Extraction of discontinuity sets of rocky slopes using iPhone-12 derived 3DPC and comparison to TLS and SfM datasets

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Abstract. Characterisation of a rock mass requires data from the intact rock along with the discontinuities. Assuming that the discontinuities are planar, its characterisation requires its number and orientation. This leads to the analysis of the normal spacing, the persistence and the roughness, among others. The geometrical analysis of the surface enables the calculation of the parameters to characterise the discontinuities, and the use of digital datasets enhance them. Remote sensing techniques, such as the Terrestrial Laser Scanning (TLS) instruments of 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. However, the cost of the TLS instrument could still be a barrier to its use to most scholars. Because of this, the community shows a growing interest in Remotely Piloted Aircraft Systems (RPAS) equipped with digital cameras or in smartphones equipped with high-quality cameras to capture digital datasets of rocky slopes. The SfM workflow processes the captured images, reconstructing the rocky slope through a 3D point cloud and textured meshes. Although previous studies show that the SfM-derived point clouds present less quality than TLS-derived datasets in terms of accuracy, the use of SfM is still of interest because of its cost. In 2020 Apple launched the Iphone-12 device, which is equipped with a LiDAR sensor that is not used to capture the surface coordinates but to enhance the photo’s quality. Since then, the community has developed several applications to reconstruct 3D surfaces using this device. This leads to consider this device as an intermediate option between the TLS and SfM to characterise rocky slopes and their discontinuities. In this communication we explore the digitalisation of a rocky slope via TLS instruments, SfM technique and using the Iphone-12 device. It comprises a 26 meter high mechanically excavated rocky slope in Cretaceous marlstones and limestones. To capture the surface, we used three configurations, and we found that to scan ground surface the distance device-surface had to be less than 3 meters. The discontinuities are characterised using the three sources of information using the DSE software. The results show a promising match compared to the TLS or SfM. This evidences that these devices will soon be widely employed for evaluating rocky slopes.

1. Introduction
Rock slope engineering requires the characterisation of the rock mass [1]. Basically, the designer needs to know the geology of the environment, the geometry of the slope to design, the hydrogeological and seismic conditions and the resistant parameters of the rock mass. The latter comprises two parts: the behaviour of the intact rock and the characterisation of the discontinuities. The intact rock is usually
modelled via the existing failure criterions, such as the Hoek-Brown failure criterion [2,3]. However, the stability of a rocky slope usually depends on the discontinuities rather than the intact rock strength.

The rock mass characterisation must focus on the description of discontinuities. The parameters and means to define the discontinuities were presented by the ISRM [4], and are summarised in Table 1. Obviously, the above mentioned suggested method only considered the instruments available at this time. However, in the 2020s 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.

Table 1. Parameters used to characterise discontinuities and methods of data collection. Modified from Riquelme et al. [5]

| Parameter          | Traditional method [4]                                                                 | Current methods                              |
|--------------------|----------------------------------------------------------------------------------------|----------------------------------------------|
| 1. Orientation     | (A) Compass and clinometer method                                                       | 3D point clouds:                             |
|                    | Compass and clinometer                                                                 | 3D laser scanning [6,7]                       |
|                    | Clino-rule of 50 m.                                                                    | Digital stereo-photogrammetry [8,9]          |
|                    | (B) Photogrammetric method                                                              | SIM [10]                                     |
|                    | Reconnaissance survey equipment                                                        |                                              |
|                    | Phototheodolite and tripod                                                             |                                              |
|                    | Control survey equipment                                                               |                                              |
|                    | Stereoscopic plotting instrument                                                      |                                              |
| 2. Spacing         | Measuring tape, min 3 m                                                                 | 3D point clouds:                             |
|                    | Compass and clinometer                                                                 | TLS and ALS [11–13]                          |
| 3. Persistence     | Measuring tape, min 10 m                                                                | 3D point clouds:                             |
|                    | Compass and clinometer                                                                 | TLS [5,11,14]                                |
|                    | 3D point clouds:                                                                        | Digital Surface Models [15]                  |
| 4. Roughness       | (A) linear profiling method and JRC [16]:                                               | 3D point clouds [17–21]                      |
|                    | Folding straight edge of at least 2 m, in mm                                             | Profiles [22]                                |
|                    | Compass and clinometer                                                                 |                                              |
|                    | 10 m of light wire, marks at 1 m                                                        |                                              |
|                    | (B) compass and disc-clinometer method                                                  |                                              |
|                    | Geological compass                                                                     |                                              |
|                    | Four thin circular plates                                                               |                                              |
|                    | (C) photogrammetric method: same as (1)                                                 |                                              |
| 5. Wall strength   | Geological hammer with one tapered end                                                  | Infill scale-independent classification [24] |
|                    | Strong pen knife                                                                       |                                              |
|                    | Schmidt hammer: JCS                                                                    |                                              |
| 6. Aperture        | Measuring tape of at least 3 m, graduated in mm                                        | Infill scale-independent classification [24] |
|                    | Feeler gauge                                                                           |                                              |
|                    | White spray paint                                                                      | Hyperspectral imaging [25]                  |
|                    | Equipment for washing the exposed rock                                                 |                                              |
| 7. Filling         | Measuring tape of at least 3 m, graduated in mm                                        | Infill scale-independent classification [24] |
|                    | Folding straight-edge, at least 2 m                                                     |                                              |
|                    | Plastic bags for taking samples                                                        |                                              |
|                    | Strong pen knife                                                                       |                                              |
| 8. Seepage         | Visual observation                                                                     | Infill scale-independent classification [24] |
|                    | Air photographs, weather records                                                        |                                              |
|                    | TLS [26,27]                                                                            |                                              |
|                    | Photographs                                                                            | Digital Photogrammetry                       |
|                    | Photographs                                                                            | Thermal images [26]                          |
| 9. N of sets       | Based on (1)                                                                           | Based on (1)                                 |
| 10. Block size     | Measuring tape of at least 3 m, graduated in mm                                        | Based on (1)                                 |
|                    | TLS [28]                                                                               |                                              |
|                    | SIM [29]                                                                               |                                              |

