

Comparative Analyses of the Point Cloud Produced by Using Close-Range Photogrammetry and Terrestrial Laser Scanning for Rock Surface

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Abstract

Point cloud produced by using theoretically and practically different techniques is one of the most preferred data types in various engineering applications and projects. The advanced methods to obtain point cloud data in terrestrial studies are close range photogrammetry (CRP) and terrestrial laser scanning (TLS). In the TLS technique, separated from the CRP in terms of system structure, denser point cloud at certain intervals can be produced. However, point clouds can be produced with the help of photographs taken at appropriate conditions depending on the hardware and software technologies. Adequate quality photographs can be obtained by consumer grade digital cameras, and photogrammetric software widely used nowadays provides the generation of point cloud support. The tendency and the desire for the TLS are higher since it constitutes a new area of research. Moreover, it is believed that TLS takes the place of CRP, reviewed as antiquated. In this study that is conducted on rock surfaces located at Istanbul Technical University Ayazaga Campus, whether point cloud produced by means photographs can be used instead of point cloud obtained by laser scanner device is investigated. Study is worked on covers approximately area of 30 m × 10 m. In order to compare the methods, 2D and 3D analyses as well as accuracy assessment were conducted. 2D analysis is areal-based whereas 3D analysis is volume-based. Analyses results showed that point clouds in both cases are similar to each other and can be used for similar other studies. Also, because the factors affecting the accuracy of the basic data and derived product for both methods are quite variable, it was concluded that it is not appropriate to make a choice regardless of the object of interest and the working conditions.

Keywords Accuracy · Analysis · Close range photogrammetry · Laser scanning · Point cloud · Rock

Introduction

Point cloud has become basic data for many interdisciplinary studies in parallel with advances in image matching algorithms and hardware technology. Using different formats in various software without loss of data, and realistic depiction of objects are some of the reasons for this tendency. Currently, two of the main ways of producing point

cloud to meet the quantitative and qualitative accuracy are close-range photogrammetry (CRP) and terrestrial laser scanning (TLS) techniques. Theoretically the main difference that distinguishes these two methods is that CRP is an optical system while TLS is based on the principle of active system. TLS emerged later than the CRP, and therefore, the researchers conducted for this method has increased in recent years (Telling et al. 2017). Parallel to advances in TLS technique, CRP has also get advantage be used in engineering applications and academic studies. Both realize their development in their own dynamics and debate on point clouds produced by using CRP refers whether point cloud obtained by means of photographs is reliable data and can be used instead of point clouds produced by using TLS which is more popular.

Terrestrial laser scanners which produces point cloud directly with 3D positioning information at regular

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intervals (Yang et al. 2015) are often used in various applications regarding 3D modelling (Skarlatos and Kiparissi 2012). However, technology enables solutions in cheaper systems as in the expensive ones such as laser scanners and point cloud can be produced with the help of photographs taken under suitable conditions depending on the hardware and software technology used. It has become quite easy because adequate quality photographs can be obtained by means of even consumer-grade digital single-lens reflex (DSLR) and compact cameras and various photogrammetric software are widely used nowadays to provide generation of point cloud support. This progress has enabled that photogrammetric techniques are preferred in many applications due to their suitability for interdisciplinary studies. The use of photogrammetric techniques by other disciplines besides Geomatics Engineering has been the subject of research in many aspects like accuracy, precision and efficiency in terms of cost and time. This makes use of photogrammetry even more widespread (Luhmann et al. 2006) and along with what it brings and promises, rock surfaces which are more interested in geology, geophysics and mining disciplines have become an interesting area for studying by using CRP, and therefore with TLS for making comparisons.

There are various studies that compare both methods by applying them separately on rock surfaces as well as the studies on which the techniques are combined. Kim et al. (2015) noted that photogrammetric techniques that allow producing 3D models as well as 2D profiles are practical in terms of determining the Geological Strength Index (GSI) associated with the rock characteristic, and thus weathering of rock. Several advantages of CRP over TLS for rock characterization including slope features and discontinuity measurements were demonstrated by Haneberg (2008). There are also similar other studies about rock surfaces evaluating CRP and TLS conducted by Gigli et al. (2014), Bitenc et al. (2015) and Cacciari and Futai (2016). It is possible to get higher accuracy by using TLS (Golparvar-Fard et al. 2011; Gasparovic and Malaric 2012). At the same time, high accuracy can be achieved by using CRP (Nuikka et al. 2008; Evin et al. 2016). For both methods, one cannot exactly say sharply that one is more accurate or more reliable than the other in all circumstances. Accuracy of TLS and the factors affecting it are still under research whereas what causes the errors and how to fix them are more obvious for CRP. A good understanding of the relationship between the actual accuracy of the data produced using a laser scanner and the expected accuracy is required (Gordon and Lichti 2004). Studies on the determination of the better method, TLS, CRP and combination of both, are in progress and will not end as long as the hardware and software technologies continue to develop (Jorda et al. 2011) or unless an overwhelming technique comes out.

In this study, whether point cloud generated by means of photographs can be used instead of point cloud produced by laser scanner device is examined in detail for rock surfaces. Both methods are jointly evaluated for rocks in literature. The area covered by the study object is larger and more natural along with other objects on and around it. The presence of various materials on the surface makes the study area more complex and more appealing to be analysed. With this motivation, study mainly focuses on whether similar results can be obtained by means of CRP and TLS on such a surface and the differences in the results are significant. In this context, comparison results must be consistent and close to each other in each technique due to the use of numerical and digital data used, regardless of whether analyses are specific or superficial. Comparing with the previous studies, area-based 2D, volume-based 3D analyses and accuracy assessment were performed. The factors affecting the accuracy of the resulting product in each technique need to be addressed in a comprehensive assessment. Therefore, it is not intended to put forward one of the methods in this paper. The evaluation and interpretation of the results of the analyses are given more broadly in the discussion part.

