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Original scientific paper

COMPARISON BETWEEN TRADITIONAL AND CONTEMPORARY METHODS FOR DATA RECORDING IN STRUCTURAL GEOLOGY

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A b s t r a c t: 3D modeling has become a favored way of analyzing 3D data, where users can collect more data with high accuracy in less time than other surveying methods. Technologies capable of providing 3D data such as Terrestrial Laser Scanners (TLS) are often expensive; thus, encouraging users to seek affordable alternatives while achieving the desired accuracies. Characterization of a rock mass requires data from the intact rock along with the discontinuities. The geometrical analysis of the surface enables the calculation of the parameters to characterize the discontinuities and receive other geological and geotechnical data. Remote sensing techniques, such as Terrestrial Laser Scanning (TLS) and Structure from Motion (SfM) technique, provide 3D point clouds that enable the geometrical analysis. The scientific community has been testing both techniques since the 2000s, and companies are introducing their use in their workflows. Today, mobile phones are becoming more capable of 3D modeling, and the most recent iPhone 12/13/14 Pro and iPad Pro provide an integrated LiDAR sensor. In this paper, we explore the digitalization of a rocky slope via the SfM technique generated using drone surveying and via iPhone-13 pro as a comparison to the "old school" data collected from the compass survey. The target of this work is one outcrop of mica-schist in the north-east part of Macedonia. To capture the surface, compass surveying is used, SfM drone imaging, and two iPhone configurations of LiDAR scanner. The data is analyzed using Pix4D and CloudCompare software. The results of iPhone LiDAR and drone SfM scanning show a highly promising match when compared to the compass measurements.

Key words: compass; LiDAR; SfM; point cloud; strike; dip; iPhone

INTRODUCTION

The use of new technologies and their specialization and development in a specific direction dictates the very orientation of today's modern world towards an open market society. Thus, a specific hardware or software component is developed mostly out of the need for its application, among other things, for purely commercial purposes.

With the development of technology in all spheres of human daily life, various tools are also being developed. In construction, geotechnics, and geology, innovative technologies for data collection, analysis, and processing are increasingly app[lied, such as complex systems based on laser technologies, the global positioning system, and fast computer hardware that together with permanently developed software are processing the data with the appropriate algorithms.

In structural geology, one of the basic tools is the geological compass, which is used to measure the orientation of geological structures. However, nowadays, through the analysis of data obtained by applying modern Terrestrial Laser Scanners (TLS), the Structure from Motion (SfM) technique, etc., there is also a possibility to obtain the orientation of the geological structures. In general, they are often expensive, thus encouraging users to look for affordable alternatives to achieve the desired accuracies.

The commercialization of LiDAR (Light Detection and Ranging) technology in phones is a novelty, but this technology has already been used for commercial purposes for some time with tools that are mounted on various devices, such as vehicles, drones, etc. However, the phone according to its characteristics (compactness, portability, everyone has it) is used in this paper to make a comparative analysis of low-budget utility.

As a result of market demand, and the desire to offer a different offering, in 2020, Apple Inc. produced the first phone with innovative built-in LiDAR-based depth sensors and an enhanced augmented reality (AR) application programming interface (API). The initial need for this phone accessory is explained by the essence of the LiDAR scanner to measure light distance and capture depth information. In essence, a precise measurement is made of the time for which the laser beam is emitted from the corresponding module of the LiDAR sensor to a surface, then is reflected from it and returned to the sensor. When the beam returns, it carries information about the distance and spatial position of the surface it contacts. Although this sensor is not ready to scan a surface as the existing TLS devices, the capture of images enables the generation of 3D meshes with a vertical orientation and scaled 1:1. Of course, for this hardware tool to work, appropriate software is also required. Multiple software works in the same way, some of which are 3D Scanner App [1], Lidar Scanner, Polycam, Lidar Scanner 3D, etc.

Software for processing 3D data contains several options with which the received data can be processed and various feedbacks can be obtained. Lengths and dips can be measured, certain characteristics can be obtained, etc. One of the tools used in this software is the virtual compass tool.

This leads to the iPhone13 being considered a candidate for the job of determining the basic geological features of a particular geological formation. The idea of scanning various lithological units using a device that we carry in our pocket could change the way structural geology experts get the data they need.

In the context of the above, this paper compares the measurements obtained from a classic geological compass, with the measurements obtained from an iPhone with a LiDAR sensor as a low-budget innovative option. Working on this problem, and to control and expand this idea, a drone that uses SfM technology (Structure from Motion) is additionally used. The idea is to collect data on dip and strike, using the mentioned three different methods, and compare the results obtained. This will provide insight into the potential of using the iPhone for this type of research.

The selected outcrop is built of mica schists and measures 20×20 meters near the village of Milutinci, in the northwestern part of Macedonia. The outcrop itself represents a prominent relief feature of the environment, and according to its dimensions, it is suitable to be scanned with both an iPhone and a drone, that is, to be analyzed using Terrestrial Laser Scanners (TLS) and the Structure from Motion (SfM) technique.

The technology is undeniably at the height of what it offers, the accuracy is high, and it solves the algorithms at a high speed. The question arises whether, in structural geology, technology can quickly, efficiently, and accurately respond to certain requirements, among other things and perhaps replace the classical compass.

MATERIALS AND METHODS

In the last decade, new massive-data acquisition systems, such as remote sensing techniques or geophysics, provide new data. This leads to the idea that the way the parameters are calculated could be redefined [2].

The traditional methods are based on physical access to the rock surface. Because of this, the collected datasets can be affected by the access to the site and the environmental conditions. Since the 2000s, remote sensing techniques have been applied to several fields, particularly to the characterization of rocky slopes [3]. The scientific community has shown a growing interest in the extraction of information on discontinuities from remote sensing-derived datasets. This is quite interesting as it enables the characterization of the discontinuities without access to the surface.

In this paper, except geological compass, two fundamental techniques have been employed to capture the rocky surface: a 3D ground-based laser scanner or Terrestrial Laser Scanner (TLS) and Structure from Motion (SfM). The first uses the Light Detection and Ranging (LiDAR) instrument. The instruments can scan surfaces up to 6,000 m [4] with high-speed data acquisition of up to 500,000 measurements/sec [5]. Despite the fast development of these instruments, the cost may still be too high for students and scientists when no funds are available. That's certainly the reason the SfM technique has shown great acceptance among the experts in this field [6]. This technique requires a digital camera and, if needed, a Remotely Piloted Aircraft System (RPAS).

Both techniques provide a 3D point cloud (3DPC) that can be analyzed to detect the discontinuity sets, and their orientations and to extract some of their parameters [7].

The strike and dip of the layers and joints were measured with a Klar compass, specifically a geological compass model from the German company Freiberger Präzisionsmechanik (Figure 1a).

