Potential possibility of using terrestrial laser scanning in petrography

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Abstract. Terrestrial laser scanning is a wide spectrum tool, applied at present both in engineering and medicine. This work presents the results of a laboratory test that was aimed at assessing the potential of using this measurement technique for the identification of petrographic varieties. Rock samples were measured with the application of a Leica ScanStation C10 scanner. Values of the intensity index obtained from point cloud data were subject to statistical analysis. The main focus was posed on comparative analyses of samples from the same petrographic varieties collected from different localities, as well as on the influence of colour and surface humidity of the samples on the change of intensity index values.

1. Introduction
Laser scanning is presently one of the most popular measurement technologies. Its versatile application in various branches of science and industry have resulted in numerous issues related with laser scanning being commonly discussed in scientific reports [1, 2].

Laser scanning is linked with the wide-ranging studies on the intensity of laser beam reflection. The value of intensity is the registered force of the laser beam reflected from the scanned object. It records all components of the reflected light signal. Factors influencing the force of laser beam reflection can be subdivided into three groups [3]:

− system factors – depending on the type of applied scanner, including: type of rangefinder, length of laser wave, detector sensitivity, transmitter force;
− atmospheric factors – air temperature, pressure, humidity and dustiness;
− factors related to the character of the scanned surface – depending on the physical-chemical properties of the material: colour, roughness and surface humidity [4-7].

Additionally, intensity values depend also on the reflection properties (glossy, smooth surfaces), incidence angle of the laser signal (the value of energy returning to the scanner diminishes with increase of laser beam incidence angle), distance between the scanner and the scanned object [3], which also influences the actual dimension of the laser spot [1]. Due to these issues, terrestrial laser scanning is a potential tool for recognizing various types of materials, including petrographic varieties. The attempt to use this indicator for the classification of rock types is the main focus of this report.
2. Materials and methods

The tests were performed in laboratory conditions. A total of 27 samples from the collections of the Faculty of Geoengineering, Mining and Geology of the Wrocław University of Science and Technology was tested (Fig. 1):

- 3 minerals: galena, chalcedony (2 samples),
- 24 rocks: limestone (2 samples), sandstone (3 samples), granite (3 samples), marble (2 samples), gneiss (2 samples), rock salt (5 samples), lignite (2 samples), hard coal, basalt, porous lava, granodiorite, conglomerate.

Part of the analysed samples was tested twice: as dry and wet samples. These included:

- granites from Strzelin, Strzegom and Karkonosze,
- sandstones: one sample from the Fore-Sudetic Monocline and two samples from the Stołowe Mts – quartzitic and glauconitic,
- marbles: two samples from Stronie Śląskie.

It should be pointed out that samples representing the same petrographic variety were collected from different geological sites or regions of Poland.

![Figure 1. A collection of rocks and minerals selected for scanning.](image)

An important task was the adequate planning of the test, i.e. preparation of the test stand to ensure precise and reliable results. The measurement was made in conditions favourable for scanning, i.e.:

- uniform light,
- close (relatively identical) distance between the scanner and the measured object,
- stable temperature.

A white background was prepared so that the laser beam would not be subject to excessive dispersion (Fig. 2). The Leica ScanStation C10 scanner was used in the tests. Measurement of each sample took place from the same free stand of the scanner. The samples were assembled at a distance of 1.5 m from the device in a perpendicular position in order to reduce the negative influence of the laser beam incidence angle on the intensity value. Moreover, the analysed rocks and minerals were photographed by a Nikon D800 digital camera with a high resolution CMOS 36 matrix. The scanning resolution was set at 1x1 cm for the distance of 100 m. A single measurement lasted for 3 – 7 minutes. In effect, a set of thirty four point cloud data were obtained, with millions of point data for each sample (Fig. 3).
The obtained point cloud dataset was processed in order to perform a reliable statistical analysis aimed at detecting changes on the values of the intensity index. CloudCOMPARE – open source software – was used in this step of the analysis. Each point cloud was cleansed manually from artefacts. The analysed area was determined by removing points situated beyond the study area (the background and all noise registered during scanning due to dispersion of the laser beam). As a result, the front of the measurement object was obtained. The effect of manual cleansing of the point cloud is presented on the basis of the Dębnik limestone (Fig. 4).

