere portion surrounding the holder. A 90° blind zone enables the holder to hide behind the scanning head and avoid being scanned inside the scene. The lidar distance meter has a nominal range of precision of 5mm + 1mm/m with a maximum range of 30m. Scanning density is 40 lines per second for Zeb-1 and 100 lines per second for Zeb-Revo. Both line scanners cover three quarters of a circle line made of 42,000 shots. A 3-axes accelerometer measures the attitude of the scanning head. Black-box simultaneous location and mapping algorithm (SLAM) build 3D cloud from these measurements assuming that the surfaces where points rebound off are rigid and non-deformable. Near-neighbor point redundancy is used to make points converge towards a unique surface. Processed outputs include 3D points in LAZ format, various decimated cloud versions and 3D Zeb head trajectory.

Surveys are established as 15 to 20 minutes hikes walking nearly at normal pace (~ 2-3km/h) looping back to the original starting point. Here, we walked four loops of 1000m to 1500m to survey 0.8ha of underground galleries and 1.8ha of above-ground streets. Sufficient overlap between loops should be achieved to register loops together. One of the loops had too little overlap with the others, hence a loss of 0.45ha of underground area impossible to tie to the rest of the survey.

Zebedee systems produce 3D point clouds with only 4 degrees of freedom (scale and horizontal are established –XYZ coordinates relative to a local origin and initial bearing to north are unknown), compared to the 6-degrees-of-freedoms of Terrestrial Laser Scanners (TLS, where scale is known) or 7-degrees-of-freedom Structure from Motion surveys (no rotation, translation or scale known).

Were Zeb surveys any good? Point precision was assessed using two perfectly planar surfaces ca. 30m<sup>2</sup> each. These reference planes were advertisement posters fixed on the *Maison de la Pierre* façade and made of tarpaulin held in tension on metal frames. Precision estimates correspond to point-to-plane deviation and come to ± 25.5 mm and 32.2 mm respectively (Q66% of residuals) for a Zeb-Revo trajectory comprised between 0.5m and 10m away from the planes (Table 1).

Table 1 : Zeb-REVO point precision assessment on two planar surfaces. Point precision is the deviation with respect to the best-fitting plane.

	Nb pts [-]	Length [m]	Width [m]	Surface [m <sup>2</sup> ]	Point density [pts/m <sup>2</sup> ]			Point spacing [mm/pts]			Point precision	
					Q2.5%	Q50%	Q97.5%	Q2.5%	Q50%	Q97.5%	1- $\sigma$ [mm]	Q17-Q83 [mm]
Surface 1	113 512	8.34	3.46	28.85	3 300	13 350	19 271	17.4	8.7	7.2	28.6	25.5
Surface 2	57 259	9.12	3.22	29.37	1 953	5 501	11 165	22.6	13.5	9.5	35.5	32.2

Above ground, median point spacing was respectively 8.7mm and 13.5mm on the modelled reference planes. Under ground, point density in 3-m-high galleries reached median point spacing of 1 point every 15mm. (Table 1). This degree of surface description is amazingly dense and fast compared to current compass/rangefinder cavity surveys.

As is standard with TLS, post-processing of raw 3D clouds involves registering individual loops together into a complete survey, and cleaning up stray points. Loop registration is today rather difficult because the scanner's own relative coordinate origin and initial azimuth are unknown. Given these two unknowns, visual recognition of common gallery sections are far more challenging than matching sequential TLS "bubble" clouds where the same problem also exists. Once coarsely matched, however, cloud to cloud fine alignment can be performed just as well.

Raw Zeb clouds do contain parasite points, often because the operator's body was scanned when it happened to come out of the lidar's blind corner. These points float in midair. Cleaning them can rely on distance between the point cloud and the Zeb head's 3D trajectory and on local point density estimates.

Once together, new information can be teased out of the 3D cloud. Most geotechnically relevant information however require the point cloud to bear some semantics: floor, walls and ceilings, underground and above ground points, pillars versus surrounding chamber walls. Segmentation can be performed with tools such as CloudCompare combined with its plugin FACETS (Dewez et al, 2016). Floor and ceilings can be segmented as being above or below the Zeb trajectory, while walls and floor/ceiling can be isolated using their normal with the interactive stereogram tool of the plugin FACETS.

At St Maximin, galleries are generally sound. In one specific location however, a gallery roof is known to collapse occasionally. At present, the roof is at 10.05 m at the highest above gallery floor, while there is only 9.35 m of over-lying terrain.

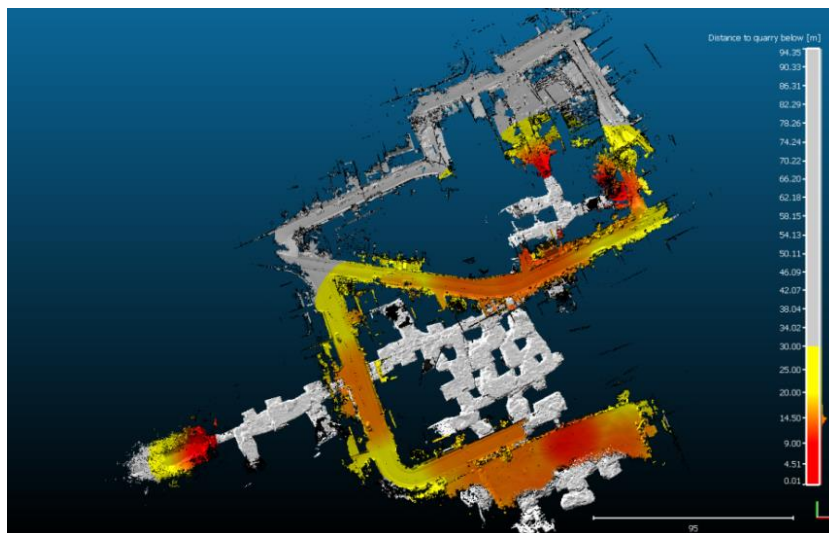


Figure 1 : Map view of 1.8 ha of above ground streets (in warm tones) and 0.8 ha of underground galleries (light gray) of the St Maximin building stone quarry (Oise, Northern France) mapped with a Zebedee Revo in March 2016. Colours depict the distance to the nearest gallery points.

## References

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