Data and Methodology

Study was conducted on rock surfaces located in Istanbul Technical University (ITU) Ayazaga Campus in order to evaluate point clouds obtained by photographs and terrestrial laser scanner. The reason of selecting rock surfaces as study object is that complicated and irregular shapes are better than an object which is geometrically regular when taking into account the area-based and volume-based comparisons for CRP and TLS. It is generally expected that both techniques give close results for such an object. Fresh and weathered parts on the surface represents the irregular surfaces whereas other objects like shrubs, yellowish soil and grass contribute to the complexity of the entire area. Study was performed on a roughly 30 m × 10 m surface. This rock is the Carboniferous aged Trachia formation of grovak which is one of the basement rocks of Istanbul.

Study object consists of partly weathered and fresh portions. Weathering is the deterioration of the original condition of the rocks due to erosion, water, wind and wave. Change in the mineral structure is called chemical weathering whereas physical weathering is the transformation of rocks to the ground by breaking up (Incekara et al. 2017; Rath 2003). In this way, CRP and TLS have been tested for regions with varied characteristics on the same object. On the surface where weathering can be clearly distinguished by the human eye, the colour of the surface gradually begins to take the colour of the soil while

the fresh areas preserve original colour of the rock. Applied methodology and study area are presented in Figs. 1 and 2, respectively.

Applied methodology consists of 4 steps for both CRP and TLS as exploratory stage of the study area, preparation before field work, field work and evaluation of the data obtained on the field. The locations of the target papers where the ground control points (GCPs) are to be marked were determined so that they can be clearly seen and measured from all the traverse points. As distinct from CRP, scanning points were decided in TLS. It is planned that one of the scans will be performed from the traverse points to be used for the measurement of the GCPs in the CRP and two from relative positions. In the preparations made before the field work, calibrations of digital cameras were made, and interior orientation parameters were found. The calculations were made according to the parameters (e.g. overlapping rate) determined for the photographing operation to be performed with these cameras. Target papers in the size of 4-inch to be used in CRP for scaling of 3D model and in TLS for registration of different point clouds with each other were prepared. In field work, the GCPs were measured, after that photographs were taken,

and the realization of the scanning was done in succession. Evaluation of gathered data and comparison of each other with the help of several analyses are the final steps and are discussed in more detail in the following sections.

Close-Range Photogrammetry (CRP)

In CRP, rock model was created by integrating photographs taken based on photogrammetric principles and 3D coordinates of GCPs marked on the surface with each other. Two different digital cameras were used. One of these cameras is Nikon D700 DSLR camera, which was mounted with a 50 mm fixed focus lens. The other was Sony DSC-H9 compact camera without interchangeable lens feature. The reason why two different cameras were used in the photograph taking process was to assess the accuracy values and other analyses results obtained by using two cameras separated by sharp differences in terms of technical specifications. Nikon D700 is a more superior camera compared to Sony DSC-H9 in terms of lens used in this application as well as other specifications like