The next step included thinning of the several million point clouds so that the minimal distance between the measurement points was 1 mm and 5 mm. The need to perform such task came from the fact that the size of the laser spot at 0 – 50 m from the scanned object is 4.5 mm (according to criterion FWHH) [8]. Data collected directly from the test are not suitable for further analysis, because the laser spot was larger than the distances between the initially obtained points. An additional positive effect of this task was the significant diminishing of the dataset size (for the minimal distance between the measurement points at 5 mm, the number of points in the dataset was from 604 to 5670 points, depending on the size of the analysed sample), which caused that elaborating the analysis and statistics was much more efficient (Fig. 5). The final step in the CloudCompare environment was the export of the dataset again to .txt format, in which Intensity (I), subject to further analysis, was the most significant information.
3. Results

Information on the reflection force of the laser beam is supplied by terrestrial laser scanners usually in the form of raw data, as RAW Intensity. The point cloud obtained from the Leica ScanStation C10 scanner saves the value of intensity from the test in the range of -2047, +2048. For further analyses, Intensity was normalized, including rescaling of the input data to the range of [0,1], in which 0 corresponds to the minimal obtainable value and 1 is the maximal value [3].

The main aim of the statistical analysis was testing whether the final values of the intensity ranges may be used to separate the point cloud into distinct groups. The task began with calculating the basic

![Figure 4. Dębnicki limestone: isometric view (a), front view (b), front view after cleaning the point cloud (c).](image1)

![Figure 5. Point cloud after subsampling - marble from Stronie Śląskie: measurement data (a), minimum distance between points 1 mm (b), minimum distance between points 5 mm (c).](image2)
statistical parameters describing the reflection force of the laser beam for all samples subject to scanning (Tab. 1). In order to construct a graphic representation of the intensity frequency, the following parameters were also determined (Fig. 6) [9]:

- Subdivision of the variability range into classes: \( k = \sqrt{n} \),
- Compartment size: \( s = \frac{n}{k} \).

Table 1. Summary of basic statistical values of intensity values for all scanned samples - after data normalization, the distance between points is 0.005 m.