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, and particularly to the characterisation of rocky slopes. As shown in Table 1, the scientific community has shown growing
interest in the extraction of information of the discontinuities from remote sensing derived datasets. This is quite interesting as it enables the characterisation of the discontinuities without accessing to the surface.

Two fundamental techniques have been employed to capture the rocky surface: 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 [30] with high-speed data acquisition up to 500,000 measurements/sec [31]. 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 a great acceptance among the experts in this field. [32]. 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 analysed to detect the discontinuity sets, their orientations and to extract some of their parameters (see Table 1). In both cases, the number of the discontinuity sets and their orientations fit reasonably well, as showed Riquelme et al. [33]. However, the intensive use of smartphones motivates the companies to develop better devices, with better cameras and more powerful processors. In 2020, Apple presented the iPhone12, which is equipped with an excellent camera and a LiDAR sensor. 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. This leads us to consider the iPhone12-derived 3DPC as a candidate to characterise a rock slope. The idea of scanning a rocky slope using a common device carried in our pocket may change the way the rock mechanics field experts capture the datasets.

In this contribution, we consider the rocky slope analysed by Riquelme et al. [33] in Alicante, Spain, using a TLS and the SfM technique. Our aim is to scan the same outcrop using an iPhone12 to detect the discontinuity sets and their orientations, and to compare them to the TLS and SfM. The results will lead to discuss the potential of this device.

2. Materials and methods

To test if the iPhone12-derived 3DPC is suitable to extract the discontinuity sets, a limestone subvertical slope is captured using a TLS, the SfM technique and an iPhone12 device. Figure 1 shows the TLS and SfM datasets are those used by Riquelme et al. [33] in a previous contribution to the Eurock Congress.

![Figure 1. 3DPC of the slope captured via (a) SfM and (b) TLS.](image)

The surface of the slope sector was captured on 17/01/2021. The acquisition using the iPhone12 device used the 3D Scanner App [34]. During this process, we tested various configurations of the confidence and the resolution: High confidence – High resolution; Medium confidence – Medium resolution – High confidence – Low resolution. Time of processing was 4 minutes, 2 minutes, and 20 seconds, respectively. The size of each textured mesh was 2085, 444 and 482 MB, respectively. The captured 3D point cloud is shown in Figure 2 (c-d-e) using the above described configurations. The
software generates a mesh that is later converted into a 3DPC using the CloudCompare software [35]. Comparing the results, we observed that using high confidence part of the slope was not reconstructed. The subhorizontal outcrops were poorly reconstructed. Contrarily, the subvertical surfaces were successfully reconstructed. The medium confidence provided a reconstruction that seems to cover the total area. However, this visual inspection is not enough to evaluate the extraction of discontinuity sets.

The inspection of the 3DPC showed two interesting things: (1) the scale was 1:1 so measurements can be extracted by measuring distance between points; and (2) the vertical axis was oriented to the OY axis. To register the 3DPC to the benchmark, it was needed to rotate the 3DPC 90 degree on the OX axis. Then, only a 3D translation and a rotation on the OZ axis was performed. We employed the Iterative Closest Point (ICP) method [36,37] available in the CloudCompare software [35]. No scale transformation was required. The final root-mean-square (RMS) point-to-point distance error was 0.0265276 m (computed on 50000 points).

