Outdoor and indoor mapping of a mining site by indoor mobile mapping and geo referenced Ground Control Scans

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Key words: underground mapping, SLAM, TLS, iMMS

SUMMARY

The paper describes the surveying methodologies implemented to carry out a survey of an underground mine, in its indoor and outdoor components. The external part of the mine, localized in a valley in North Italy, is subject to several collapses which are affecting some houses built near the mine. A global three-dimensional survey was therefore necessary to connect the underground internal part of the mine to the external part, and to carry out a geotechnical and geological study of the global site behavior. Indoor Mobile mapping SLAM based technology has been chosen as the most appropriate technology to survey the underground section of the mining site. In fact the iMMS technology guarantees the required accuracy of 3-4 cm, with the required timing. Unfortunately the disused mine was difficult to access, because the two main entrances have been closed with ground to avoid illegal entrances; the dimension of the entrances have made impossible to realize a classic topographic network with total station, to measure control points inside the mine and to connect the outside environment to the indoor one. The only way found to connect the three-dimensional model of the indoor part of the mine, measured with iMMS, with the outside one, was to apply the innovative approach of using Ground Control Scans (GCS). Several static scans have been taken so to assure an outside/inside connection and the static scans acquired in the open air part of the two mine entrances, have been geo-referenced thanks to control points measured with total station connected to vertices measured with GNSS in RTK. In this way the 3D model acquired by iMMS have been connected with external part of the mine. The use of GCSs is possible inside the SLAM (Weingarten, J, and Siegwart, R., 2005) post processing software, before the generation of the final point cloud model. The use of GCSs it is also useful to correct the drift effects often present in the SLAM approach. Altimetric drifts, in the part of the underground mine farthest from its entrances, have been reduced thanks to the transport of the external environment to the internal share of the mine, thanks to an inspection hole realized for inspection purposes. The experience shows an interesting integration between different surveying technologies.

RIASSUNTO

L'articolo descrive le metodologie di rilevamento messe in atto per effettuare il rilievo di una miniera sotterranea, nelle sue componenti indoor e outdoor. La parte esterna della miniera, localizzata in una vallata del Nord Italia, è soggetta a numerosi crolli che stanno interessando alcune abitazioni costruite nei pressi della miniera. Si è reso quindi necessario un rilievo

tridimensionale globale per collegare la parte interna sotterranea della miniera con la parte esterna, e per effettuare uno studio geotecnico e geologico del comportamento globale del sito. La tecnologia basata su SLAM è stata scelta come la tecnologia più appropriata per rilevare la sezione sotterranea del sito minerario. Infatti la tecnologia iMMS garantisce la precisione richiesta di 3-4 cm, con la tempistica richiesta. Purtroppo l'accesso alla miniera dismessa era di difficile accesso, perché i due ingressi principali sono stati chiusi con terreno per evitare ingressi abusivi; le dimensioni degli ingressi hanno reso impossibile realizzare una classica rete topografica con stazione totale, misurare punti di controllo all'interno della miniera e collegare l'ambiente esterno a quello interno. L'unico modo trovato per collegare il modello tridimensionale della parte interna della miniera, misurata con iMMS, con quella esterna, è stato quello di applicare l'approccio innovativo dell'utilizzo di Ground Control Scans (GCS). Sono state effettuate diverse scansioni statiche in modo da assicurare un collegamento esterno/interno e le scansioni statiche acquisite nella parte a cielo aperto dei due ingressi minerari, sono state georeferenziate grazie a punti di controllo misurati con stazione totale collegata a vertici misurati con GNSS in RTK. In questo modo il modello 3D acquisito da iMMS è stato collegato alla parte esterna della miniera. L'utilizzo dei GCS è possibile all'interno del software di post-elaborazione SLAM, prima della generazione del modello finale della nuvola di punti. L'utilizzo dei GCS è utile anche per correggere gli effetti di deriva spesso presenti nell'approccio SLAM. Le derive altimetriche, nella parte della miniera sotterranea più lontana dai suoi ingressi, sono state ridotte grazie al trasporto dell'ambiente esterno nella quota interna della miniera, grazie ad un foro di ispezione realizzato a scopo ispettivo. L'esperienza mostra un'interessante integrazione tra diverse tecnologie di rilevamento.