SfM technique has been performed using a low-altitude camera drone – Phantom 4 RTK manufactured by the Chinese company DJI. It belongs to Low-Altitude Unmanned Aerial Vehicles which is employed to capture the ortho and oblique images during the flight (Figure 1b).

Phone measurements are made using the smartphone iPhone-13 Pro released in September 2021, by the US company Apple. The device constitutes a relatively inexpensive competitor to current hardware solutions used in surveying requiring moderate accuracy. It does not perform surface scanning in the sense of TLS devices, but it can obtain a color point cloud at a scale of 1:1. (Figure 1c).

a) b) c)

Fig. 1. Used hardware: a) Klar compass, b) Camera drone – Phantom 4 RTK, c) iPhone-13 Pro

The measurement with the geological compass is made by placing the compass on a flat surface of rock, leveling, and reading the data provided by the position of the magnetic needle, and the angle ruler.

For the SfM technique using Low-Altitude Unmanned Aerial Vehicles (drone), there are several steps that should be done. Before starting the recordings on the field, Ground Control Points (GCPs) are marked with a color that should be easily visible when recording with a drone and phone.

Those points are recorded with a GPS device to reference the recorded terrain for the needs of further processing of the obtained point cloud. A minimum of 4 reference points enables a high degree of precision in georeferencing the point cloud. The points were geodetically recorded with a Leica Viva GS08 with global positioning satellite navigation using a permanent Makpos station.

With the SfM technique using the drone, the entire object was recorded by navigating the drone to take pictures and record all visible surfaces (Figure 2a). The resolution of the RGB sensor is 5472 × 3648 pixels. When recording, the drone positions itself using its own coordinates. To realistically position the obtained cloud of points, it is later georeferenced using software in the required coordinate system. Therefore, the previous spray marks are used as georeferenced markers.

Using the 3D Scanner App tool from the iPhone-13 Pro, a LiDAR scan of the terrain was made using two different approaches: Lidar and Lidar Advanced. To record, the application is activated from the phone and the available area is recorded using the LiDAR sensor located on the back of the phone (next to the camera). During recording, the phone is held 0.5 to 3 meters from the surface (Figure 2b).

a) b)

Fig. 2. Scanning: a) with drone b) with iPhone

MEASUREMENT PRINCIPLE

Light amplification by stimulated emission of radiation

The acronym LASER (or laser) stands for Light Amplification by Stimulated Emission of Radiation. A laser is a device that produces and emits a beam (or a pulse series) of highly collimated, directional, coherent, and in-phase electromagnetic radiation. Laser systems can be used for the acquisition of large amounts of 3D information on the terrain at an extremely fast recording rate (Figure 3). Although LiDAR is a term commonly used in literature, laser scanner or laser range finder are preferred, which makes the link with past methods (laser ranging and laser profiling) [8].

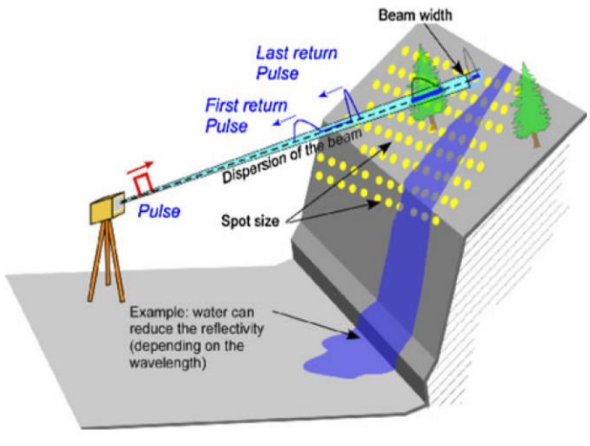


Fig. 3. Principles of laser scanner data

Laser scanning was developed in two ways, depending on the position of the sensor: airborne-based for ALS and ground-based for TLS. Basic principles and processing of the former are well-known issues since the end of the 1990s.

Literature on TLS has rapidly grown during 2005–2010. Petrie and Toth [9] are a good reference for understanding basic principles of TLS. Detailed guidelines that should rule the use of the TLS in all the projects managed by the California Department of Transportation were written by Hiremagalur et al. [10].

A laser scanner consists of a transmitter/receiver of a laser beam and a scanning device. Two different methods for range determination are possible [11]: the phase method and the pulse method. The former allows more accurate range determination but suffers from a limited range [9].

The LiDAR sensor used in iPhones, including the iPhone-13 Pro, utilizes the time-of-flight (TOF) or pulse method for capturing depth information. This method involves emitting laser pulses and measuring the time it takes for the pulses to return after hitting objects in the environment. By calculating the round-trip time of the pulses, the LiDAR sensor can determine the distance to various points in the scene and create a depth map or point cloud representation of the surroundings. Apple does not disclose the specific accuracy specifications of the LiDAR sensor in iPhones.

Structure from motion

Structure from Motion (SfM) [12] is a photogrammetric range imaging technique for estimating three-dimensional structures from two-dimensional image sequences that may be coupled with local motion signals.

There are several approaches and algorithms to reconstruct camera orientation and geometry from images. Currently, one of the most used methods is based on the employment of Structure-from-Motion (SfM) algorithms. These algorithms belong to the computer vision research field and together with stereo-reconstruction techniques provide the opportunity to create accurate 3D models from images without prior information about the location of image acquisition, or about the camera parameters used to perform the acquisition [13].

With the SfM method, the 3D scene geometry and camera motion are reconstructed from a sequence of 2D images which are taken by a camera that moves around the scene. The SfM algorithm detects common feature points in multiple images and uses them to reconstruct the movement of those points throughout the image sequence. With this information, the locations of those points can be calculated and visualized as a 3D point cloud (Figure 4).

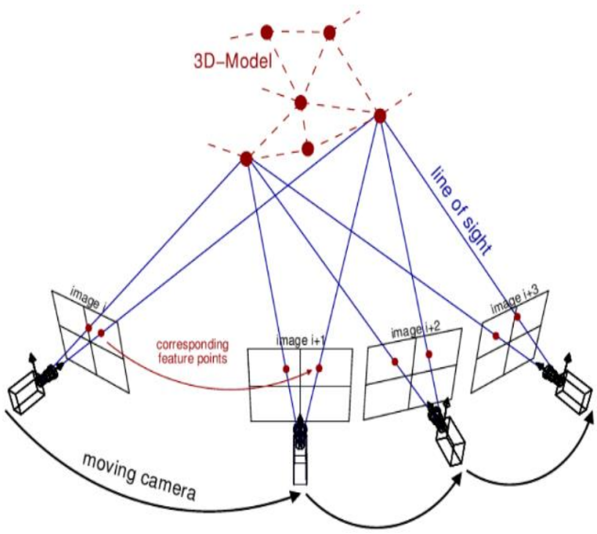


Fig. 4. Principles of SfM method

USED SOFTWARE

For the purposes of getting the final product of the surveys done with iPhone and drone, several software should be used.