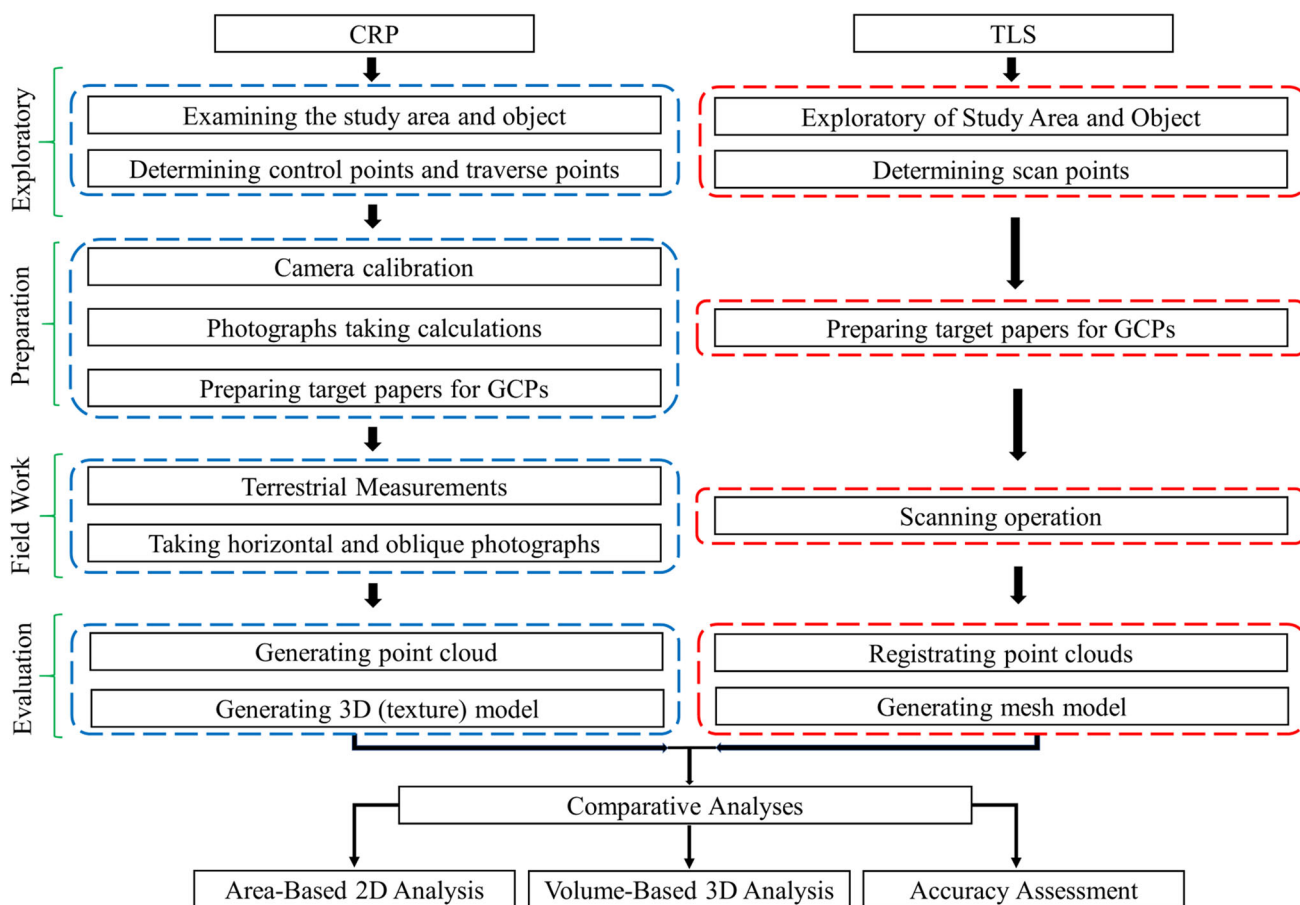


Fig. 1 Methodology used

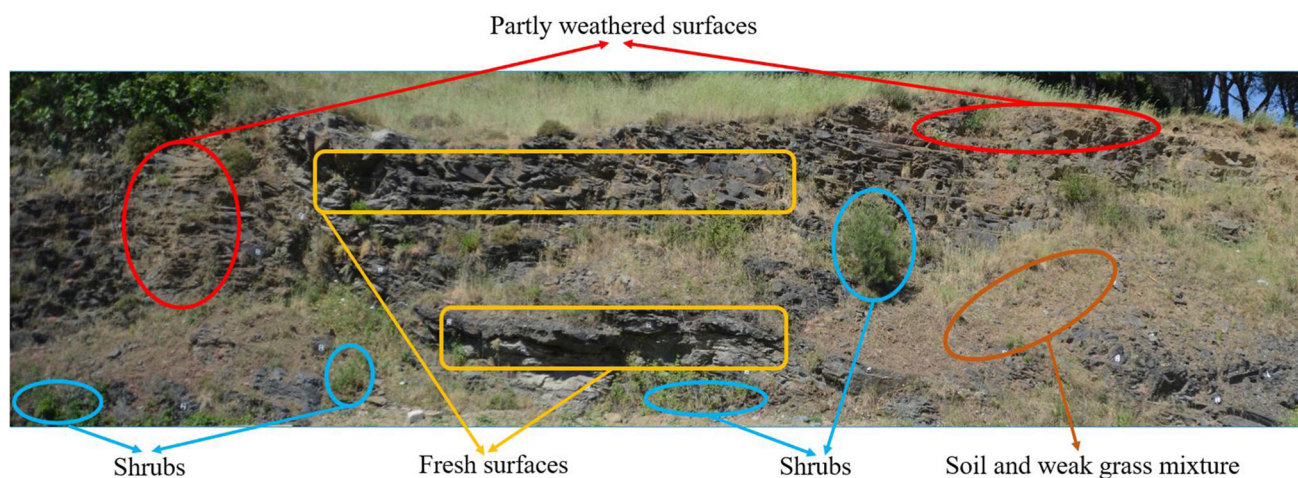


Fig. 2 Study area

maximum resolution and sensor size. These factors affect the qualitative and quantitative accuracy.

The calibrations of the cameras were carried out with the help of the photographs taken for the calibration paper consisting of 100 measuring points and 4 target points to determine and control interior orientation parameters before field work. With each camera, a total of 13 photographs were taken, 3 in each direction of the calibration paper with different positions and 1 in the top. According to the calibration result, perpendicular distance between exposure centre and image plane were calculated as 52.54 mm for Nikon D700 (50 mm in instrument prospectus) and 5.34 mm for Sony DSC-H9 (5.2 mm in instrument prospectus).

24 GCPs were marked on the object as homogeneously distributed as possible before taking of the photographs. The target papers with 4-inch size representing the GCPs were marked on the rock surface. Photographs were taken by two cameras with approximately 80% horizontal and 60% vertical overlapping rates. Photographing distances were determined so that the ground sampling distance (GSD) values for the photographs obtained with both cameras are close to each other. Both the horizontal and the oblique photographs were taken to reduce the hard-to-see areas on the surface as much as possible because the study object has a complex structure. Each GCP was measured at two traverse points. Points 9 and 23 were excluded from the evaluation since they were inconsistent according to the values obtained from two different traverse points. Weak point cloud, dense point cloud, mesh model and object model were created respectively with the help of photographs taken by both cameras. The rock models were scaled and coordinated by matching known GCPs with coordinate values. The rock models created by means of photographs obtained with both cameras are presented in Fig. 3.

Terrestrial Laser Scanning (TLS)

In TLS, Leica Scan Station C10 terrestrial laser scanner equipped with maximum 360° horizontal and 270° vertical field of view was utilized. The density of the point cloud increases as the scanning resolution goes up from low to high. In this application, three different scanning at medium resolution were performed for the rock surface in successive. In Fig. 4, TLS application is represented. First operation was carried out from traverse point with known coordinates and the other from the relative points. It was aimed to reduce the number of areas as much as possible where the laser beam cannot produce points on the surface. Point clouds were registered by using iterative closest point (ICP) algorithm proposed by Besl and Mckay (1992) in order to obtain a single cloud. Positioning in local coordinate system was performed by using indirect positioning method with at least 3 common points between clouds.