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1. INTRODUCTION

We have seen in the last decades, a fast introduction of innovative technologies in the geomatics sector. The transition from the theodolite to the total station, with the introduction of phase shift or TOF EDMs; the use in the surveying field of the Global Positioning techniques followed by the use of LiDAR scanning tools, later integrated with Mobile Mapping approaches whose use has recently been extended to indoor environments thanks to the introduction of SLAM algorithms; the development of the Photogrammetric approach, that rapidly have been moving from analog to digital with the ever increasing automation of automatic algorithms for the three-dimensional reconstruction of reality. These examples show how innovation has deeply touch the world of geomatic technologies. It should be also considered that compared to the numerous engineering technologies, in which innovations often completely or consistently replace consolidated technologies, in geomatics we are witnessing a process whereby consolidated technologies undergo innovation processes, but are rarely completely removed. Therefore the current surveyor must be able to properly manage numerous technologies, from the consolidated ones (as levels, total stations,…) to the last one, as iMMS, UAVs and more. For these reason it is becoming complex to correctly plan a surveying activity; in fact to provide the best solution to run the surveying campaign, it is often required a deep knowledge of several surveying technologies that must be used and integrated to obtain the most successful result.
It should also be noted that survey activities that were impossible to carry out in the past, often due to an unsustainable cost-benefit ratio, are obviously currently achievable thanks to the use of innovative instruments and their correct integration with the consolidated procedures. Innovative technologies are having a particular impact in the methods and techniques of detection in the underground mining sector, where the 3D surveying approach using LiDAR technologies, although strongly desired, has always found problems due to operational difficulties and measuring time that the static TLS approach imply. Since the introduction of innovative mobile mapping LiDAR based devices, based on SLAM data processing algorithms, the 3D underground mapping has started to be sustainable. However, the problems of operational efficiency of this approach, in particular for georefering the 3D models and to control the geometrical drifts are present.

1. THE CASE STUDY

The case study consists of a dismissed underground lime mine located (Figure 1) in an Italian Alpine valley, with an underground development organized on four levels, for and extension of the several hundreds of meters.