3D Scanner App is commercial application developed by international company Laan Labs [1]. It is used as an application enabling the iPhone-13 Pro to conduct the scanning.

Pix4D mapper is a commercial software from a company from Switzerland that specializes in photogrammetry It can operate on desktop, cloud, and mobile platforms [14]. It is used for the photos received from drone imaging to be turned into a cloud of points.

CloudCompare [15] is a 3D point cloud processing open-source software (such as those obtained with a laser scanner). It can also handle triangular meshes and calibrated images. CloudCompare provides a set of basic tools for manually editing and rendering 3D points clouds and triangular meshes. It also offers various advanced processing algorithms. The user can interactively segment 3D entities (with a 2D polyline drawn on the screen), interactively rotate/translate one or more entities relative to the others, interactively pick single points or couples of points (to get the corresponding segment length) or triplets of points (to get the corresponding angle and plane normal). CloudCompare is available on Windows, Linux, and Mac OS X platforms, for both 32- and 64-bit architectures. It is developed in C++ with Qt.

GEOLOGICAL AND TECTONIC-MORPHOLOGICAL CHARACTERISTICS OF THE TERRAIN

The subject location is in the northern part of the Milutinci village, about two kilometers north of the village of Ginovci (Figure 5). In geological-structural terms, the terrain is part of the Serbian-Macedonian massif, which is built of pre-alpine structural complexes. Morphologically, the investigated part belongs to the German block, in the lower Precambrian metamorphic complex [16], which constitutes the base of the terrain [17].

According to the lithological-stratigraphic characteristics, this rock belongs to the geological formation of metamorphic rocks that make up the base of the terrain. Lithologically, the outcrop is in mica-schists. They are typical mica schists with large scales of mica (30–40%), sometimes they also contain garnet crystals (up to 1 cm) or grains of albite, which, in addition to quartz and mica, are essential ingredients.

Interlayers of quartzites, banded gneisses, amphibole rocks, and metabasites are found in mica-schists. Mica-schists is yellowish to brown rock with a distinct slaty texture and a content of coarse mica. They are mostly composed of quartz (20–50%) and micaquartz (30–40%). In some places, garnet or albite is included as an essential ingredient in the composition of mica-schists. Some also contain orthite as a secondary ingredient.

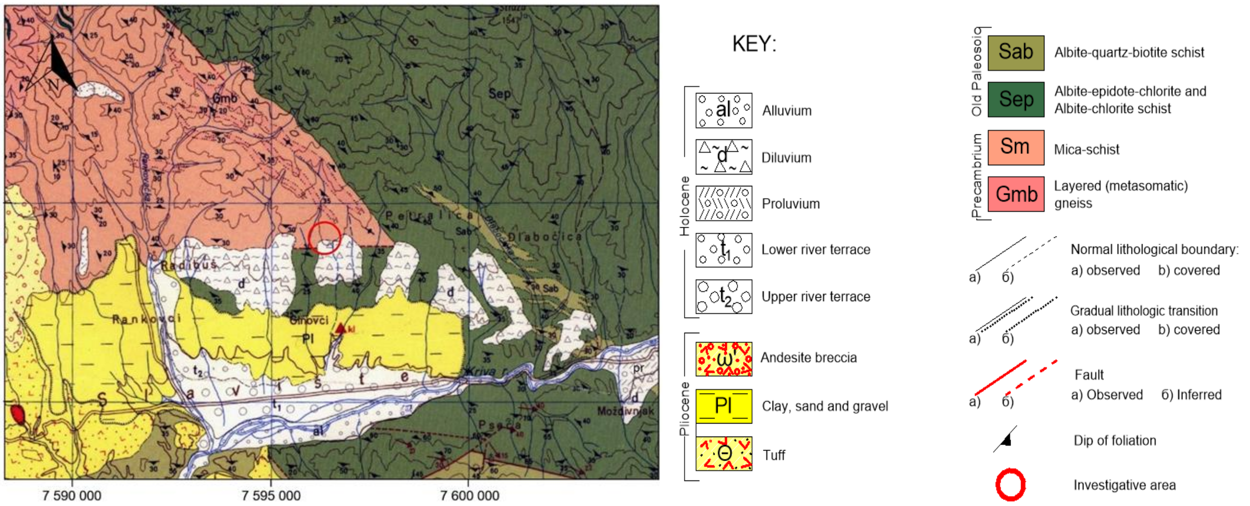


Fig. 5. Geological map of the wider area

The outcrop is located on an elevation in the immediate vicinity of the Milutinci village, which is bounded by a slope to the east, west, and south. This elevation also represents a distinctive feature of the surrounding terrain, with characteristic outcrops, especially towards its southeast side (Figure 6a). The measurements were performed on an outcrop that is represented by relatively solid mica-schists with a general dip towards the east-northeast (Figure 6b).

a) b)

Fig. 6. a) Surrounding area of the outcrop, b) Mica-schist outcrop

DATA PROCESSING

Processing of data obtained from drone footage

With the SfM technique, the entire object (outcrop) was recorded using the drone, and 271 photos were obtained.

The SfM recording, i.e., the photos obtained with it, is first processed in the Pix4D software program. In doing so, a cloud of points is obtained from the available photos. During the processing in Pix4D, a visualization of the exact positions of the camera while the photos were taken is obtained. Very high-density point clouds can be extracted from these photos, but to be able to work properly, an optimal point density number is chosen. Figure 7 shows the photo collage and camera positions.

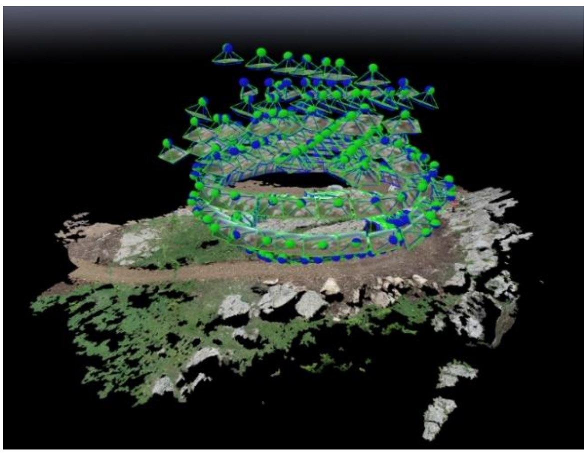


Fig. 7. Positions of the camera during the flight

With the complete processing, the model is obtained, i.e., the cloud of points (Figure 8).

Fig. 8. Final model/point cloud derived by Pix4D

The resulting model is saved in one of the many available extensions .las, .laz, .ply, .xyz, etc.

