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Original article

Measurement in Network-RTK for the Survey And Representation of A Quarry: Potentials And Limits

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Abstract *- The survey of quarries by geomatics techniques represents an important activity for the monitoring and protection of the landscape. In general, there are several techniques for monitoring a quarry, such as ALS (Airborne Laser Scanning), traditional airborne or UAV (Unmanned Aerial Vehicle) photogrammetry, total station or GNSS (Global Navigation Satellite System). In this paper, a survey of a quarry using the GNSS (Global Navigation Satellite System) and Network Real-Time Kinematic (NRTK) method shows the simplicity, cost-effectiveness and potential of this approach. This approach allowed obtaining accuracy in real-time of a few centimetres; moreover, thanks to specific functions implemented in the GNSS receiver, it was possible to determine, with high accuracy, the position of inaccessible points or points where it was not possible to obtain a good geometric receiver-satellite configuration. High accuracy in positioning leads to benefits in estimating the extracted volumes in a quarry's 4D monitoring activity and is useful for environmental and civil engineering design activities. The paper shows the validity of the NRTK method by the analysis of a case study of a quarry of about 8 hectares located in Italy.*

Keywords — *NRTK, quarry, survey, GPS, CAD.*

I. INTRODUCTION

The extraction of solid minerals from mines and quarries represents a primary activity, with a high environmental impact but also the foundation of all other productive activities and, consequently, the development and well-being of the population. However, it is necessary to identify monitoring strategies for landscape conservation and protection. A recent study on the state of quarries on Italian territory [1] shows that there are 4,752 active quarries while there are 13,414 disused quarries in the Regions where monitoring exists. In addition, there are 2,012 Municipalities with at least one active quarry present on their territory (25.1% of the Italian Municipalities, although slightly decreasing, are a quarter of the total) and almost 1,000 Municipalities with at least 2 quarries. The number of quarries present in the territory is correlated to the great development of the works in the building and civil field. Consequently, in order to verify that these limited resources are used correctly, it is necessary to carry out a precise survey and monitoring of the quarries.

In recent years, various surveying techniques and methods have been used to survey and monitor quarries. Examples of applications of geomatics techniques, and in particular of the UAV (Unmanned Aerial Vehicle) photogrammetry, can be found in several works [2, 3, 4]. These latter works are based on the use of the well-known SfM-MVS (Structure From Motion - Multi-View Stereo) technique, which allows reconstructing the geometry of an object or an area from images acquired with high overlap; in particular, it is possible to obtain, through highly computerized and automatic processes, a dense point cloud [5, 6, 7]. Jawecki et al., 2018 [8] wrote about estimating water retention in post-mining excavations using lidar ALS (Airborne Laser Scanning) data for the Strzelin quarry in lower Silesia. Costantino and Angelini [9] discussed the survey of quarry in Apulia region by the use of Terrestrial Laser Scanner. Mijic (2019) [10] describes UAV-based laser scanning technology for surface scanning of a quarry; in particular, the acquired data are processed in AutoCAD Civil 3D system providing a rich set of geodetic tools and add-ons which dramatically speed-up surveyed data post-processing, visualization and analysis [11]. Nikolakopoulos et al., 2015 [12] describe the monitoring of a quarry realized by UAV photogrammetry and GPS (Global Position System) measurements supported by a Geographic Information System (GIS). Of course, the choice of survey technology and method depends on the size of the quarry under investigation. If, at the same time as surveying, it is necessary to verify or control certain processes during excavation operations, GNSS (Global Navigation Satellite System) technology can be a valid tool for estimating the volumes of a quarry. Moreover, the ability of modern tools to acquire data from several constellations [13] facilitates the real-time acquisition of a point in the quarry and, in particular, the points positioned below particularly steep steps. Experiences in the field of civil and environmental engineering can be found in some works present in the literature [14, 15].

In this paper, a case study of the survey of a quarry carried out by GNSS technology shows the precision, reliability and speed of this survey using data from CORS (Continuously Operating Reference Station) and the real-time kinematic (RTK) positioning algorithms.