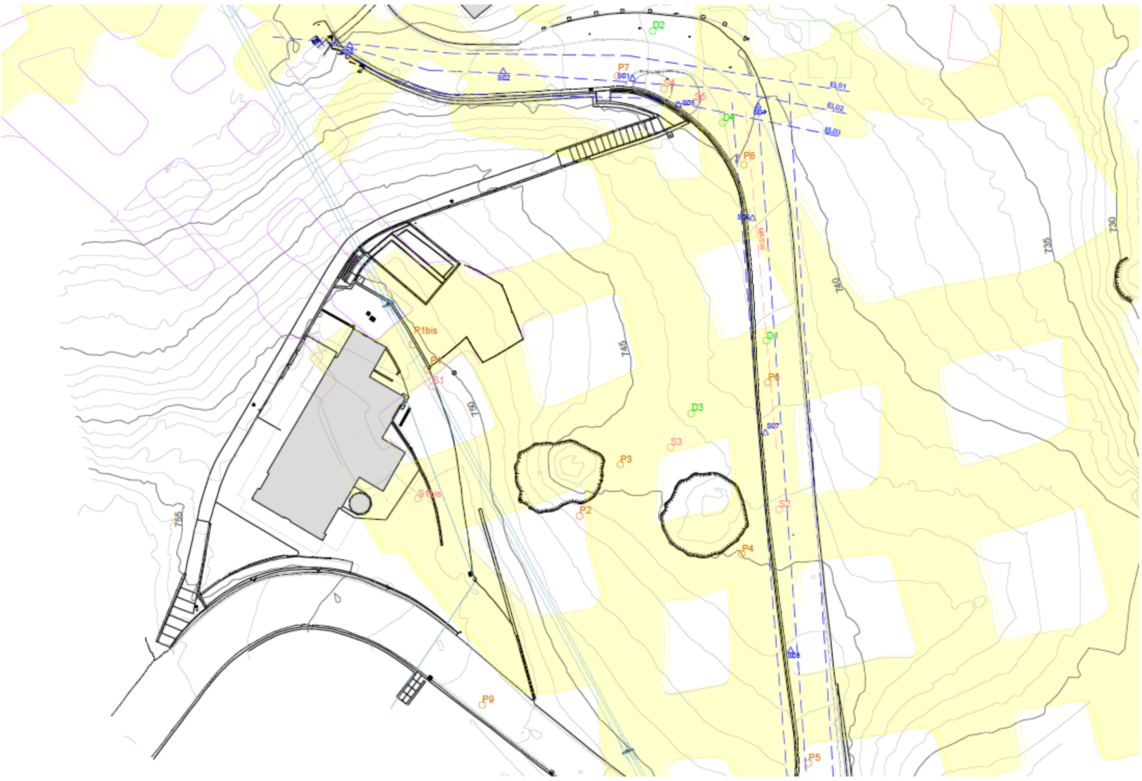

Figure 1: Planimetric view of the site, with one mine level over imposed with the local cartography. (Courtesy of Studio Associato di Geologia Spada, Studio geologico Dott. Baio, Studio Ingegneria Rossi)

The quarry has been closed to cultivation since 1980s. Unfortunately for the characteristics of the rock that makes up the excavated substrate, made of lime, a minimum percolation of water can created a collapse of the vault of the quarry with the consequent formation of conical sinkholes on the outdoor surface. In Figure 1 it is possible to observe the approximate position of two sinkholes already present in the present case. This situation can be very dangerous for the buildings and infrastructures located nearby (Figure 2). For this reason it is necessary to map the geometries and location of the dismissed quarry, the relative heights between the quarry and the external surface, with particular regard to the thicknesses of the soil between the external surface and the upper vault of the quarry, as well as correct position of the quarry related to the cartography.

Figure 2: Sinkholes already present in the site

2. THE SURVEY APPROACH

To support the geotechnical structural analysis of site, a three-dimensional survey of the underground part of the mine and of external part was needed. The survey must satisfy the following characteristics:

- To provide a 3D mesh model of the underground mine, with a local accuracy of 2-3 cm, and a global accuracy of 5-10 cm

Figure 4: Outside part of the Mine

Figure 3: The wooden area outside the mine

- To measure a 3D model of the outdoor area the cover the mine. (Figure 3 and 4)

- To join the indoor model of the mine with the outdoor part that cover the mine, in the way to have a single global 3D point cloud/mesh model. An relative accuracy of the order of 4-5 cm on the relative orientation of the two models was required (the accuracy of the relative altimetric orientation between exterior and interior is of particular importance as for geotechnical studies the trend of the material thickness between the upper vault of the mine and the external surface is one of the required details)

The main problem was to connect the two parts of the survey (indoor and outdoor), made with different instrumentation (Figure 5).