| sample name                                      | \( n \) | \( \text{min} \) | \( \text{max} \) | \( R \)  | \( \bar{x} \) | \( \sigma \) | \( k^* \) | \( s^* \) |
|--------------------------------------------------|---------|-----------------|-----------------|--------|-------------|------------|---------|---------|
| p01 - porous lava (unknown origin)               | 3295    | 0.167           | 0.321           | 0.154  | 0.202       | 0.014      | 57      | 0.003   |
| p02 - galena (unknown origin)                    | 650     | 0.151           | 0.939           | 0.788  | 0.213       | 0.071      | 25      | 0.031   |
| p03 - Dębnik limestone (black color)             | 2739    | 0.157           | 0.255           | 0.098  | 0.190       | 0.014      | 52      | 0.002   |
| p04 - limestone (white color; unknown origin)    | 3256    | 0.239           | 0.439           | 0.200  | 0.333       | 0.031      | 57      | 0.004   |
| p05 - Rotliegend sandstone                       | 1691    | 0.177           | 0.263           | 0.086  | 0.216       | 0.012      | 42      | 0.002   |
| p06 - quartzitic sandstone (unknown origin)      | 1724    | 0.235           | 0.424           | 0.189  | 0.347       | 0.025      | 42      | 0.005   |
| p07 - glauconitic sandstone (unknown origin)     | 851     | 0.217           | 0.357           | 0.140  | 0.262       | 0.022      | 30      | 0.005   |
| p08 - Strzelin granite                           | 945     | 0.233           | 0.398           | 0.165  | 0.293       | 0.026      | 31      | 0.005   |
| p09 - Strzegom granite                           | 1928    | 0.197           | 0.444           | 0.248  | 0.273       | 0.036      | 44      | 0.006   |
| p10 - Karkonosze granite                         | 1644    | 0.184           | 0.327           | 0.144  | 0.230       | 0.019      | 41      | 0.004   |
| p11 - marble #1 from Stronie Śląskie             | 2723    | 0.202           | 0.412           | 0.210  | 0.280       | 0.042      | 52      | 0.004   |
| p12 - marble #2 from Stronie Śląskie             | 3245    | 0.204           | 0.365           | 0.161  | 0.258       | 0.023      | 57      | 0.003   |
| p13 - granodiorite (unknown origin)              | 1827    | 0.179           | 0.361           | 0.182  | 0.221       | 0.020      | 43      | 0.004   |
| p14 - Kowary gneiss                              | 2178    | 0.133           | 0.259           | 0.126  | 0.192       | 0.018      | 47      | 0.003   |
| p15 - basalt (unknown origin)                    | 3048    | 0.142           | 0.222           | 0.081  | 0.178       | 0.011      | 55      | 0.001   |
| p16 - conglomerate (unknown origin)              | 2146    | 0.163           | 0.284           | 0.121  | 0.199       | 0.014      | 46      | 0.003   |
| p17 - rock salt from Wieliczka                   | 2297    | 0.169           | 0.446           | 0.277  | 0.216       | 0.025      | 48      | 0.006   |
| p18 - rock salt from Kłodawa                      | 2329    | 0.163           | 0.268           | 0.105  | 0.198       | 0.013      | 48      | 0.002   |
| p19 - rock salt (unknown origin)                 | 5670    | 0.138           | 0.477           | 0.339  | 0.202       | 0.027      | 75      | 0.004   |
| p20 - rock salt from Sieroszowice                 | 2243    | 0.192           | 0.315           | 0.123  | 0.220       | 0.010      | 47      | 0.003   |
| p21 - rock salt from Bochnia                      | 730     | 0.155           | 0.264           | 0.109  | 0.184       | 0.010      | 27      | 0.004   |
| p22a - chalcedony #1 (unknown origin)             | 880     | 0.227           | 0.491           | 0.264  | 0.336       | 0.060      | 30      | 0.009   |
| p22b - chalcedony #2 (unknown origin)             | 849     | 0.235           | 0.470           | 0.235  | 0.340       | 0.045      | 29      | 0.008   |
| p23 - Sowie Mts gneiss                           | 604     | 0.168           | 0.588           | 0.419  | 0.247       | 0.048      | 25      | 0.017   |
| p24 - lignite from Jaroszów                       | 4175    | 0.154           | 0.244           | 0.090  | 0.190       | 0.015      | 65      | 0.001   |
| p25 - lignite (Lower Silesia)                     | 2072    | 0.164           | 0.182           | 0.018  | 0.174       | 0.006      | 46      | 0.000   |
| p26 - hard coal from Guido Mine                   | 3612    | 0.076           | 0.190           | 0.114  | 0.141       | 0.014      | 60      | 0.002   |

* calculated value for preparing histograms; \( k \) - number of classes, \( s \) - class width.

In order to test which of the selected samples are characterized by a normal distribution, graphic analysis was performed in ArcMap 10.2.2 software, y=using the Normal QQPlot tool available in Geostatistical Analyst. It is worth noting that a normal distribution characterizes samples for which observations on the quantile-quantile (QQ plot) are arranged along a line at an angle of 45°. Quantile values for the standard normal distribution lie on the X axis, whereas the standard quantile values of the dataset is situated on the Y axis (Fig. 7) [10]. Analysis of the remaining plots suggests that the registered intensity values for samples:

- p04, p05, p08, p14, p15, p22b – almost completely overlap with the reference line, i.e. are characterized by normal distribution, and will be subject to further analysis;
- p02 – do not overlap with the reference line, therefore the sample does not have a normal distribution; this may result from the fact that the sample represents a mineral;
- p01, p03, p06, p07, p10, p11, p16, p18, p20, p21, p22a, p23, p24, p25, p26 – are only slightly deflected from a straight line, which may be caused by bending of the laser beam against the scanned surface;
− p09, p12, p13, p17, p19 – overlap the reference line only to a certain degree.

**Figure 6.** Summary of intensity distribution histograms for all scanned samples after data normalization in the range of [0.1], distance between points is 0.005 m.
The obtained dataset was characterized by a normal distribution, which allowed for using its properties.

In the next step, intensity ranges were created for samples that were characterized by normal distribution in order to test if they may form ranges completely corresponding to particular samples. Analysis was performed on the following samples: white limestone, Rotliegend sandstone, Strzelin granite, Kowary gneiss, basalt and chalcedony.