II. METHOD AND DATA

A. Surveying procedures: RTK and NRTK

In general, in applications where the accuracy of the GPS in stand-alone is not sufficient, position determination is carried out for pairs of points, on which two receivers must be placed simultaneously. In recent years, more solutions have been developed that allow positioning with respect to monumental GNSS permanent stations with high accuracy. Depending on the type of survey to be performed and the accuracy to be achieved, different operating modes can be adopted, either static or kinematic. The kinematic survey greatly reduces the time needed to determine a baseline, and generally, it requires one receiver to remain fixed (master) and one in motion (rover); in this mode, the survey can only start after an operation called "initialization" which allows determining the initial ambiguity. If, during the survey operations, for any reason, the hooking with the minimum number of satellites (cycle slip) is lost, the operation must be repeated. Latest generation dual-frequency receivers allow resuming the survey immediately after an interruption of the hooking with the minimum number of satellites through a procedure called *On The Fly* (OTF) or *Initialization While Moving* (IWM). The kinematics technique is not unique but differs according to how the master and rover are used. Of particular interest from the application point of view within the kinematic survey, techniques are RTKS (Real-Time Kinematic Survey) or, more simply, RTK (Real-Time Kinematic). This technique makes it possible to determine the position of a point directly in the countryside, i.e. at the very moment when the point to be determined is occupied by the mobile receiver. In this mode, a connection between the basic receiver and the rover (dual-frequency) receiver via radio, modem or GSM is required, as well as appropriate software for data storage, management and processing [16]. The connection between the two receivers is made according to a circular protocol, the RTCM (Radio Technical Commission for Maritime), which allows the transmission of phase measurement corrections. In addition, for the RTK procedure, both receivers must observe at least five satellites. The RTK algorithm is based on double differenced observables that can eliminate selective availability effects as well as other biases. At a given epoch and for a given satellite, the simplified carrier phase observation equation is the following [17]:

$$\phi = \rho - I + Tr + c(b_{Rx} - b_{SAT}) + (N\lambda + \varepsilon)\phi \qquad (1)$$

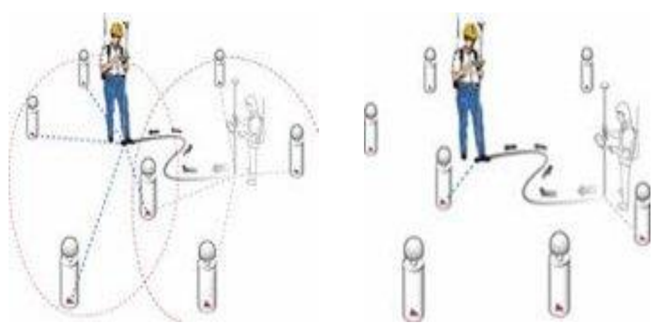
where:

I	signal path delay due to the ionosphere;
Tr	signal path delay due to the troposphere;
b_{Rx}	receiver clock offset from the reference (GPS) time;
b_{Sat}	satellite clock offset from the reference (GPS) time;
c	vacuum speed of light;
λ	carrier nominal wavelength;
N	ambiguity of the carrier-phase (integer number);
$\varepsilon\phi$	measurement noise components, including multipath and other effects;
ρ	geometrical range between the satellite and the receiver computed as a function of the satellite (X_{Sat}, Y_{Sat}, Z_{Sat}) and receiver (X_{Rx}, Y_{Rx}, Z_{Rx}).

The double difference equations also eliminate the clock offsets of both receivers.

B. Permanent Stations

In recent years, networks of Permanent Stations (PS) for real-time NRTK-GNSS (Network RTK) survey have been developed as they not only allow the user to determine their position directly in the Reference System in which the PS of the Network are framed. PS allow the reduction of errors dependent on distance with consequent greater accuracy and faster initialisation [18, 19, 20]. In addition, the use of PS allows users with only one receiver to carry out a real-time and differential survey with clear economic benefits. The most common and different services available to users are available: Virtual Reference Station(VRS), Master Auxiliary (MAC or MAX or i-MAX) and Flächen-Korrektur-Parameter (FKP) (Fig. 1a). Nearest Differential Correction or Nearest station (NRT) is an easy, cheaper and fast survey method where if the distance master-rover is below 30 km and using suitable GNSS receiver, NRT method allows to improve the user position by one PS belong the network (Fig.1b), i.e. allows to obtain a centimetre positioning.



