USING THE iPhone AS A TOOL IN STRUCTURAL GEOLOGY

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Abstract

3D modeling has emerged as a preferred method for analyzing three-dimensional data, enabling users to collect extensive and highly accurate data in a shorter time compared to traditional surveying methods. The characterization of rock masses necessitates data for discontinuities. Remote sensing techniques, such as Terrestrial Laser Scanning (TLS), generate 3D point clouds (3DPC) that facilitate geometrical analysis. Since the 2000s, the scientific community has been rigorously testing these techniques, and companies have increasingly incorporated them into their workflows. Today, mobile phones have become more adept at 3D modeling, with the latest iPhone models (12, 13, 14, 15 Pro) and iPad Pro featuring integrated Light Detection and Ranging (LiDAR) sensors. This paper investigates the digitalization of a rocky slope using the iPhone 13 Pro, comparing it to traditional data collection methods like compass surveys. The target of this work is one outcrop of platy and thick-bedded limestones near the village Farish in the Central part of Macedonia. To capture the structural features of the rock, such as dip and dip direction, compass surveying and LiDAR scanning for obtaining 3DPC using an iPhone are performed. Georeferencing of the 3DPC is done using a GPS instrument. The 3DPC data is analyzed using the CloudCompare software. The obtained results from geological mapping compared to the mapping using the 3DPC, show a highly promising match.

Key words: Compass; LiDAR, point cloud, dip direction, dip, iPhone, Macedonia

INTRODUCTION

The advancement of new technologies across all facets of daily life has led to the development of various innovative tools.

In structural geology, a fundamental tool has long been the geological compass, traditionally used to measure the orientation of geological structures. This method of discontinuity information collection requires geo-engineers to manually measure the exposed rock surface using a geological compass. The main shortcomings of this method are (1) lack of accuracy because of sampling difficulties, choice of sampling method, human bias and instrument error, (2) time-consuming and incomplete for the inaccessible areas, and (3) dangerous for geo-engineers because of the rock fall of unstable rock mass [1-3].

Nowadays, with the advent of modern techniques such as Terrestrial Laser Scanners (TLS) and Structure from Motion (SfM), it is possible to determine the orientation of these structures with enhanced accuracy.

The integration of LiDAR (Light Detection and Ranging) technology into smartphones represents a significant advancement, although this technology has been commercially utilized for some time through devices mounted on vehicles, drones, and other platforms. The inherent advantages of smartphones—compactness, portability, and widespread availability—make them ideal for conducting a comparative analysis of low-budget utility in this study.

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 as 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.

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 [4], Lidar Scanner, Polycam, Lidar Scanner 3D, etc.

This leads to the iPhone 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. Also, this paper represents a continuum from previous analyses of this type [5] made in another geological environment. The purpose is to practice multiple implementations of the iPhone as an important asset in structural geology. One recent study [6] found that the iPhone was able to provide accurate and precise measurements for these objects, with an average accuracy of 0.5-1.5 cm and an average precision of 0.2-0.5 cm.

The selected outcrop is built of platy and thick-bedded limestones near the village Farish, in the central part of Macedonia. The outcrop according to its dimensions, is suitable to be scanned with an iPhone, that is, to be analyzed.

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.

Figure 1. Location of the research area (latitude, longitude 42.178670, 22.201061 Google Map).

STUDY AREA

The study area represents a small part of a south slope at the hill Straza, with dimensions 10x5 meters near the village Farish (Fig. 1). The rock is identified as platy and thick-bedded limestone that has a high percentage of calcium carbonate, and a lower degree of metamorphism. The structure of these limestones is crystal. The geological age belongs to the Senonian [7] (Fig.2).

The appearance of the rocky outcrop testifies to the existence of greater pressures at the time of active tectonic movements in this zone. Therefore, even on the rock itself, completely planar surfaces, on which multiple measurements with a compass would be obtained, are not common. The curvature of the joint planes is due to those same tectonic units. In general, fold structures with different forms of anticlines and synclines are seen throughout this area. The location was chosen carefully, as the surveyed positions, to avoid the plane curvatures, and thus to control the validation process of the performed recordings and measurements.