Analyses

The analyses performed are 2D area-based and 3D volume-based analysis for specific regions determined on the surface and accuracy assessment for the whole model. 4 different regions were determined for area and volume-based analyses and comparisons. In order to evaluate different character and quality surfaces, both partly weathered (Region 1–2) and fresh regions (Region 3–4) were selected. The selected regions are cleaner than their surroundings, since the grass or other facts on the surface are considered as a disruption factor for areal and volumetric analyses in comparison to rock. These regions were simultaneously extracted from three overlapped point cloud data obtained by different sources (Laser Scanner, Nikon DSLR and

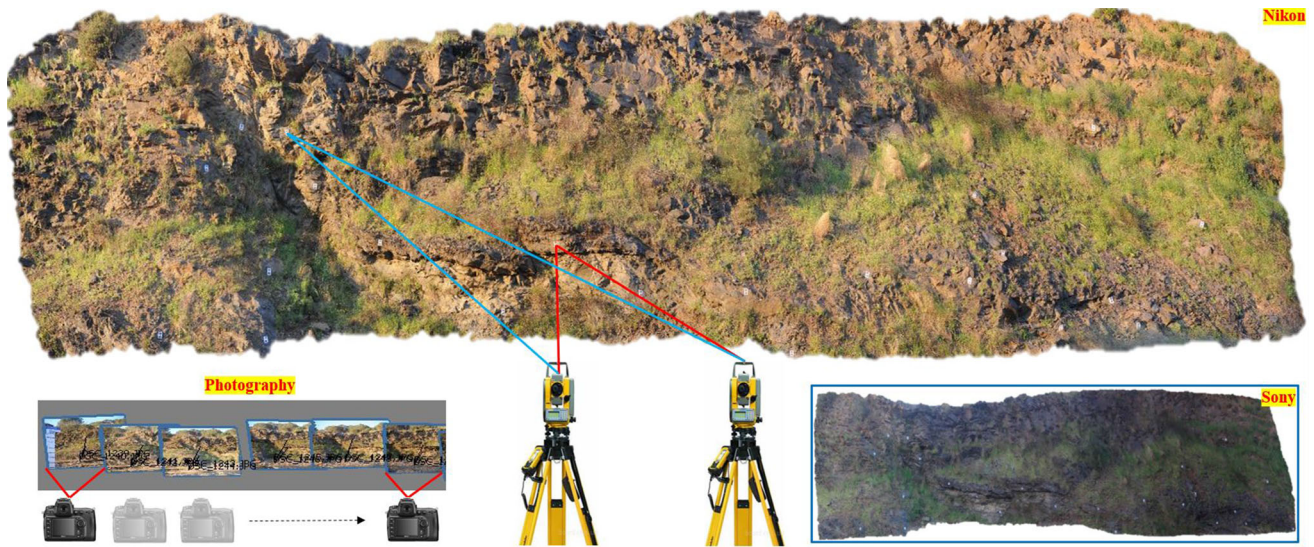


Fig. 3 Field work including photography and geodetic measurements (bottom left) and 3D models created with Nikon D700 (upper) and Sony DSC-H9 (bottom right)

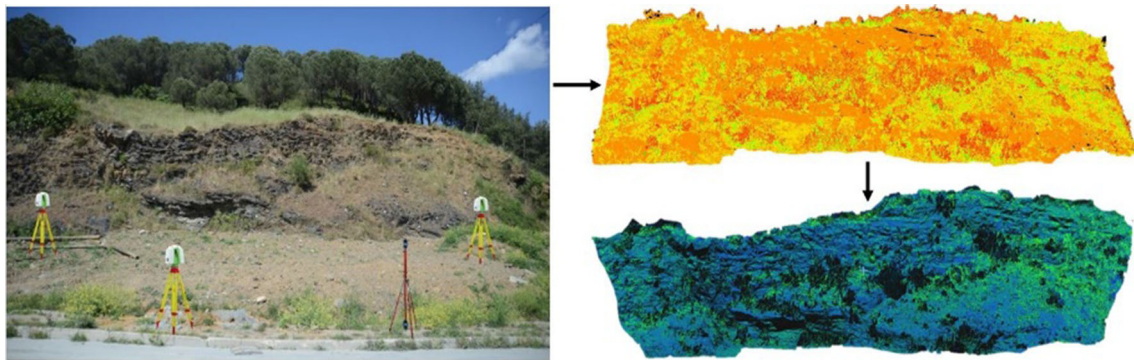


Fig. 4 TLS application: field work (left), registered point cloud (top right), mesh model (bottom right)