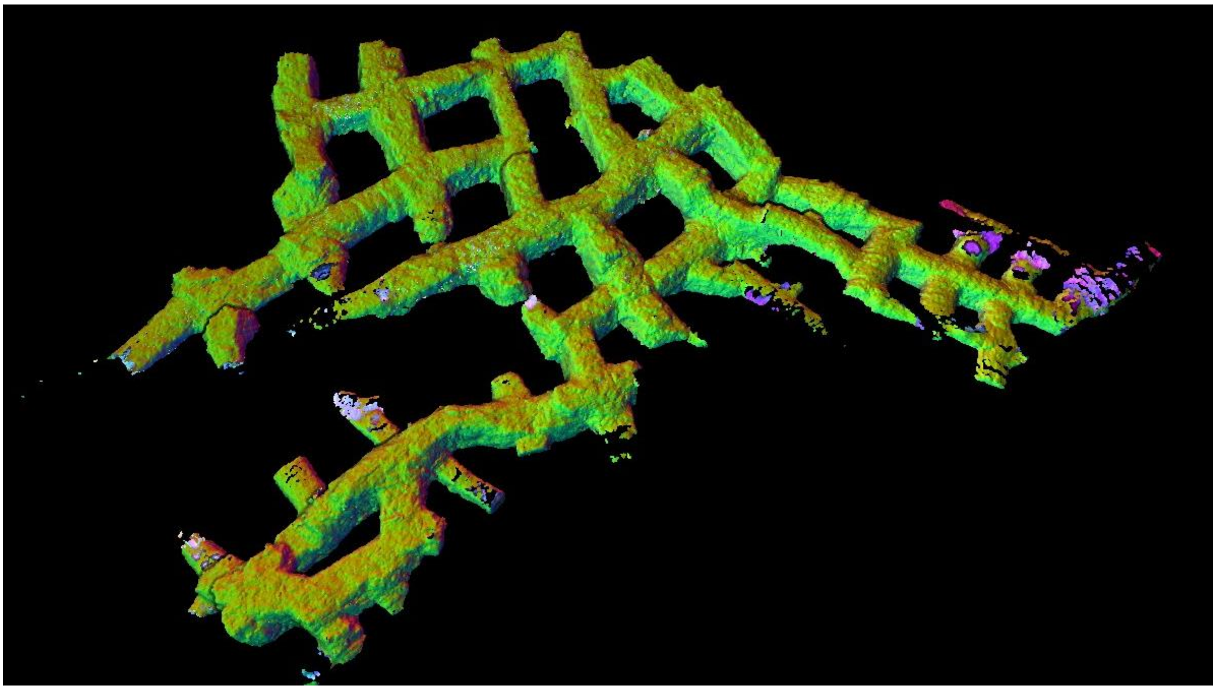

Figure 5: The underground behavior of the highest level of the underground mine (Mesh model of the underground survey)

The geometry of the underground mine (see figure 5) it is impossible to be mapped with a TLS approach, mainly for costs and mapping time. For this reason it was obvious to decide to use an indoor, SLAM based, mobile mapping system. In particolar the HERON MS Twin Color (figure 6) (Gexcel 2022). The main problem of this approach consists on the connection between the indoor sector with the outdoor. The underground mine has only two connection with the outdoor, and both the entrances have a very small and difficult access. For this reason it is almost impossible to create and measure, by total station, inside the mine (figure 6).

Figure 6: Mapping the underground mine by HERON MS TWIN COLOR

Figure 6: The underground mine entrance

For this reason it has been decided to connect the indoor part of the mine with the external part, by using the innovative approach of the Ground Control Scans. Several static scans, acquired using FARO Focus scanner (Figure 7), have been used to connect the indoor part with the ourdoor, creating a point cloud model aligned with an automatic registration approach.

Figure 7: The scanning phase to connect with TLS the underground mine with the ourdoor