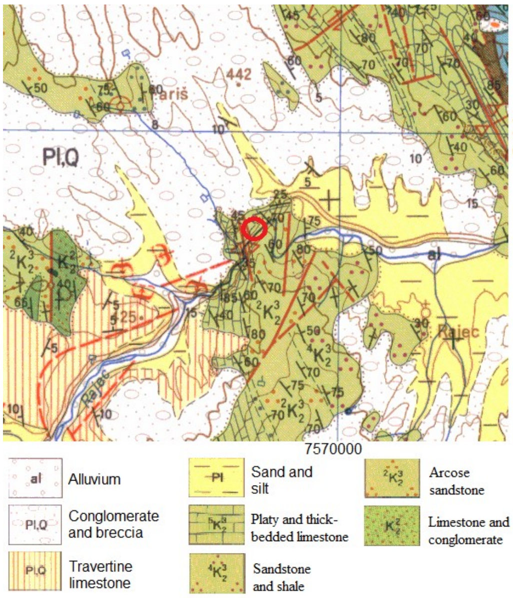

Figure 2. Geological map of the wider area

USED METHODS, HARDWARE, AND SOFTWARE

The traditional methods are based on physical access to the rock surface. Since the 2000s, remote sensing techniques have been applied to several fields, particularly to the characterization of rocky slopes [8]. The scientific community has shown a growing interest in the extraction of information on discontinuities from remote sensing-derived datasets.

The classic measurement of the dip and dip direction of the planar surfaces was made using the geological compass by placing the compass on a flat surface of the rock, leveling, and reading the data provided by the position of the magnetic needle, and the angle ruler. For this paper, a Klar compass is used, a model from the German company Freiberger Präzisionsmechanik (Fig. 2a).

Except for the geological compass, another technique has been employed to record the dip and dip direction of the planar surfaces at the rock: a 3D laser scanner that uses the LiDAR instrument mounted on the back of an iPhone.

This technique provides a 3D point cloud that can be analyzed to detect the discontinuity sets, and their orientations to further extract some of their parameters [9].

LiDAR measurements are made using the smartphone iPhone 13 Pro released in September 2021, by the US company Apple (Fig. 2b).

The points intended for georeferencing the 3DPC were recorded using a GPS TOPCON GRS 1 surveying instrument (Fig. 2c). Five points were recorded on-site for the purpose of georeferencing the 3DPC.

Figure 3. Used hardware: a) Klar compass b) iPhone-13 pro c) GPS Topcon GRS 1

Using the 3D Scanner App application from the iPhone 13 Pro, a LiDAR scan of the terrain was made. It is a commercial application developed by the international company Laan Labs [4]. 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.

For analyzing the 3DPC, the open-source software Cloudcompare was used [10] which is a 3D point cloud processing software that can also handle triangular meshes and calibrated images. It is available on Windows, Linux, and Mac OS X platforms, for both 32- and 64-bit architectures. It is developed in C++ with Qt. For measuring the dip and dip direction from the point cloud, virtual compass tool was used.

RESULTS

The measurements collected with the geological compass were recorded in the notebook. At the same time, all positions where the geological compass was applied were recorded using the camera. This was done, so that later, when in Cloudcompare the dip and dip direction will be measured using the virtual compass, to determine the exact positions where the measurements were taken with the geological compass, that is, to perform control measurements of the 3DPC at the identical positions on the rock where they were made.

Having in mind that the measurement was done in area that was under strong tectonic movements in the geological past, some surfaces of the rock were folded and not very flat. So, the measurements were done on the parts of the rock where the surface was adequate. In addition, to obtain reliability, three measurements with the geological compass were performed at each measuring point. At each respective measurement point, three measurements using the virtual compass were also made. Due to the specific structure of the rock, during the three measurements at one place (within a radius of about 20 cm), different results are always obtained for the dip and dip direction. These data are later analyzed accordingly.

A total of 28 measurement points were done, with three measurements at each measuring place (Table 1).

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

Analysis of received deviations.

When measuring with the geological compass, the maximum difference in dip direction for three measurements at one measurement point is 16°, while for the dip is 6°. For the virtual compass, the differences are 32° and 11° respectively.