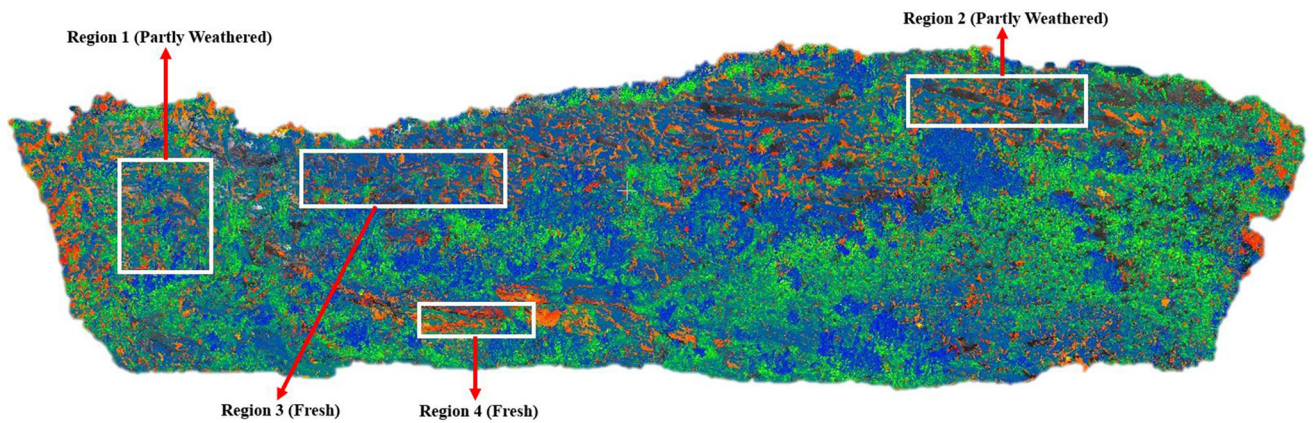


Fig. 5 Four analysis regions on the three overlapped point cloud data

Sony compact camera) as indicated in Fig. 5. Analyses were implemented on a total of 12 mesh models produced for these point clouds.

Area-Based 2D Analysis

Area-based analysis was carried out for comparing the mesh models in 2D space. For this purpose, sections were

formed on each mesh model created separately. Sections corresponding to each other for each region were evaluated. As presented in Fig. 6 which belongs to Region 4, two ends of the sections were joined with a line and area values between the section profiles and lines were calculated. Thus, the changes in the sections representing the fluctuation in surface were examined whether a significant difference for several data sources is caused. The results obtained for each data source are presented in Table 1.

Volume-Based 3D Analysis

Volume-based analysis was performed to compare 12 models in 3D space. The computed volume values are for the region between the back side of the surface, and the plane formed in the $X-Z$ plane as indicated in Fig. 7. So, the axis standing for the 3rd dimension is Y -axis, which provides depth-related information in terrestrial studies irrespective of whether CRP or TLS is used. Coordinate for Y -axis was determined to be the same in all the volumetric analyses for the reference plane since the volume of a space between the surface and the plane would be calculated. The sampling interval for the straight lines forming the volume values between the two surfaces was set at 0.1 and 0.01 m. The results obtained for different regions are presented in Table 2.

Accuracy Assessment

In any accuracy analysis and research, it is necessary to compare the results with the data accepted as correct or reference. Data are produced by deriving in CRP and it can be accepted that measured values in the field are raw data and model coordinates are reference dataset. In TLS, field coordinates of GCPs measured by total station were accepted as reference data in order to compare the data obtained by scanner. Coordinates of the GCPs for the TLS was determined over the raw point cloud. The point cloud was coloured according to intensity values and point size

Table 1 Area values between lines joining the ends of the sections and section profiles (m^2)

Data source	Region 1	Region 2	Region 3	Region 4
Laser scanner	0.3015	1.6252	0.6023	0.3814
Nikon	0.3008	1.3244	0.5834	0.3796
Sony	0.2979	1.2872	0.5613	0.3773

was enlarged to make a better choice of measured part of the target paper. The error values calculated along the 3 axes are presented in Table 3.

Discussions

In this study, objective phenomenon is the raw point cloud data and 3D models derived from them, and not the data sets such as indexes of rock surface produced on the data. The values in Table 1 obtained by 2D analysis have proved that sections formed on models created by using different data sources are almost coincident with each other. The area values between the lines that connect the two ends of the sections and section profiles are very close to each other, indicating that the sections are highly overlapped. Sections are important data for discontinuity and the roughness which are the focus points of the studies carried out with different data on the rock. These results have exhibited that any investigation to be made on rock surfaces including determining the roughness angles of rock surface on the discontinuity regions by using sections will give similar results. With 2D analysis, this foresight was confirmed by a basic analysis for primary data. When the maximum and minimum differences between the three data sources are analysed depending on the diverse featured surfaces, it can be seen that the differences between CRP and TLS are more for the weathered regions as indicated in Fig. 8.