In order to achieve this task, normal distribution was taken into account, which involves the rule of 3 sigma—3 standard deviations. Based on this rule it can be assumed that [9]:

- 68.26% of the observations are within one standard deviation: \(1\sigma\), in the range of \((\bar{x} - \delta; \bar{x} + \delta)\);
- 95.45% of the observations are within two standard deviations: \(2\sigma\), in the range of \((\bar{x} - 2\delta; \bar{x} + 2\delta)\);
- 99.73% of the observations are within three standard deviations: \(3\sigma\), in the range of \((\bar{x} - 3\delta; \bar{x} + 3\delta)\).

The obtained results are presented in Tab. 2 and Fig. 8:

**Table 2.** \(1\sigma\) and \(2\sigma\) intensity ranges for samples with a normal distribution.

| sample | \(x\)  | \(\sigma\) | range \(1\sigma\) | range \(2\sigma\) |
|--------|--------|------------|------------------|------------------|
| p04    | 0.333  | 0.031      | 0.302            | -0.364           | 0.270             | -0.396          |
| p05    | 0.216  | 0.012      | 0.204            | -0.228           | 0.193             | -0.239          |
| p08    | 0.293  | 0.026      | 0.268            | -0.319           | 0.242             | -0.345          |
| p14    | 0.192  | 0.018      | 0.174            | -0.209           | 0.157             | -0.227          |
| p15    | 0.178  | 0.011      | 0.167            | -0.189           | 0.156             | -0.200          |
| p22b   | 0.340  | 0.045      | 0.294            | -0.385           | 0.249             | -0.430          |

**Figure 7.** Plot of normal QQ normal for intensities with points not lying near the reference line (points marked in light blue) in the XY system, data for Dębnik limestone - p03.
4. Discussion

Mutual pervasion of the intensity values of samples subject to the analyses can be observed for both 1σ and 2σ ranges. The overlapping intensity ranges for 1σ are much narrower compared to 2σ.

Mutual ranges for 1σ standard deviation occur for the following pairs of samples:

- p15 and p14 (0.174 – 0.189);
- p14 and p05 (0.204 – 0.209);
- p08 and p22b (0.294 – 0.319);
- p8 and p04 (0.302 – 0.319);
- p22b and p04, where the values of intensity for the chalcedony sample overlap the entire range of the limestone sample.

There is a break in the intensity values in the range of 0.228 to 0.268 within one standard deviation. Above the upper boundary of this break occurs granite, limestone and chalcedony. Higher values of the reflection force of the laser beam for these samples may be caused e.g. by colour, grain size and mineral composition. Among samples characterized by normal distribution, chalcedony displays the widest range of intensity values.

Determining unequivocal boundaries between particular rock types by constructing ranges of typical values of a particular feature is not effective. It is hampered by the insufficient number of breaks between the values for the analysed objects. The reason for such result may be e.g. the insufficient quality of the
input data. The analysis may be improved by including a larger number of samples representing the same rock types to the analysis in order to obtain average ranges of 1σ and 2σ.

5. Conclusions

This report presents the possibilities of using terrestrial laser scanning in petrography. Analysis of intensity distribution shows significant differences between varieties of the same petrographic types. The largest difference of the average value of intensity display limestones (0.143) and sandstones (0.131 between quartz sandstone and Rotliegend sandstone). Differences in the average value of the intensity index were also observed for granites (the largest difference, 0.063, was between the Strzelin and Karkonosze granites), gneisses (0.055), rock salt (the highest, 0.036, between white rock salt from Sieroszowice and rock salt from Bochnia) and lignite (0.016). For granites and marbles, intensity lies in a similar range, as opposed to gneisses, in which the difference was 0.462 and hard coals (coal from Jaroszów has a twice larger interval). Similar values of this parameter were observed for chalcedony (difference of the average intensity vale was only 0.003) and marble (0.022).

Galena clearly stands out from among the analysed samples. It is characterized by very wide dispersion of intensity (0.151 to 0.939), and the fact that as much as 93.07% observations (605 out of 650 points) is in the range of average intensity values (including standard deviation). Additionally, intensity values, as the only ones in the dataset, do not display a normal distribution. It may be concluded that these discrepancies are caused by the fact that galena is a mineral and not a rock or group of minerals.

The attempt to classify rock and mineral samples according to the presented methodology did not bring expected results due to the lack of clear boundaries between the analysed objects, which may be linked with the low quality of the obtained measurements. It may be assumed that a larger number of samples for each rock type and averaging of the obtained ranges may result in a more efficient analysis.

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