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

Table 1. Dip and dip direction measurements

No	Geological compass measurement			Virtual compass measurement		
	1	2	3	1	2	3
1	33/26	28/29	36/28	35/25	37/25	40/29
2	42/38	37/33	31/32	38/31	37/32	35/31
3	45/29	44/30	35/24	46/26	44/26	46/25
4	265/69	267/65	271/66	264/63	260/70	260/61
5	262/66	259/64	260/69	261/65	260/66	261/63
6	258/61	256/60	259/61	250/59	256/57	256/62
7	173/78	175/80	172/76	172/73	176/73	172/80
8	1/89	3/89	360/85	4/86	4/85	4/85
9	271/59	269/60	278/57	272/65	278/62	275/59
10	43/48	37/48	35/45	40/50	36/52	43/51
11	266/60	268/58	267/61	272/57	270/56	267/54
12	261/66	264/59	263/60	262/67	261/72	265/68
13	265/50	264/49	264/51	256/50	261/50	269/45
14	253/53	259/50	254/49	264/45	265/47	260/52
15	31/21	47/25	25/19	39/19	24/17	43/18
16	57/38	56/40	52/40	65/39	56/42	53/50
17	59/60	57/63	56/61	55/72	55/71	61/70
18	225/80	224/81	223/80	229/75	228/81	227/83
19	248/65	247/62	248/63	251/73	252/72	251/73
20	61/50	63/49	62/49	65/53	59/58	66/53
21	51/54	53/55	50/58	54/60	53/65	49/66
22	268/48	273/49	272/54	276/55	277/53	277/52
23	231/85	236/84	233/79	239/77	239/80	240/78
24	256/79	258/80	259/78	258/77	266/82	258/79
25	149/80	144/79	146/79	146/73	149/74	147/72
26	357/76	354/78	355/79	359/81	355/77	358/74
27	337/82	336/85	338/85	358/79	326/80	340/89
28	142/89	145/88	142/88	146/85	146/85	146/85

The difference is expressed as a deviation of the point cloud measurement 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. Fig. 4 shows the dip direction deviations, and Fig. 5 shows the dip deviations.).

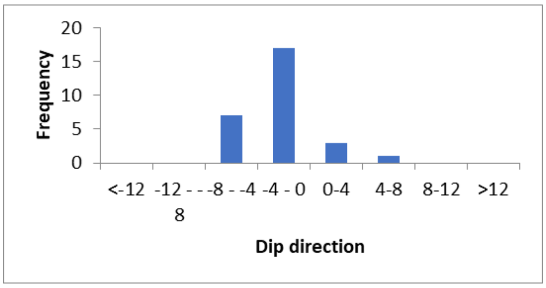

Figure 4. Display of distribution of deviations in dip direction measurements

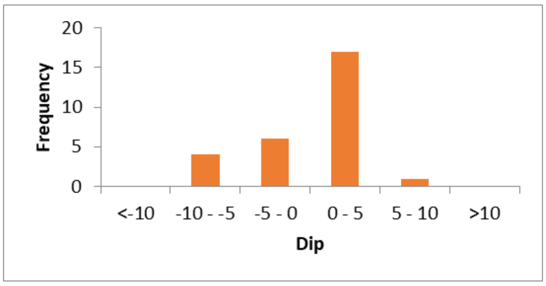

Figure 5. Display of distribution of deviations in dip measurements

The maximum average difference for the dip direction between the geological and virtual compass is from -7.67° to 6.33° and for the dip is from -9.67° to 6.33°.

The standard deviation from these two averages for the dip direction is 2.95, and for the dip is 4.26.

Regression analysis

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

Thus, a higher value of R^2 indicates a strong relationship between the two variables. In the following (Fig 6-9), the regression analyses performed for all values obtained from the measurements according to both methods are shown.