The file is then opened in the CloudCompare software package. If the recording covers a wider part of the environment as seen in the previous images, the unnecessary part of the recording is cut. After the appropriate processing, a cloud containing 34,057,274 points was obtained.

The next step is georeferencing the point cloud and positioning it in a known coordinate system.

This was done using the align tool. Four control points from each point cloud had to be selected to align the point clouds together. The coordinates for these points were obtained previously using GPS survey. Using the sub-tool "Aligns two clouds by picking (at least 4) equivalent point pairs" we are referencing the cloud. The checking of the coordinates is done by the tool Point picking (Figure 9).

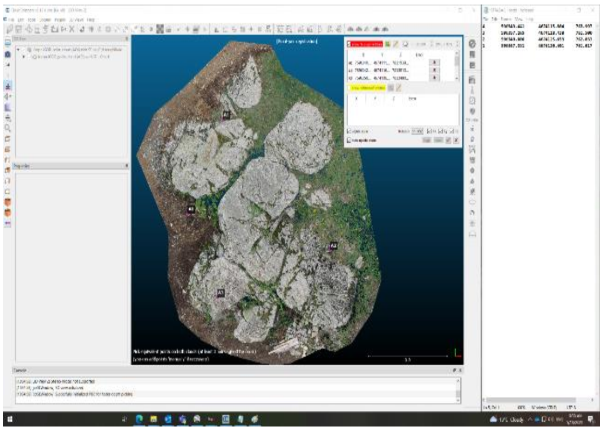


Fig. 9. Georeferencing the point cloud and checking the coordinates

Processing of data obtained from iPhone

Two recordings were made with the phone using two different options from the available app: Lidar and Lidar Advanced. Both phone recordings took 3–4 minutes each. Files recorded on the phone can be exported in many different extensions. In this case, the extension (.xyz) was used. The first exported file is 65.2 MB in size and the second one is 61.6 MB in size. The size of the files depends on the time spent on recording and the area covered. The difference between the two options is in the different appearance of the phone screen, while no noticeable differences were obtained during data processing.

During the two phone shots, due to parts of the terrain that are more difficult to access, the percentage of rock coverage is different. This is considered during data processing.

After the point cloud is loaded into Cloud Compare, it is georeferenced in the same way described earlier (Figure 9). In our case, since recordings were made with the Lidar and Lidar Advanced options, two separate files were processed.

A cloud with 2,062,833 points was obtained from the Lidar file. From the Lidar Advanced file, a cloud with 1,940,668 points was obtained. At first glance, these two files look identical. Using the Compute cloud/cloud distance tool, a comparison of these two clouds is made (Figure10).

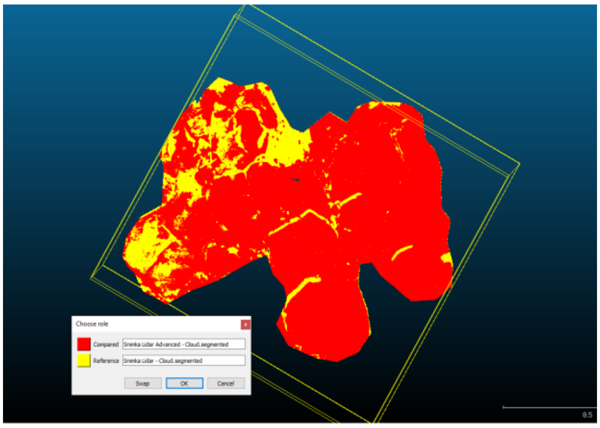


Fig. 10. Comparing the point clouds

During the comparison, the parameters shown in Figure 11 are obtained.

It can be noted that very high precision factors are obtained, with which it can be concluded that both images overlap in fractions of a centimeter. The overlapping of the two recordings with their deviations is shown in Figure 12, where it is noted that most of the deviations are marked with dark blue color, that is, deviations close to zero. The histogram itself shows that more than 95% of the points have a deviation of several centimeters. The mean error is 8.6 centimeters. The bigger deviations are in the parts where there is an appearance of certain vegetation, that is, in the extreme parts of the clouds from points where no measurements were made. If the effects of vegetation are cleared, the accuracy will increase even more.

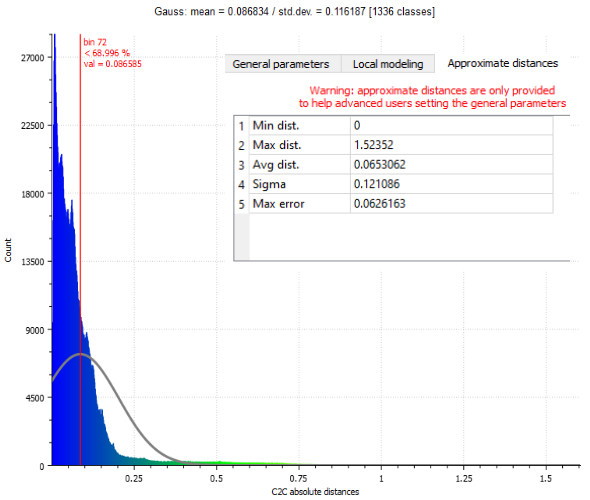


Fig. 11. Distribution of errors between Lidar and Lidar Advanced

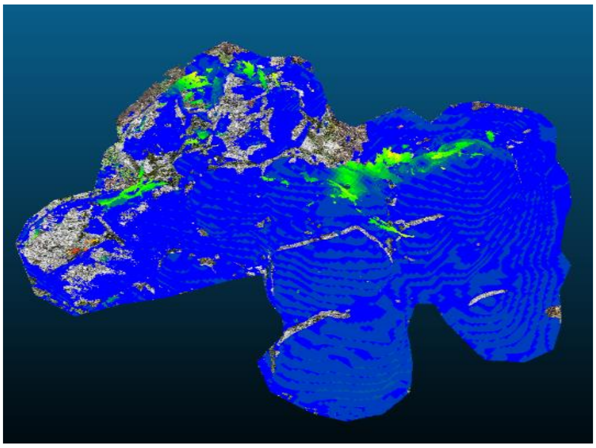


Fig. 12. Approximate distances of errors

In the first case, the measurement was carried out in more detail, with longer stays at the measurement points. When comparing the number of points obtained with the recordings it indicates that the Lidar image has better coverage than the Lidar Advanced image.

Comparison between SfM and LiDAR point clouds

Having established that the two images obtained with the iPhone 13 are identical, the next step is to compare the Lidar point cloud, which is more accurate than the two available methods, which were captured with the iPhone, and the point cloud obtained with the SfM image.

Again, using the Compute cloud/cloud distance tool a comparison of these two clouds is made. In doing so, it is obtained that these two clouds are positioned with very high precision.