![Figure 2](image.png)

**Figure 2.** (a) surface scanning with the iPhone12 at maximum 3 metres from the slope; (b) screen capture of the scanning process; captured 3DPC using the following configurations: (c) High confidence - High resolution; (d) Medium confidence medium resolution and (e) High confidence – Low resolution.

We analysed the three 3DPC using the Discontinuity Set Extractor software [7,38]. To determine the normal vector associated to each point, the analysis used thirty neighbouring points to fit a local plane. After calculating the normal vector, the corresponding normal vector pole was calculated and plotted into a stereonet. Finally, we computed the non-parametric density function of all the poles via the Kernel Density Estimation method [39]. Then, for each 3DPC, the stereonet was plotted and the principal poles were extracted.

3. Results

Figure 3 shows the stereonets of the three iPhone12-derived 3DPC and those captured using the TLS and the SfM technique. Two discontinuity sets were clearly detected in all cases: $J_1$ (87/325) and $J_2$ (40/125). Figure 4 shows the analysis of the orientations and the result of the classification of the iPhone-12-derived 3DPC (Figure 3 a) and the TLS 3DPC (Figure 3 d). Despite of the non-reconstructed surfaces of the iPhone’s 3DPC (Figure 2 e), the number and orientation of the principal poles have better correspondence to the TLS and SfM 3DPC rather than the other two configurations.
Figure 3. Stereonet of the poles for the three iPhone12-derived 3DPC (a-c), the TLS (d) and the SfM (e) 3DPC.

Figure 4. Coloured 3DPC (c and e) according to the HSV colour scheme of the corresponding normal vector pole (a and d); classified 3DPC according to the assigned DS (c and f).

To assess the potential of this data, we have applied the Coltop 3D [40] concept of assigning a colour to every point according to the position of the corresponding pole on an HSV colour scheme (Figure 4 a and d). In this figure, sub-figures (b) and (e) show two predominant colours (magenta for J1 and green for J2), and to minor colours (orange J3 and dark blue J4). This assessment is automatic and requires no
interaction with the user. The correspondence between the two-point clouds shows the promising potential of this device to reconstruct rocky slopes surfaces and to extract both the number and orientations of the principal discontinuity sets.

To continue with our assessment, the DSE software extracted the principal discontinuity sets and classified both 3DPC. The Figure 4 (c) and (f) show the coloured classification of the TLS-derived and the iPhone12-derived 3DPC, respectively. This visual interpretation shows an excellent fit between the use of both datasets. We can also compare their stereonets, as shown in Figure 3 (a) and Figure 3 (d). The most interesting part of this result is the excellent match in the number of the discontinuity sets, their orientations, and the visual inspection of the classified point cloud.

The Figure 3 also shows that the configuration of the acquisition plays a key role in the results. The first configuration (i.e., high confidence and high resolution) provides better results than the other two configurations, despite the empty areas shown in Figure 2. This leads us to consider the use of the iPhone12 device as an excellent candidate to analyse rocky slopes.

4. Discussion
We have seen that the analysed data provides excellent results when using the configuration high confidence and high resolution. However, we have also observed that some areas cannot be reconstructed.

The way we capture the data is a key factor. During the scan, the distance between the surface and the device was approximately less than 3 m. Compared to the used TLS (Leica ScanStation C10 [41]) that ranges up to 200 meters, and the SfM technique that can employ even a giga pixel imaging [42,43], the range of this device is a handicap for its use in the field.

A positive aspect of the use of this device is the 1:1 automatic scale. Because of this, we can consider the idea of measuring normal spacing and persistence of the discontinuity for further studies. Another aspect is the time of processing (only four minutes), regardless of the capturing time (i.e., scanning or taking the photos). When using the SfM technique, it can take two hours approximately depending on the used machine. Contrarily, when using the TLS, it can take seconds to register all scan stations when targets are used. However, to extract the orientations, the iPhone-12 dataset must be registered to a global reference system aligned to the north and to the vertical line. Despite this processing time, the results lead to the idea that this device will become soon the standard process for this measurement.

5. Conclusion
We have explored the application of the iPhone12 device to capture the surface of a rocky slope and the extraction of discontinuity sets. We tested three configurations, being the best one “high confidence and high resolution”, and the processing time was four minutes. We analysed the 3DPC and extracted the number of discontinuity sets and their orientations using the open-source software Discontinuity Set Extractor. Then, we compared the results with those got using the TLS and SfM-derived 3DPC, showing promising similarities.

This contribution evidences the high potential of the iPhone12 device as a common tool to assess rocky slopes. Despite the range limitation, the fast development of these devices points to a near future where engineers and geologists will use their smartphone jointly with their geological compass. We expect that in a near future, the community will launch an app that enables users to identify during the fieldwork the number of discontinuity sets, their orientations and calculates the normal spacing, persistence and roughness.

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