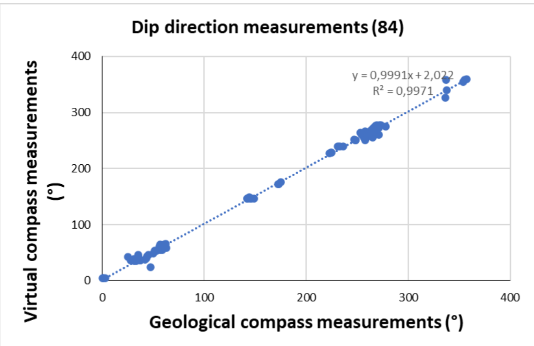

Figure 6. Regression analysis from all dip direction measurements

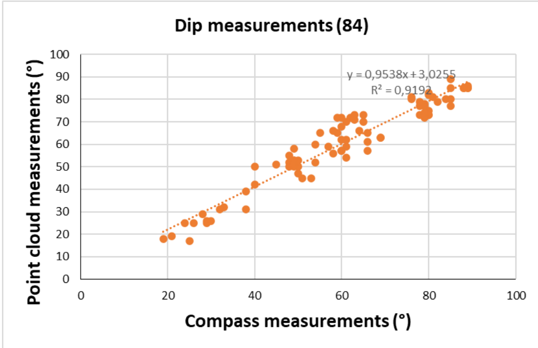

Figure 7. Regression analysis from all dip measurements

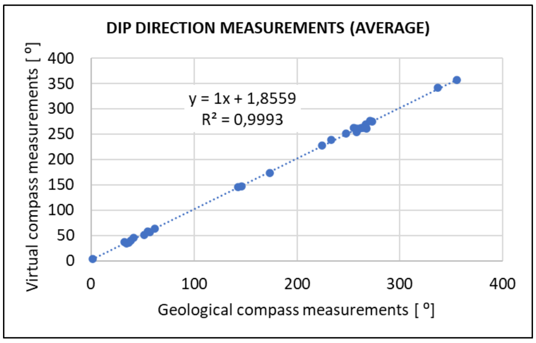

Figure 8. Regression analysis from average dip direction measurements

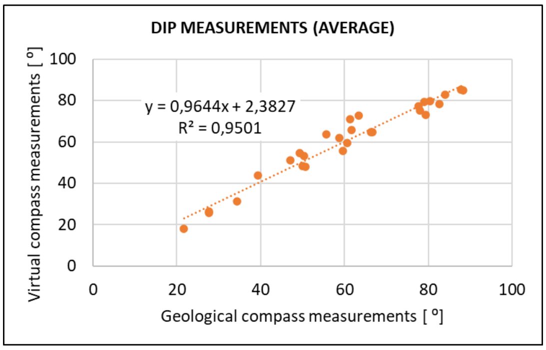

Figure 9. Regression analysis from average dip measurements

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

- For all measurements, R^2=0.9971 for the dip direction and R^2=0.9192 for the dip).
- For the average values, R^2=0.9993 for the strike and R^2=0.9501 for the dip).

Analysis of groups of measurements

If the results of all 28 measuring points are grouped according to related results, the following groups are obtained:

- 10 measuring points belong to group 1 with a general direction to the northeast.
- 6 measuring points belong to group 2 with a general direction approximately to the west and a dip angle of approximately 40°.
- 3 measuring points belong to group 3 with a general direction to the east-northeast.
- 2 measuring points belong to group 4 with a general direction to the southwest.
- 2 measurement points belong to group 5 with a general direction to the south-southeast.
- 2 measurement points belong to group 6 with a general direction to the north.
- 1 measurement point belongs to group 7 with an approximate general direction to the south.
- 1 measuring point belongs to group 8 with a general direction approximately to the west and a dip angle of approximately 80°.
- 1 measurement point belongs to group 9 with a general direction to the north-northwest. (Fig.10).

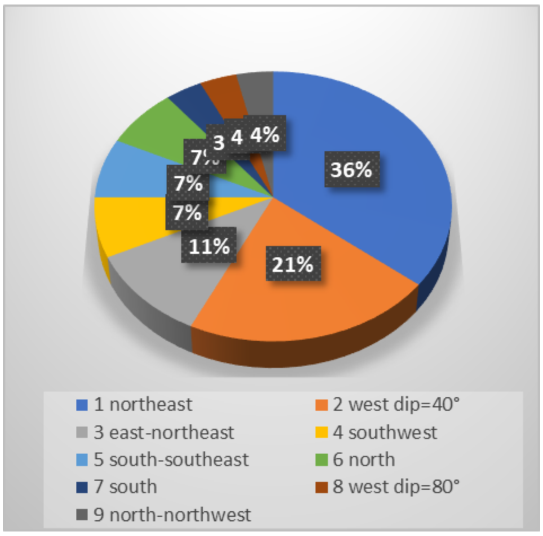

Figure 10. Share of related measurements

From this diagram, we can confirm that there are two main discontinuity planes, one dipping toward the northeast and the other dipping toward the west.

Bland-Altman plot

A Bland-Altman plot is a graphical method to compare two measurement techniques by plotting the differences between the two methods against their averages. It helps to identify any systematic biases between the methods and assess the agreement between them, highlighting any potential discrepancies.

This is a method for comparing two measurements of the same variable. The concept is that the X-axis is the mean of two measurements, and the Y-axis is the difference between the two measurements. The chart can then highlight anomalies, for example, if one method always gives too high a result, then all points are above or below the zero line [11] (Fig. 11 and 12).