The histogram itself shows that more than 95% of the points have a deviation of several centimeters. The mean error is 3.9 cm. The bigger deviations are in the parts where there is an appearance of certain vegetation. Moreover, in certain parts where no measurements have been taken. We can freely draw the conclusion that any of these clouds obtained with the aforementioned technologies when georeferenced overlap with high accuracy (Figures 13 and 14).

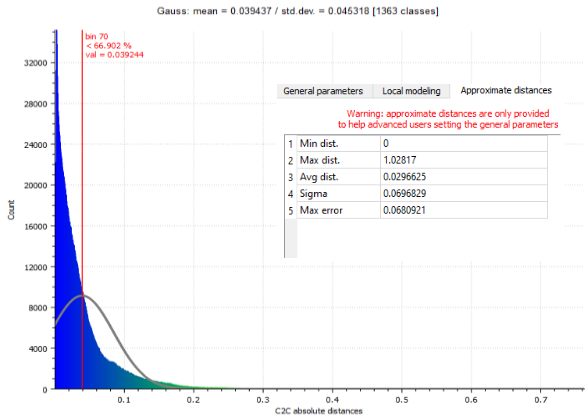


Fig. 13. Distribution of errors between Lidar and SfM

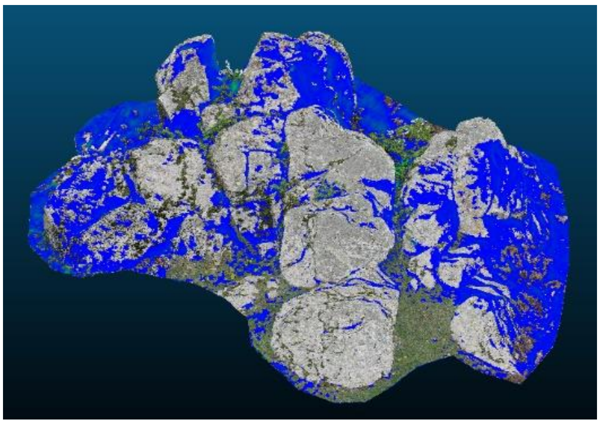


Fig. 14. Approximate distances of errors between LiDAR and SfM

MEASUREMENTS

When doing mapping with the geological compass, three measurements were taken from each mapped position. A total of 71 points were recorded with a compass, that is, 213 measurements were made. With three measurements of one part of the outcrop, different values are usually obtained, something that is due to the unevenness of the rock, where some of its parts are relatively flat in a larger area, and in other parts, there are certain curvatures. Care has been taken to take elements of dip and strike from all sides of this outcrop, i.e., to obtain diversity in the area of obtaining different falls and angles.

Measurements of point cloud outcrop elements can be performed in the CloudCompare software using the "A virtual compass for measuring outcrop orientations" tool which is used in structural geology to interpret and analyze virtual outcrop models. It combines the flexible structural data of available geological interpretation with a series of tools for computer-aided digitization and measurement. The Plane tool is used to measure the orientation of available planar structures, such as cracks or layers. With the Plane tool, the planes are selected where the measurements are needed. In doing so, the positions are chosen where the previous measurement with the compass is made. That is, during the measurement with a compass, all the positions where the measurements were taken are noted using photos on which the measurement points are noted (Figure 15).

Fig. 15. Some of the measurement points made at sight

When working with CloudCompare, these positions of the cloud of points are recognized and the measurement with the virtual compass is performed at the identical position.

The virtual compass tool selects the same positions previously measured with a geologic compass. In doing so, three characteristic measurements are performed again for each measuring point. With each click on the surface from the point cloud, a vector representation of it is obtained, and the corresponding drop elements are displayed on the left side of the desktop (Figure 16). In doing so, equivalents for measured dip and strike elements are obtained.

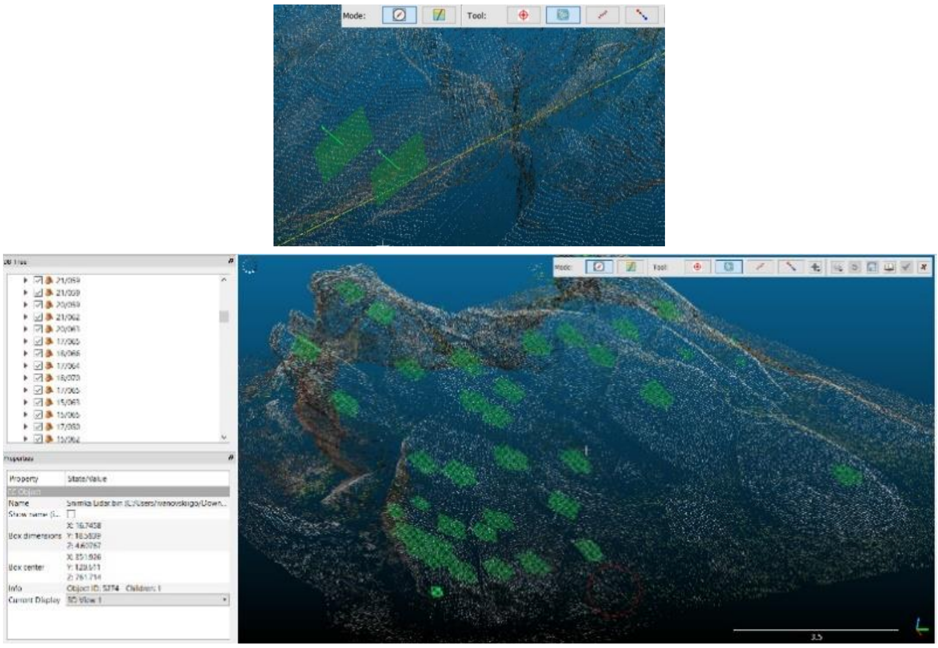


Fig. 16. Some dip and strike measurements using the virtual compass

ANALYSIS

After obtaining all the results of the above procedures, certains analyses can be done.

Analysis of received deviations

The nature of the rock that was the subject of analysis is such that, although it is represented by larger surfaces with relative uniformity in the part of its plane, still by placing the rigid geological compass on that surface, for one measuring point with three measurements carried out, deviations are obtained in the part on the strike up to a maximum of 21 degrees, and for the dip up to a maximum of 13 degrees.

Using the virtual compass tool in CloudCompare, it is observed that the trend obtained in the compass measurements is maintained. With this tool, for one measuring point where three measurements were made, deviations in the strike are up to a maximum of 23 degrees, and for the dip up to a maximum of 13 degrees.

In the parts of the outcrop where the planes are smoother, the matches of the measurements with the classic compass and the virtual compass have a very similar trend. Also, the measurement of uneven parts gives greater deviations in the obtained values both with the geological and with the virtual compass.

If an analysis of average differences in a set of three measurements for one measurement site is made for both the strike and the dip of the obtained values, then additional data on the compatibility between these two methods can be obtained.