(a) (b)

Fig. 1 Real-time correction from permanent stations: area correction (a), Nearest correction (b).(Images taken from the website: https://www.eurotecpisa.eu/prodotti/strumenti-misura/gps/reti-ntrip/item/249-leica-smartnet-italpos.html)

C. Instrumentation

Currently, there are several types of GNSS geodetic receivers on the market capable of achieving high accuracy in real-time.

In this study, the Hi-target V8 GPS instrument was used for the experimentation.
The main feature of the system is: receiver with 72 independent channels on 2 RTK/NET + WCT frequencies with simultaneous tracking of satellites GPS, SBAS complete with GSM/GPRS Modem Integrated in the receiver, Radio Modem UHF 0.5, 1Gb Flash RAM integrated into the receiver, RTK, Bluetooth type 2 integrated into the receiver, antenna with a choke with virtually zero phase centre integrated into the receiver and Firmware option for band noise suppression, multi-path mitigation option. In addition, the controller is an ultra-rugged QMini Waterproof with GPS for GIS integrated and complete with a pole mount.

D. Experimental setup

Taking into account the features of the Nearest approach, the assessment of the NRTK survey was investigated. This task was addressed in two parts. In the first part, the reliability of the NRTK measure was tested, while in the second part, the experimentation, the survey of a quarry was described.

The reliability of the NRTK measure can be realized on a benchmark belong a geodetic network, i.e. a point with precise coordinates ($N_{REFERENCE}, E_{REFERENCE}, h_{REFERENCE}$); the test site is a few kilometres away from the quarry under investigation. This distance allows comparing the values obtained with the test site with those of the quarry under consideration. On the test site, more measures can be performed and, consequently, to analyze the spatial coordinate values over time. This means to calculate the difference of coordinates ($\Delta N, \Delta E, \Delta h$) starting from the difference between the NRTK measures ($N_{RTK}, E_{RTK}, h_{RTK}$):

$$\begin{cases} \Delta N = N_{RTK} - N_{REFERENCE} \\ \Delta E = E_{RTK} - E_{REFERENCE} \\ \Delta h = h_{RTK} - h_{REFERENCE} \end{cases} \tag{2}$$

The survey of the quarry by GNSS instrumentation, in the real-time survey and with correction by PS can be achieved in the following steps.

Planning of the best time to carry out the survey in relation to the satellite geometry configuration.
The status of the satellite configuration cab is obtained by several geomatics software o tools available online, such as GNSS planning provided by Trimble company able to generate sky plot (see Fig. 2).

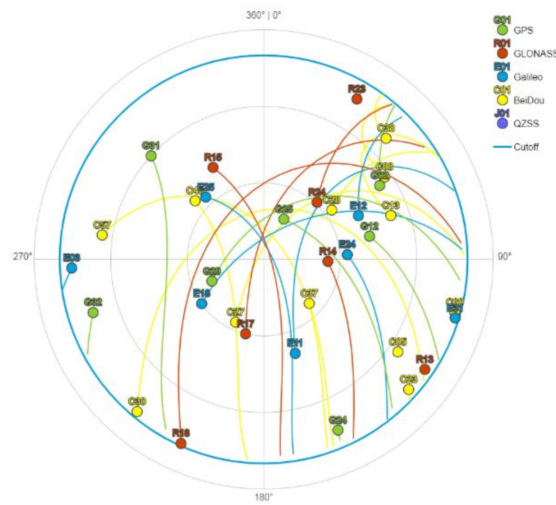


Fig. 2. Example of Sky plot.

GNSS Survey of the characteristic elements of the quarry (structures, elevation points, slopes, steps, boundaries).
Management and analysis of acquired data.

Transformation of the ellipsoid height in orthometric height by the use of the geoid ondulation model. The best geoid undulation present on Italy territory is Italgeo 2005 geoid model, which is provided on the grid format; in addition, specific software is used in order to perform a bilinear interpolation on the grid.

Import in CAD (Computer-Aided Design) software and representation of the quarry. In this step, it is possible to organize and manage the representation of the area of interest.

Building TIN (Triangulated Irregular Network) and DEM (digital elevation model) model in GIS environments [22, 23]. TINs have been commonly used in the field of geomatics and represent a digital means of representing surface morphology; in fact, TINs are a form of digital geographic vector data and are constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. A DEM, instead, is a raster representation of a continuous surface, usually referencing the surface of the area of interest. This raster format makes it possible to obtain additional thematic maps (maps of slopes, exposure, altitude ranges, etc.).