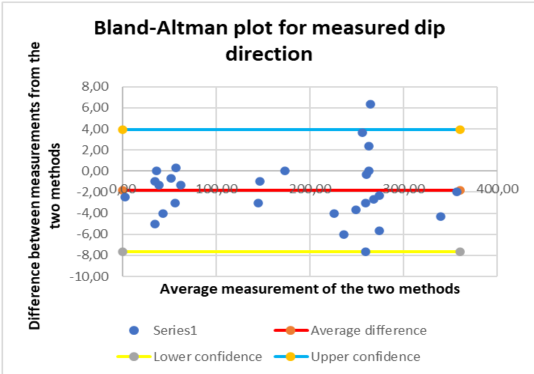

Figure 11. Bland-Altman plot for measured dip direction

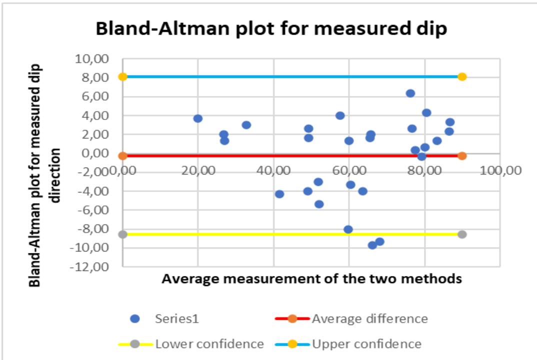

Figure 12. Bland-Altman plot for the measured dip

Each blue dot represents the difference between the two measurements plotted against their average. The red line represents the mean difference between the two measurement methods. This line indicates the average bias between the two methods. If the line is close to zero, it suggests that there is no significant bias between the two methods. The upper confidence limit is shown by the blue line, and the lower confidence limit is shown by the yellow line. These lines represent the mean difference ± 1.96 times the standard deviation of the differences.

For both measurements, i.e., for the dip direction and the dip measurements, most of the data points lie within the limits of agreement, which indicates good agreement between the two methods for most measurements. A few points are near the limits of agreement, and some might be outside. These outliers could be due to measurement errors, extreme values, or other factors affecting the measurements. The plot suggests that the two measurement methods generally agree well, with most differences falling within the expected range. Both plots show that most data points fall within the limits of agreement, suggesting good overall agreement between the two measurement methods. The overall agreement is strong, indicating that the methods can be used interchangeably for most measurements.

Display on a stereogram

Doing the 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.

One way to represent the measured dip and strike together is to show the maximum of poles on stereograms using the software Dips (Fig. 13 and 14).

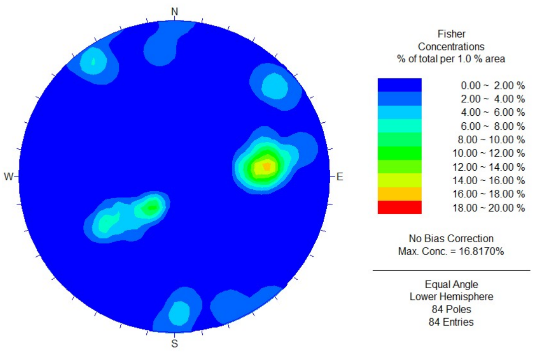

Figure 13. Maximum of the poles – geological compass

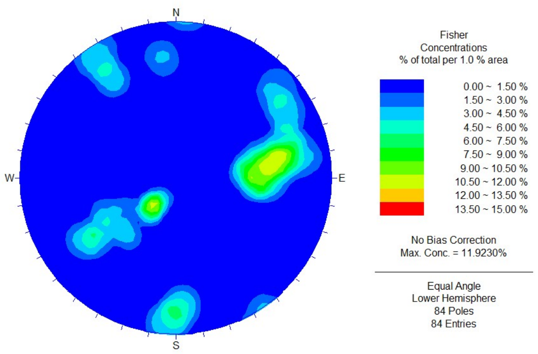

Figure 14. Maximum of the poles – virtual compass

From the above, it can be concluded that the resulting poles obtained with geological and virtual compass coincide quite well.

CONCLUSION

This paper aims to explore the potential of inexpensive data collection using modern technology, in this case, iPhone 13 Pro, for purposes of structural geology. 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 this new technology is consistent with the data obtained by an experienced geologist equipped with a geological compass.

The variations of the measurements obtained with the geological and virtual compass are very similar. It is safe to say that the obtained point cloud via the iPhone with high precision reflects the state of the terrain, which was previously proved by classical measurement using a geological compass. The variances of the deviations of the obtained values are very close to the values obtained with the geological compass compared to the values obtained from the point cloud.

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 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 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.

Every geologist should have in mind the structural and environmental setting of the mapped area. In this case, we had bedded limestones, that at certain places were folded and the measurements with the geological compass, gave different results on neighboring positions. We tried to eliminate those data to avoid wrong data collection. Those same positions that were not suitable for the geological measurements, were also challenging to measure with the virtual compass. By avoiding unsuitable positions, we managed to create a stable set of measurements that proved to be comparable to one another.

In the end, we can emphasize that every engineer working in this field should bear in mind that this new method should be approached with caution. A good understanding of geological predispositions and processes is crucial for proper result interpretation.

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