An analysis of the frequency of the differences in the values obtained with a compass, i.e. with a point cloud, was made in order to gain an insight into the distribution of the deviations.

The difference is expressed as a deviation of the point cloud measurement in relation to the compass measurement, that is, the mean values of the differences for a measurement point in the point cloud are subtracted from the mean values of the differences for one measurement point obtained by the compass measurement. Figure 17 shows the strike deviations, and Figure 18 shows the dip deviations.

From the obtained results for the strike measurements, it can be concluded that most of the deviations in the measurements (97.18%) are in the range of up to ±12º. Expressed as a percentage in relation to possible values for the direction (0 – 360º), it can be said that 97.18% of the measurements deviate in error to 3.33%, that is, 3.72% of the measurements have a maximum error of 3, 52%.

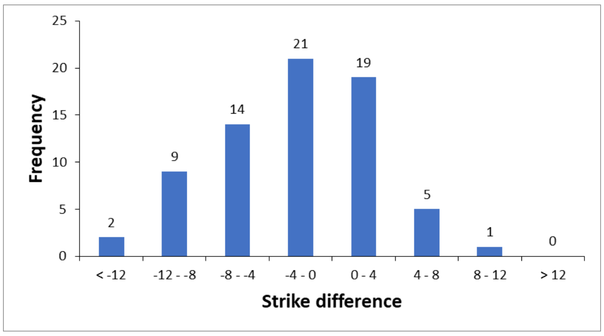


Fig. 17. Display of distribution of deviations in strike measurements

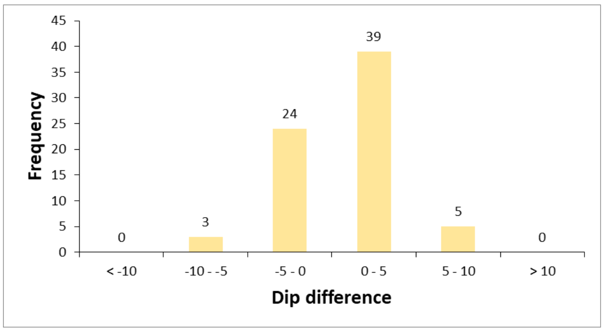


Fig. 18. Display of distribution of deviations in dip measurements

From the obtained results for the dip measurements, it can be concluded that the most of the deviations in the measurements (88.73%) are in the range of ±5º. Expressed as a percentage in relation to possible values for the dip (0 – 90º), it can be said that 88.73% of the measurements deviate within an error of 5.55%, that is, 11.27% of the measurements have a maximum error of 10, 37%.

Regression analysis

In order to gain insight into the relationship between the values for the measured elements obtained by both methods, a regression dependence was made. This kind of analysis makes it possible to define the results of the research with some kind of analytical relationship or equation. The least squares method is the most suitable for such purposes. The coefficient of determination (R^2) is used as an indicator of the strength of the relationship between the variables. In fact, the reliability of the regression dependence is determined by the size of the coefficient (R^2), where it has a value from 0 to 1, and the following criteria are most often used:

- if $R^2 = \pm$ 0.3 there is almost no dependence,
- if $R^2 = \pm$ 0.3 to 0.5 there is a correlative dependence,
- if $R^2 = \pm$ 0.5 to 0.7 there is moderate dependence,
- if $R^2 = \pm$ 0.7 to 0.9 there is a strong dependence,
- if $R^2 = >$ 0.9 there is a very strong dependence.

Thus, a higher value of R^2 indicates a strong relationship between the two variables. In the following (Figures 19–22), the regression analyses performed for all values obtained from the measurements according to both methods are shown.

Analysis of all measurements made (213 data)

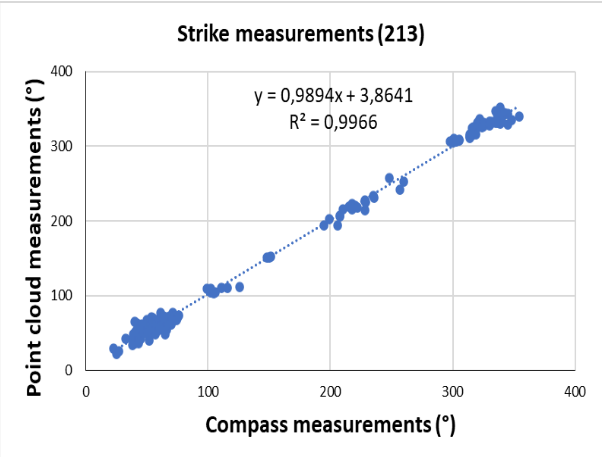


Fig 19. Regression analysis from all strike measurements

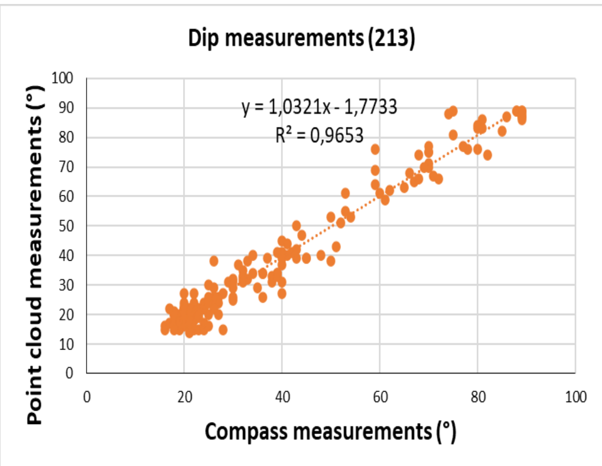


Fig. 20. Regression analysis from all dip measurements

Analysis of average values (71 measuring points)

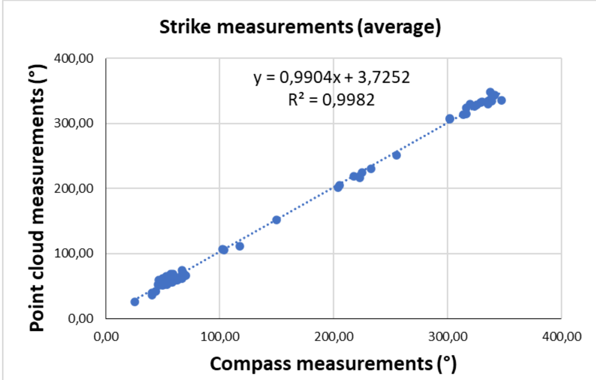


Fig. 21. Regression analysis from average strike measurements

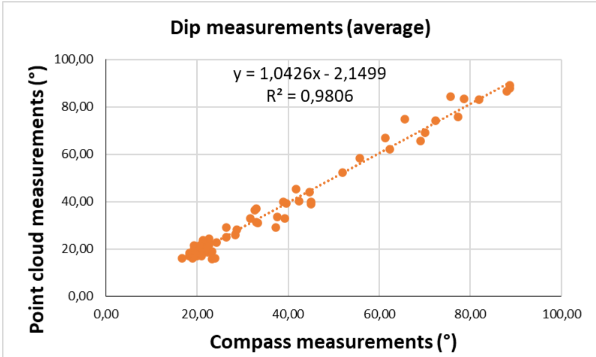


Fig 22. Regression analysis from average dip measurements

According to the analyses made, it can be concluded that there is a strong dependence between the obtained values for both the measured fall and the measured direction, according to both methods of measurement. Namely, the correlation coefficient is:

– for all measurements, R^2 = 0.9966 for the strike and R^2 = 0.9653 for the dip;

– for the average values, R^2 = 0.9982 for the strike and R^2 = 0.9806 for the dip.