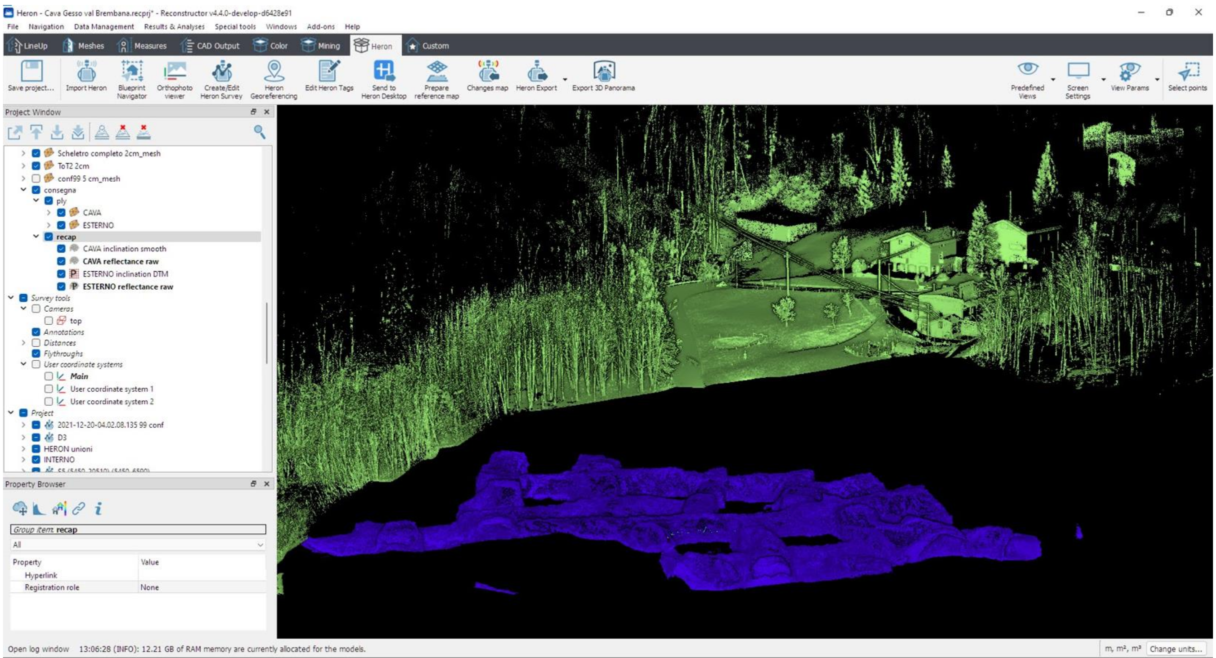

Figure 8: The two models, in the same reference system

Thanks to the capability of the SLAM post processing software (HERON Desktop) of the HERON indoor mobile mapping instrument, has been possible to use the static point cloud models as constrains in the computation of the indoor point cloud model. The point cloud models, used as constraints, have previously georeferenced using a GNSS and Total Station surveying campaign. This innovative approach allow to georeference with high accuracy models acquired with an indoor mapping approach. The model acquired have been easily connected with the outdoor mapping campaign with the results displayed in Figure 8

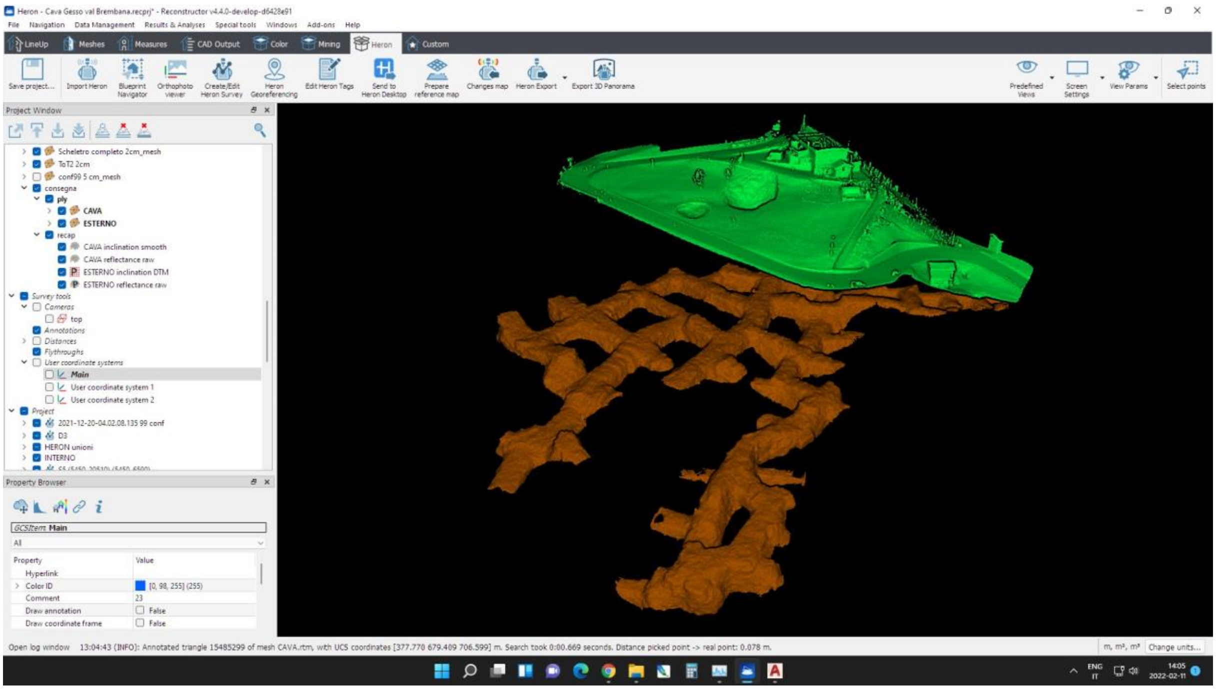

Figure 9: Final 3D mesh model

CONCLUSIONS

This example shows how the use of the GCSs (Ground Control Scans) can be a solution to georeferenced models acquired using mobile mapping systems. In several projects, as the case study presented in this paper, the use of control points would have been impossible and the accurate connection, between the indoor model of the mine and the external part of the site, almost impossible.

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BIOGRAPHICAL NOTES

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