The method just described has been applied to the survey of a quarry in Italy, where the monitoring and naturalistic management of the landscape assumes an important role.

III. Evaluation of reliability of the NRTK in an open sky environment

In order to verify the reliability of the NRTK measurement with "Nearest" correction, 30 measurements were performed in 3 days, i.e. 10 measurements were performed for each measurement session (one measurement every 2 minutes).

In this way, it was possible to obtain independent measurements.

The benchmark taken into consideration belong to the IGM95 Italian geodetic network. In particular, the point called "198904 EBOLI", belong the Italian Fundamental Network, was used for the experimentation.

The NRTK data acquired in this way were analyzed in a Microsoft Excel environment.

In particular, once calculated the mean of the single coordinates, it was possible to calculate the difference between the coordinates and, of consequence, to build the following graph (Fig. 3) in relation to the East, North and ellipsoid height coordinates.

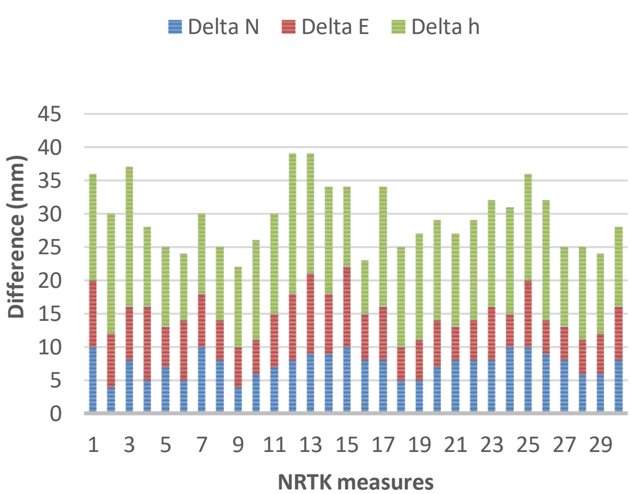
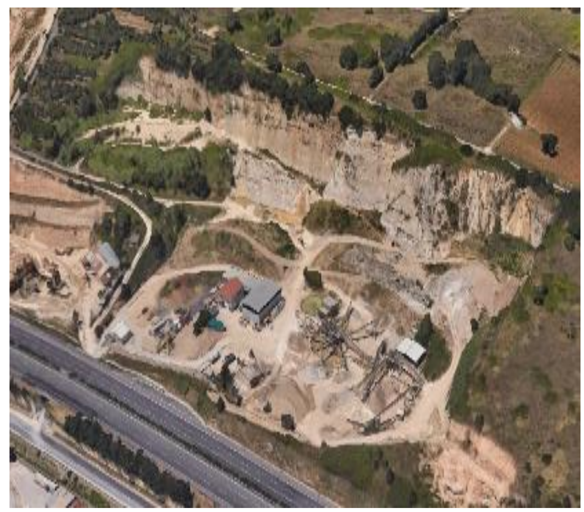


Fig. 3. Difference of the single coordinates than a reference point.

From the analysis of figure 3, it is possible to notice that the height coordinate shows a greater dispersion than the single planimetric coordinates. The variability of the single planimetric coordinates is of the order of a centimetre while the height one is about 2 centimetres. These values are in line with previous research, such as shown by Aykut et al., 2015 [21] in a case study in Turkey of RTK measurements and using the CORS infrastructure. Once identified, the level of accuracy was archived by NRTK positioning using geodetic instruments, an application for the terrestrial survey was applied in the south of Italy. In particular, the object of the survey was mining, whose extension was about 8 hectares is located in the Campania region, as shown in Fig. 4a.

(a)



(b)

Fig 4. Quarry under investigation: positioning on Google Earth Pro (a); 3D model of the quarry from Google Earth Pro (b).

The centre point of the survey area is located at the following geographical coordinates (latitude and longitude): φ=40°36'15" N; λ=15°01'37" E. A representation of the quarry in 3D, available in the Google Earth Pro-environment, is shown in figure 4c. In this latter image, it is easy to visualize excavation areas.

As regards the altimetry of this area study, the quarry presents a difference in the height of about 50 meters with steep gradients, as shown in figure 4c. In order to cover the area of interest, 490 points were in NRTK mode using HxGNSmartNet CORS.