Analysis of groups of measurements

If the results of all 71 measuring points are grouped according to related fall elements, the following groups are obtained:

– 38 measuring points belong to group 1 with a general direction to the east-northeast,

– 13 measuring points belong to group 2 with a general direction to the north-northwest and an angle of about 30–40°,

– 5 measuring points belong to group 3 with a general direction to the south-west,

– 3 measuring points belong to group 4 with a general direction to the east,

– 3 measurement points belong to group 5 with a general direction to the north-northwest and an angle of about 80–90°,

– 9 measurement points do not belong to any of these groups and are measurements of surfaces that deviate from the main elements of strike and dip.

A display of all the measurements performed with a classic, i.e., with a virtual compass is presented in the diagram in Figure 23.

The percentage share of each of these groups is presented in Figure 24.

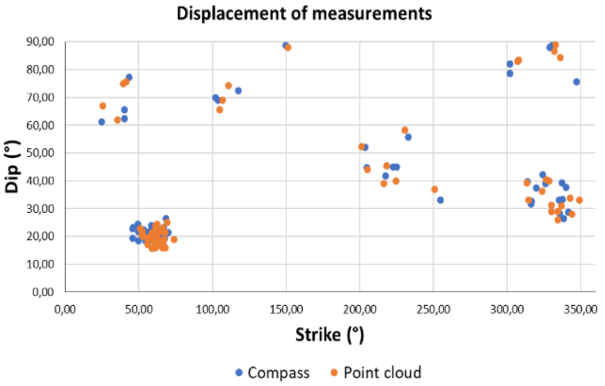


Fig 23. Display of performed measurements with classic and virtual compass

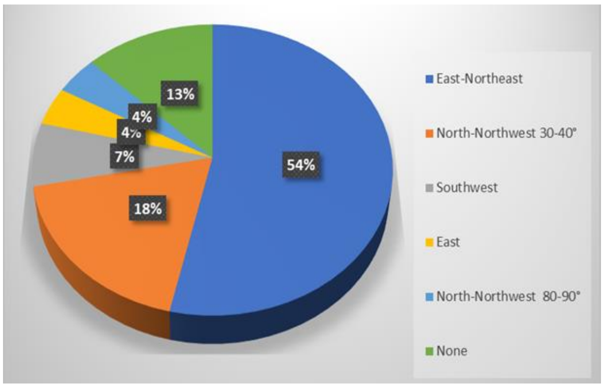
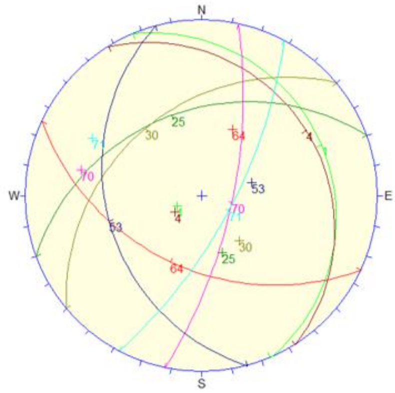


Fig 24. Percentage of related measurements

Display of the plane orientations on a stereogram

Doing some analysis, we must bear in mind that together, the strike and dip measurements provide a complete description of the orientation of the geological feature. They cannot be condensed into a single number because they represent two distinct aspects of the feature's geometry. That is why the previous comparison of the results is done separately for the strike and the dip.

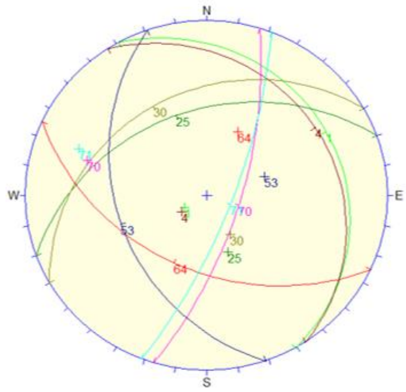
One way to represent the measured dip and strike together is to show their planes and poles on stereograms. Due to a large number of measurements, and with the aim of insight into the overlaps of the two methods of measurement, a random selection of only a few measurements with the geological and virtual compass was made, and they are shown in Figures 25 and 26. Without insight into the values themselves, it can be concluded that the resulting planes and their poles coincide quite well.



Orientations

ID	Dip / Direction
1	17 / 067
4	20 / 058
25	38 / 340
30	37 / 320
53	33 / 255
64	45 / 205
70	70 / 102
71	70 / 118

Fig. 25. Display of stereogram for geological compass measurements



Orientations

ID	Dip / Direction
1	16 / 061
4	19 / 057
25	38 / 340
30	29 / 330
53	37 / 251
64	44 / 205
70	69 / 107
71	74 / 111

Fig. 26. Display of stereogram for virtual compass measurements

Statistical analysis

For each measuring point, three measurements were performed both with a compass and with the point cloud. Thus, for each measuring point, the mean obtained value for the direction and angle of incidence can be calculated. By mutually subtracting the values for each measurement site obtained from the geological and virtual compass, a mean value is obtained, as well as the maximum and minimum deviation for each measurement separately. The deviation of the mean values for the strike is a maximum of 12.67°. For the dip, the maximum deviation from the mean values is 9.33°. This is how the average deviation in the strike of 4.46°, and in the dip of 2.38° is obtained.

In statistics, the standard deviation is a measure of the amount of variation or dispersion of a set of values [18]. A low standard deviation indicates that the values tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the values are spread over a wider range.

For the strike, the standard deviation is 3.53, and for the dip, the standard deviation is 2.24.

The Bland-Altman plot can also be used as a statistical analysis. The Bland-Altman plot is used to visualize the differences in measurements between two different instruments or two different measurement techniques. It is useful for determining how similar two instruments or techniques are when measuring the same construct.

Bland and Altman believe that any two methods designed to measure the same parameter (or property) should correlate well when a set of samples is selected whose properties to be determined differ significantly.

In our case, the average difference between the two measurements, and the intervals of the lower and upper confidence lines are determined. At the same time, 95% of the values from the average difference are taken as the lower and upper confidence lines (Figures 27 and 28).