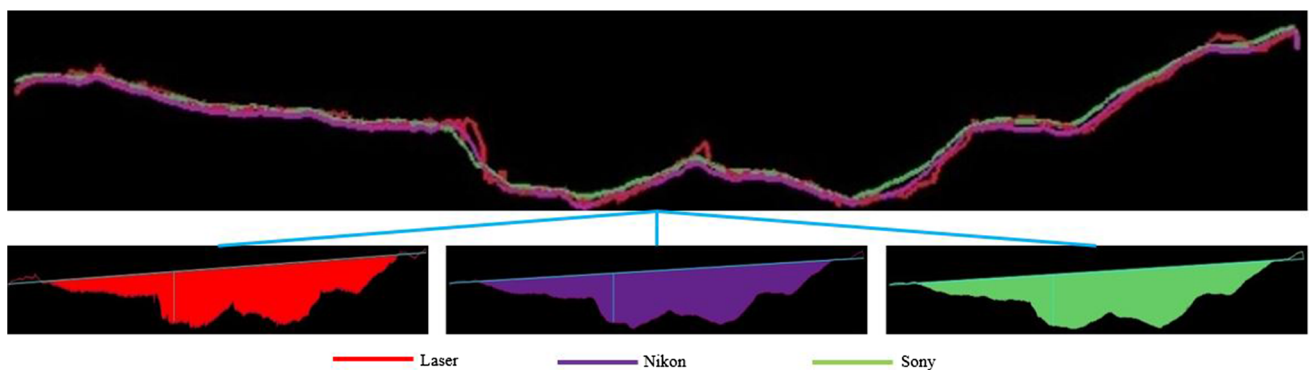


Fig. 6 Sections created on the surface and area calculation for each data source

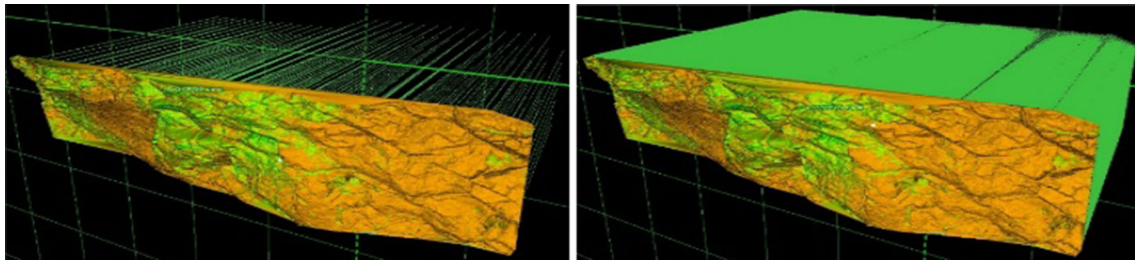


Fig. 7 Volumetric calculation through X–Z plane with sampling step of 0.1 m (left) and 0.01 m (right)

Table 2 Volume values with sampling step of 0.1 and 0.01 m between the back of the surface and plane (m³)

Data source	Sampling step of 0.1 m				Sampling step of 0.01 m			
	Region 1	Region 2	Region 3	Region 4	Region 1	Region 2	Region 3	Region 4
Laser	14.8097	22.8794	4.6687	4.5179	14.8097	22.8567	4.7289	4.5682
Nikon	14.7705	22.3590	4.6955	4.5161	14.6631	22.3169	4.7446	4.5427
Sony	14.7138	22.3360	4.7096	4.4979	14.6717	22.3023	4.7536	4.5653

Table 3 Values corresponding to various accuracy criteria for 3 data sources (mm)

Item	Total station-TLS			Total station-CRP (Nikon)			Total station-CRP (Sony)		
	X	Y	Z	X	Y	Z	X	Y	Z
Max. value	15	9	8	7	9	7	16	16	17
Min. value	0	0	1	0	0	0	1	0	1
Mean value	6.9	1.6	4.95	2.27	2.64	1.86	8.82	4.68	5.91
RMS value	8.07	2.62	5.29	2.61	3.63	2.59	10	6.01	7.81

Fig. 8 Maximum area differences between cross sections of different data sources (m²)

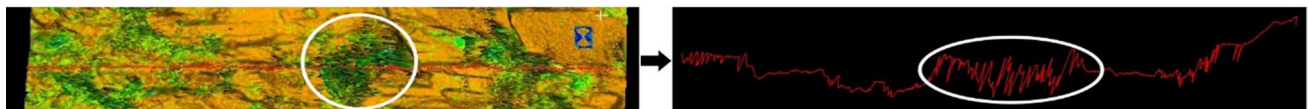
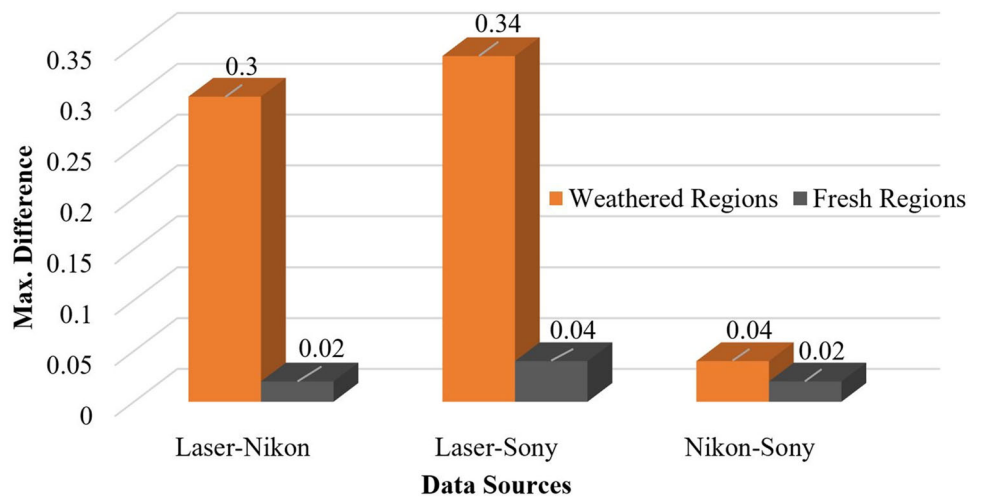


Fig. 9 Change of section on grass

In addition to the surface character, another factor that causes slight differences between overlapping sections is grass data encountered by the section given in Fig. 9. Data

outside the pure rock surface cause zigzags with numerous depth and peak point on section profile. This is particularly evident if the data source is laser scanner. About 4 times of

one of the two data sources used in the CRP for this study and 2.5 times of the other one was produced by laser scanner.