HxGNSmartNet is an open-standard correction service that can use any GNSS device and is constantly monitored to ensure its integrity, availability and accuracy. In addition, with over 4,500 reference stations based on Leica Geosystems technology ensuring position accuracy in any application, HxGNSmartNet is easy to use and delivers precise positions at high speed.

NRT approach was used to obtain a correction in real-time. In all phases of the survey, the maximum error that occurred was 3 cm in planimetry and 3 cm in altimetry. Moreover, 90% of the points showed a planimetric accuracy contained in 2 cm.

In addition, the PDOP (Positional Dilution Of Precision) limit value has been set at 3.

In this case, it was not possible to position the GPS receiver directly on the surveying point, e.g. in the case of corners of buildings or points covered by obstructions of various kinds, COGO (coordinate geometry) functions implemented in the receiver controller were used. In fact, by detecting two (or rather three) points close to the object with the GNSS receiver and measuring the distance between them and the point to be surveyed, it is possible to calculate in real-time the coordinates of the points that cannot be easily and precisely surveyed with the GPS method.

A total of about 400 points were acquired in one working day. In general, no particular transmission problems were reported during the measurement session.

At the end of the survey, it was possible to download the geo-data acquired. In general, it is possible to associate other information that allows the user to evaluate the quality of positioning, such as ID, North, East, Z, Height of antenna, N root mean square, E root mean square, Z root mean square, Number of satellites and PDOP (generally less than 3).

Lastly, because the elevation coordinates produced by GNSS systems provide ellipsoidal height (h) and because in the project, the orhometric height (H) was required, it was necessary to convert this height. Indeed, knowing the geoid undulation model (N) and using suitable software, the orthometric points acquired in NRTK mode were obtained.

The transformation of height was carried out by the use of Verto software, which allows, besides the transformations of the planimetric coordinates for the change of datum, also the transformation of ellipsoidal heights into orthometric heights. The geoid model chosen for calculations was Italgeo 2005 that which is distributed by IGMI (Italian Military Geographic Institute) in the form of a grid of points. The software performs a bilinear interpolation. Considering a point of coordinates (E, N) within a mesh of four nodes and indicating with j and k the indices for which we have$x_j < x < x_j + 1$ and $y_k < y < y_k + 1$, the bilinear interpolation takes the following expression:

$$z(x,y) = (1-t)(1-u)z_{j,k} + t(1-u)z_{j,k+1} + tuz_{j+1,k+1} + (1-t)uz_{j,k+1} \qquad (3)$$

where:

$$t = \frac{x - x_j}{x_{j+1} - x_j} \qquad u = \frac{y - y_k}{y_{k+1} - y_k} \qquad (4)$$

In this way, it was possible to transform the ellipsoid heights obtained from the NRTK survey of the quarry in geoid height.

The Plano-altimetric modelling of the quarry was performed in a CAD environment. In this way, it was possible to obtain the morphology of the area and all the equipment, infrastructure, and structures present inside the quarry.

In addition, thanks to the use of special tools, it has been possible to build, once identified, the single areas (or even called AOI - Area of Interest) and the altimetric model, the contour lines.

Each object (lines and polygons) present in the quarry have been represented, in the CAD environment, as 3D Polyline (Fig. 5).

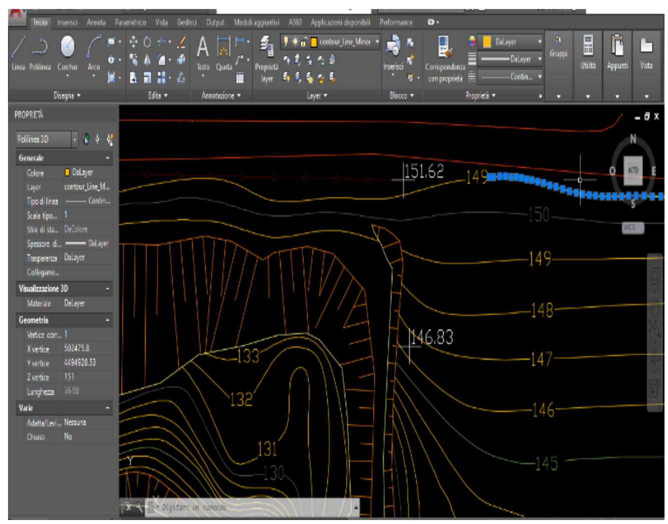


Fig. 5. Representation in CAD environment of (part of) the quarry: 3D polyline to manage the altimetry data.