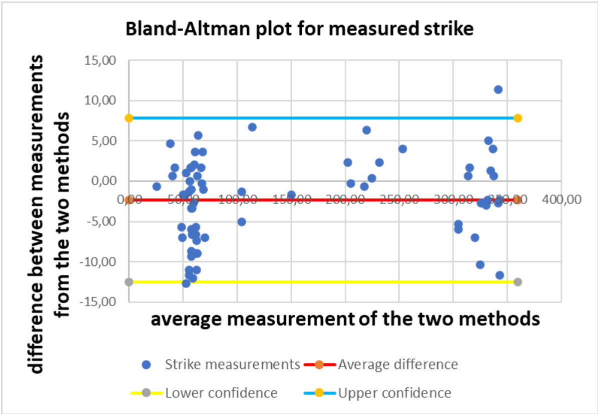


Fig. 27. Bland-Altman plot for measured strike

For strike, an average difference of –2.33 is obtained, for the lower confidence interval of –12.52, for the upper confidence interval of 4.86.

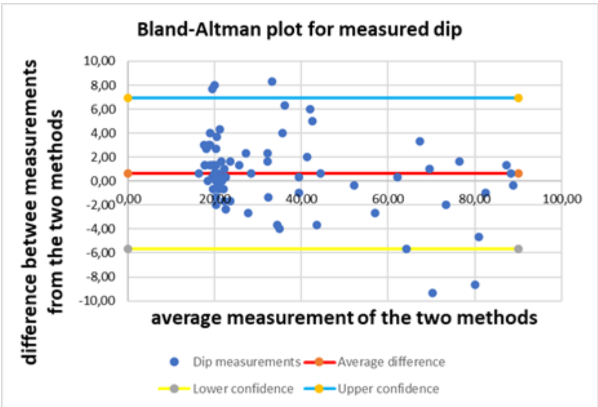


Fig. 28. Bland-Altman plot for measured dip

In the part of the measured dip, an average difference of 0.62 is obtained, for the lower confidence interval of –5.69, for the upper confidence interval of 6.94.

These plots show that the differences between the two measurement methods are small and random, with most points clustered near zero, indicating good agreement and minimal systematic error between the two methods.

CONCLUSION

The purpose of this paper is to explore the potential of inexpensive data collection using modern technology for geological or geotechnical purposes. During this process, certain advantages and disadvantages were noticed which are described in the previous chapters. In general, it can be emphasized that the data obtained by using these new technologies are consistent with the data obtained by an experienced geologist equipped with a compass and a notebook.

The variation trends of the measurements obtained with the geological and virtual compass are very similar. In the part of our measurements, it is safe to say that the obtained point clouds reflect with high precision the state of the terrain, which was previously proved by classical measurement with a geological compass. The variances of the deviations of the obtained values are almost identical to the values obtained with the compass compared to the values obtained from the point cloud.

Given that the advantages outweigh the disadvantages of these new methods, and considering the rapid development of technology, one gets the impression that it is only a matter of time before these new technological aids successfully replace the "old" methods of data collection. Of course, in no way can the old methods be thrown out of use. Their use remains unquestioned, as the new technologies can undoubtedly reach their accuracy. The fact is that these data are registered and recorded in a very clear and visually accessible way, and the recordings can be reused countless times compared to classical field measurement, where the repetition of measurements is limited by revisiting or changing the appearance of the place (executive excavation, or another way of destroying the outcrops or the original appearance of the terrain). In this way, these technologies can be easily imposed in the work of future engineers in geology and geotechnics. Also, through the introduction of new technologies to a larger number of engineers, and attempts to implement them, the utility of repetition and learning from mistakes is obtained, which can also contribute to the deviation of shortcomings and a more efficient performance of technology in geology and geotechnics.

It is evident that technology is rapidly developing in parts of engineering where its application is dictated by expensive and fast processes. In the area of structural geology, there is no great probability that we should expect direct progress of these technologies and the development of AI that would overcome the initial shortcomings in this sphere. However, it is reasonable to expect that certain achievements in the field of GIS and remote sensing can be put into operation indirectly.

By the very appearance of the processed outcrop, one can get some idea of the accuracy of this new technology that is dependable on the geometry of the mapped area. With new measurements of other types of geological formations, new and original data can be obtained, and thus appropriate new conclusions can be drawn. For example, perhaps measurements of dip and strike elements in limestones would give smaller deviations.

It remains for us engineers to be open to all future innovations and vigilantly monitor their development, no matter in which sector of human existence they appear, as well as try to implement them in our sphere of work.

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Р е з и м е

ТРАДИЦИОНАЛНИ И СОВРЕМЕНИ МЕТОДИ ЗА ЕВИДЕНЦИЈА НА ПОДАТОЦИ ВО СТРУКТУРНАТА ГЕОЛОГИЈА

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Клучни зборови: компас; структура од движење; LiDAR; облак од точки; насока; агол; iPhone

3D моделирањето стана омилен начин за анализа на 3D податоци, каде што корисниците можат да соберат повеќе податоци со висока точност за помалку време од другите геодетски методи. Технологиите способни да обезбедат 3D податоци како што се копнените ласерски скенери (TLS) често се скапи, на тој начин охрабрувајќи ги корисниците да бараат прифатливи алтернативи додека ги постигнуваат посакуваните точности. Карактеризација на карпеста маса бара податоци од недопрената карпа заедно со дисконтинуитетите. Геометриската анализа на површината овозможува пресметување на параметрите за карактеризирање на дисконтинуитетите и примање други геолошки и геотехнички податоци. Техниките за далечинско набљудување како што се терестријалното ласерско скенирање (TLS) и структурата од движење (SfM), обезбедуваат облаци со 3D точки што овозможуваат геометриска анализа. Научната заедница ги тестира двете техники од 2000-тите, а компаниите ја воведуваат нивната употреба во своите работни процеси. Денес мобилните телефони стануваат поспособни за 3D моделирање, а најновите iPhone 12/13/14 Pro и iPad Pro сега обезбедуваат интегриран LiDAR сензор. Во овој труд ја истражуваме дигитализацијата на карпеста падина преку SfM-техниката генерирана со помош на геодетски дронови, и преку iPhone-13 Pro како споредба со податоците од „старата школа“ собрани од истражувањето со компас. Предмет на разгледување на ова дело е една појава на микашкрилци во североисточниот дел на Македонија. За да се сними површината, се користи премер со компас, сликање со дрон SfM и две конфигурации на LiDAR скенирање на iPhone. Податоците се анализираат со помош на софтверите Pix4D и CloudCompare. Резултатите од скенирањето на iPhone, LiDAR и дрон SfM покажуваат многу ветувачко совпаѓање во споредба со мерењата со компас.