The values obtained in Table 2 represents the results of 3D analysis for 4 regions with different sampling intervals. The approach in this analysis, where the volume values of the models with a reference plane are calculated, is the straight lines that form the references between the two surfaces along Y-axis. It is the Y-axis which gives depth information in the model produced by 2D photographs or by the point data generated from the laser beam which is sent to the surface by the scanner. When the values in the Table 2 are examined, it is seen that the differences between the results are quite small. When the maximum and minimum differences between the three data sources are analysed depending on the diverse featured surfaces, it can be seen that the differences between CRP and TLS are more for the weathered regions as indicated in Fig. 10 (left). Some areas which have no point data for surface but closed due to triangulation in meshing need to be deleted. This can change the proximity of different data sources in CRP to TLS results. When compared based on different sampling intervals, the average of the results obtained with the two data sources used in the CRP method is close to TLS results as indicated in Fig. 10 (right). As already mentioned, regions determined for 2D and 3D analyses are cleaner than surrounding environment and do not contain many non-surface objects. When the volumetric calculation is performed for an area of approximately 150 m² including many grass, shrub and soil, dissimilarity between techniques can be clearly sensed. In this case, volume difference between TLS and CRP can be up to almost 11 m³.

One of the most important issues for a study made by utilizing the discipline of geomatics engineering is the error calculation and error propagation law. The approach based on the results obtained in Table 3 is that for CRP, there are raw coordinate values measured for the GCPs in the field

and their measured values on the model, but not in the TLS. Therefore, if an accuracy analysis is performed using coordinate values for TLS, a data set that can be considered as a reference is required. Except for the errors affecting the accuracy originated from measuring instruments used in both methods such as centring and levelling, the main difference between the two hardware is the accuracy of distance measurement. Therefore, since the distance measurement accuracy for the instrument used in the CRP is 2 mm ± 2 ppm for paper reflector and in the TLS is ± 4 mm according to instrument prospectuses, the values obtained by total station were used as a reference in the accuracy analysis of the TLS. That is why accuracy comparison for the rock models created by using two techniques is based on the measurement error values specified by the manufacturer. Accordingly, model errors calculated according to Table 3 are approximately 5.2 mm for CRP (Nikon D700), 10 mm for TLS and 14 mm for CRP (Sony DSC-H9). This approach is not a standard. It is a way to evaluate the 3D model entirely instead of interpreting the whole model with the help of comparisons to be made at certain parts on the model. At the same time, the accuracy values for the models produced by both TLS and CRP are an interior accuracy. If an accuracy analysis is to be performed independent of the total station for TLS, reference values can be obtained using callipers for objects with regular geometric shapes (Gumus and Erkaya 2011; Alkan and Karsidag 2012) but, this is not the case for the object in this study due to its nature. The differences between laser scanner and total station for 22 control points are presented in Fig. 11.

The coordinate differences between the values obtained by the two measuring instruments range from 0 to 1.5 cm. When the points with the greatest difference are examined, it is highly probable that the laser beams cannot perform the expected return at these points due to the location of marked target papers and their cross stance on the surface. At this point, incidence angle is an important variable. The

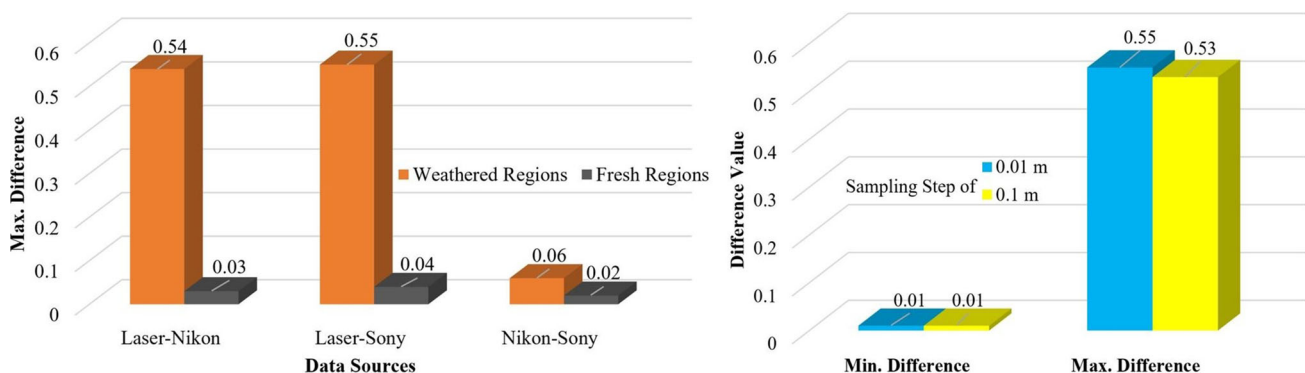
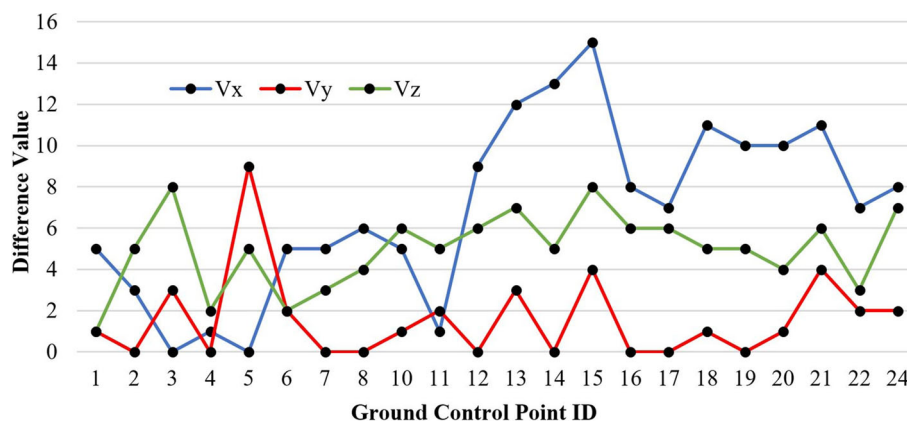


Fig. 10 Maximum volume differences for surfaces with varied characteristics (m³) (left) and variation in volumetric values depending on the sampling step (m³) (right)

Fig. 11 Coordinate differences of GCPs obtained by total station and laser scanner



incidence angle of the laser beam directly affects the accuracy of the coordinates. Kersten and Mechelke (2008) reached difference values up to 12 mm in their research performed with different laser scanners depending on the incidence angle. When some points such as 13, 14, 15, 18 and 21 are excluded from the analysis, it is possible to mention an accuracy of around 7 mm for the model produced by using TLS. According to Fig. 11, maximum differences were increased to 15 mm in TLS and 17 mm in CRP. These highest values belong to target papers for these GCPs. Additionally, it may not always be possible for the laser scanner to catch the middle part of the target paper perfectly (Sturzenegger and Stead 2009).