The equidistance between contour lines is 1m in order to make a 1:1000 scale cartography.

Subsequently, in order to create a graphic layout that increases the readability of the cartography, a clear representation of the quarry was realized [24, 25], as shown in Fig. 6.

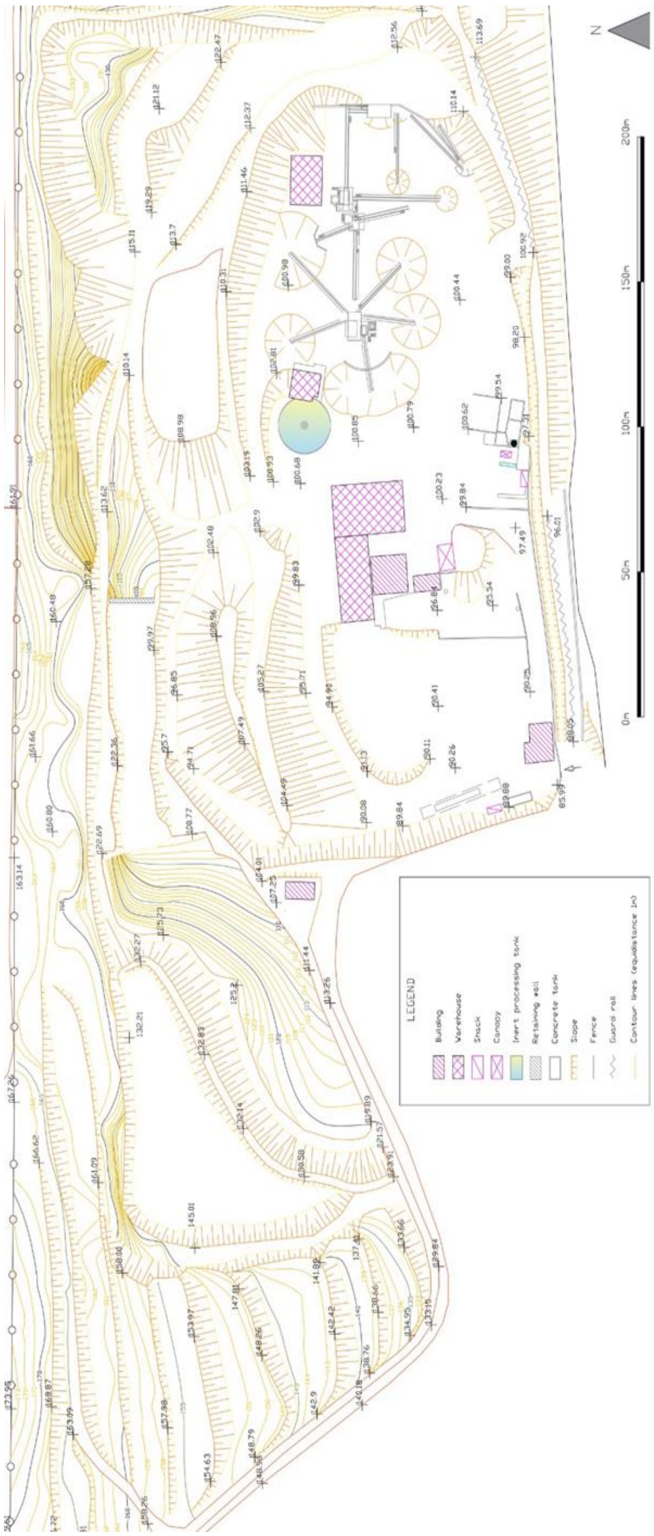


Fig.6. A survey in the CAD environment of the quarry.