What is really important for error calculation is to stay within the specified error limitation. If this can be done by both methods, the factors that determine preferences for methods are cost and time. If the study object is rock, the quantitative accuracy obtained with every 3 data sources is sufficient in this study. Other than these, it is also known that the accuracy criteria for laser scanners can vary from instrument to instrument (Boehler et al. 2003). After this point, three matters come to the fore: software, scanning distance and material properties. Different results can be obtained when the same data are evaluated in different software (Stumpf et al. 2015; Fau et al. 2016; Morgan et al. 2017). If the accuracy values for the CRP and TLS are highly close to each other; this range may increase or decrease in different software. The variety of image matching and mesh generation algorithms is the main reason for this.

The distance between the object and the scanner affects the length of time the laser beam travels and the accuracy obtained in TLS is also dependent on the distance (Kajzar et al. 2015). The effect of distance on the accuracy in CRP comes from interfering with the value of GSD. The GSD value drops as the distance is reduced owing to the fact that photographs are taken at the same focal distance and the pixel pitch value is independent from all of them and constant. Another considerable factor that needs to be

considered in accuracy assessment is object type and surface materials. Determining the model accuracy values given in the instrument prospectuses for scanners as reference is contradictory to study conducted by Kedzierski et al. (2015) as contradict to results obtained in the study. Calculated values in Figs. 8 and 10 (left) obtained according to 2D and 3D analyses clearly proved that different results can be obtained for different surfaces. In CRP, the difference in surface properties and object type play an important role in accuracy achieved due to texture. High texture and dense colour range allows the dense point cloud to be produced at the required level during the photographs are matched to each other. The articles in which the CRP and TLS yields better results on different surfaces of the same object published by Sturzenegger and Stead (2009) and Gonzalez-Jorge et al. (2012) have supportive qualification for approach applied on rock surface and results obtained in this study. In the CRP, other factor affecting the accuracy is the camera, and thus environmental conditions which affect the optical system. It can be understood that Nikon D700 with better technical specifications than Sony DSC-H9 perform preferable results when investigated the Gauss-Curves formed for point clouds from both cameras as presented in Fig. 12. It can be said that surface texture can be better depicted by Nikon D700 than Sony DSC-H9.

Conclusions

As a result of the all analyses and comparisons, the most important result obtained in the study is that it is not possible to make a definite judgment that CRP or TLS is better than the other due to the variability and overage of the factors affecting the accuracy in both methods. TLS is, of course, more technological, more independent from the error source “human”, but the values obtained by the analysis made in the laboratory or a test field for the laser scanners indicate the maximum achievable. Therefore, it is

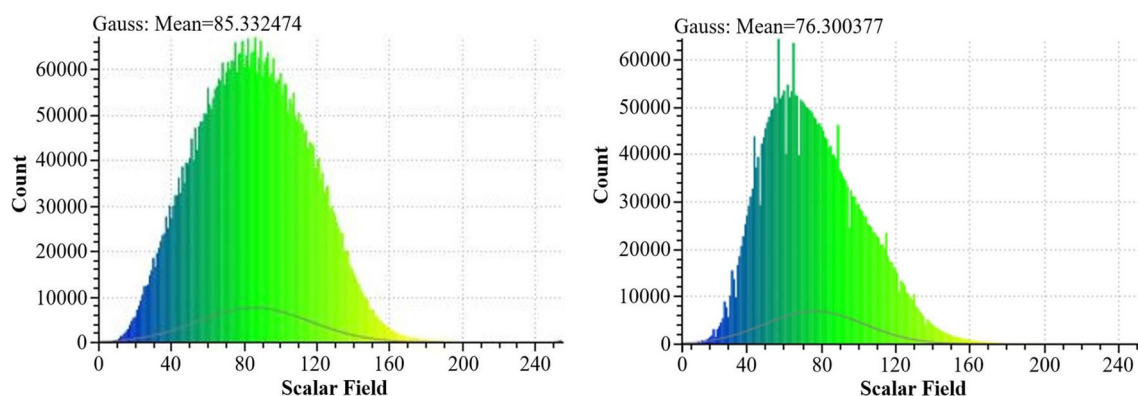


Fig. 12 Gauss curves for point clouds produced from Nikon D700 (left) and Sony DSC-H9 (right) in CRP

important to consider real-world accuracy when one of the techniques is preferred. If sufficient accuracy can be obtained with both method, other essential criteria such as cost and time gain more importance.

Research and studies on the TLS have been accelerated in recent years, and both methods continue to develop within their dynamics. The reason for their continuous development is restrictions available for both. The reason of why investigations are made is to remove these constraints or reduce them as much as possible. The use of same type of data produced by different theoretical principles with both techniques is a better option. This needs to be done for more extensive studies. So, instead of evaluating both methods as opponents and glorifying one another against the other, it is a more logical viewpoint to take advantage of each other as complementary.

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