The CAD data (contour lines, points, roads, etc.) were used in order to build the TIN model of the quarry; this latter task was carried out by commercial GIS software (Fig. 7)

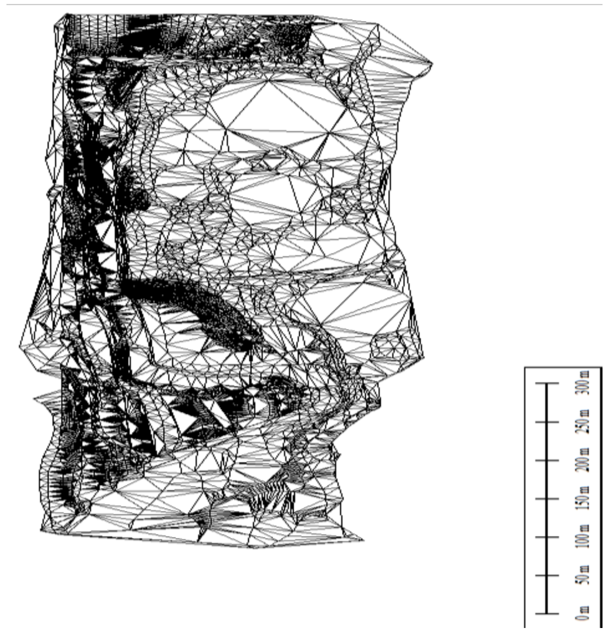


Fig. 7. TIN model of the quarry.

In addition, a DTM of the quarry was generated in Global Mapper software, as shown in Fig. 8. This latter representation allowed to obtain an idea about the relief of the study area and is very useful for map algebra operations (e.g. slope calculation, map of exposure, 4D analysis, etc.).

Lastly, in the GIS environment were performed, the variation of the volume was compared with a previous terrain model derived from an aerial photogrammetric survey. The calculation showed very low excavation volume values. In fact, the small changes concern areas where work has been carried out to renovate and improve the quarry itself.

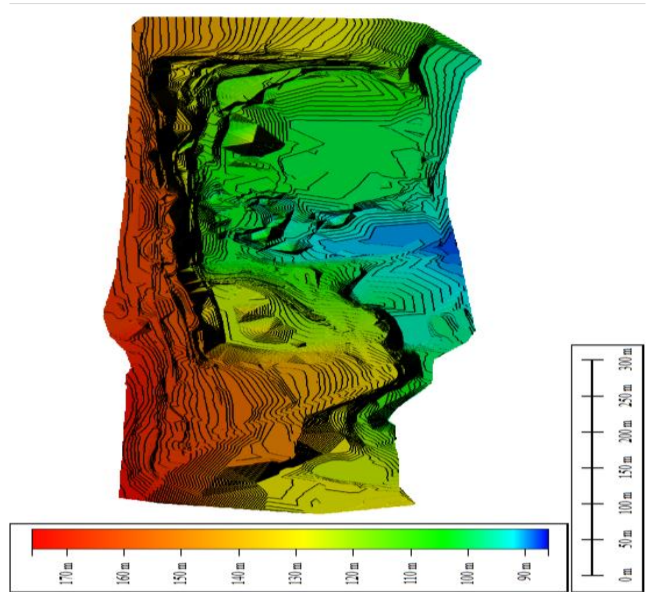


Fig. 8. DEM of the quarry.

IV. CONCLUSIONS

The analysis of the positioning obtained by NRTK allowed a three-dimensional reconstruction of the quarry. In general, the survey and post-processing of GNSS data were very quick and rather fast.

The level of accuracy achievable with this method is a few centimetres; this means that it is possible to estimate the excavation volumes inside a quarry with elevated accuracy. In addition, it was possible to carry out the positioning of the excavation areas from the project in real-time and, more generally, to determine the boundaries of the property in real-time. Therefore, the GNSS survey can be used in a quarry environment, not only to determine the ground control points for aerial surveys with active or passive sensors but also for surveying the entire area and to carry out continuous quarry monitoring operations. It is obvious that the limit of the use of GNSS technology is related to the size of the quarry, the morphological characteristics and the safety of the operator during the survey operations. The examined quarry has an extension of about 8 hectares; however, as the size and complexity of the quarry increases, the laboriousness of the GNSS survey increases. This means that it is necessary to consider these factors just mentioned in order to identify the best geomatics technique and technology in order to survey and model a quarry.

In addition, it should be pointed out that when the quarry to be examined is located in a no-fly zone, either for aircraft or UAVs, a terrestrial survey may be the only solution for carrying out a representation and modelling of a quarry.

Finally, as shown in the case study of the mining survey, the NRTK technique can be used in many fields of civil and environmental engineering and, more generally, in the various geomatics fields where centimetre accuracy is required.

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