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# ACQUISITION OF A THREE-DIMENSIONAL VIRTUAL MODEL USING POPULAR CAMERAS

# GENEROWANIE MODELI 3D PRZY WYKORZYSTANIU POPULARNYCH KAMER

**Michał Kowalczyk, Jakub Markiewicz**

Department of Photogrammetry, Remote Sensing and Spatial Information Science,
Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland

KEY WORDS: close range photogrammetry, laser scanning, virtual model, point cloud comparison

ABSTRACT: Generation of precise and, at the same time, high resolution architectural documentation, acquired on the basis of terrestrial laser scanning or dense point clouds from digital images is still and open issue, which forms many challenges. Today, close range photogrammetry has great potential for development through the use of low-cost image acquisition tools. Mobile phones, digital camcorders or compact cameras are all sources of data, which potentially allow for the creation of reliable and accurate three-dimensional models of analysed scenes. This paper presents the results of a comparison between these aforementioned sources of image information, acquired by simple and popular cameras, and data acquired from a close range laser scanner. These sets of photos produced several virtual models of small architectural details, supported by Agisoft software. A final rating was conducted using data acquired for the same object using a laser scanner, which was taken as a referential approximation of the three-dimensional shape.

## 1. ANALYSED OBJECTS

Architecture and other monuments of the past are part of human cultural heritage, and thus need to be properly registered by modern applied measurement technologies. Sometimes there can be obstructions concerning the availability of these objects for measurement using proper metric equipment. This situation can occur under such conditions as war or other forms of conflict. Sometimes taking weighty equipment is impossible because of the cost this operation can incur. The main aim of this research was to check the quality of registrations performed by a non-metric, low-cost camera installed on a mobile phone and a simple SLR (single-lens reflex) camera.

Today, close range photogrammetry has great potential for development through the use of low-cost image acquisition tools. Mobile phones, digital camcorders or compact cameras are all sources of data, which potentially allow for the creation of reliable and accurate three-dimensional models of analysed scenes (Al-Hamad and El-Sheimy, 2014, Bakuła and Flasiński, 2014, Drap *et al.,* 2003,Masiero *et al*., 2014, Sirmacek *et al*., 2014, Tokarczyk *et al*., 2007).

Controlling the accuracy of the measurement methods should possibly be fulfilled using a diverse range of surfaces. For the purpose of these experiments, the frontal elevation of the stairs leading from the main hall of the main building at Warsaw University of Technology to the changing area was used. Beside this wall, a detail from the part of the balcony over the stairs was selected (Fig. 1).

The studied objects have a surface consisting of both smooth planes and rough details, which should potentially answer the question of how robust close-range photogrammetric techniques are in this particular case, in comparison to measurements using a laser scanning.

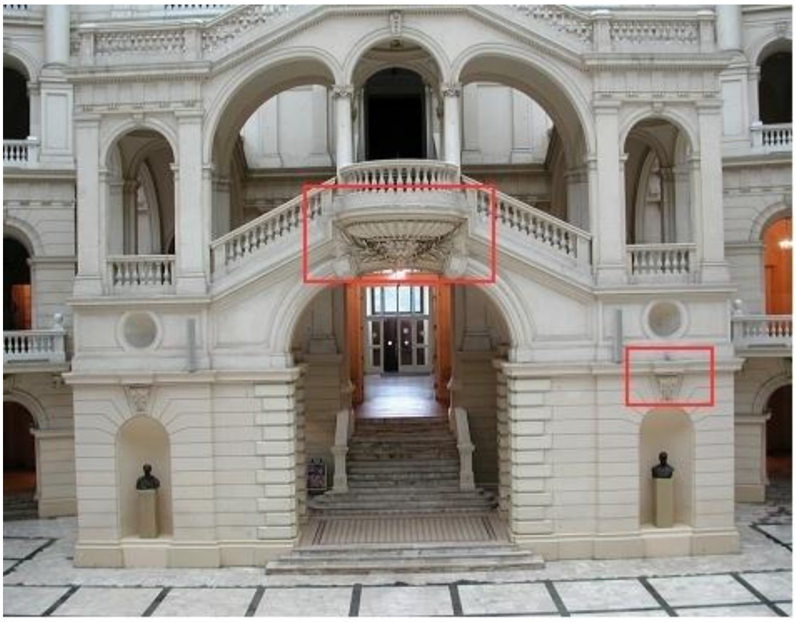


Figure 1. The wall surface and selected details for analysis

## 2. REFERENTIAL LASER SCANNING DATA

As a reference dataset, a collection of points taken using the Z+F 5006h close-range laser scanner was applied, with a high density parameter, i.e., a 6 mm gap between the points with a distance of 10 m from the instrument station. The technical parameters and an image of the scanner used are shown in Figure 2.

| distance \ rms [m] [mm] | black 10% | grey 20% | white 100% |
|---|---|---|---|
| 10 | 1.2 | 0.7 | 0.4 |
| 25 | 2.6 | 1.5 | 0.7 |
| 50 | 6.8 | 3.5 | 1.8 |

Figure 2. Theoretical accuracy and image of the terrestrial laser scanner used in the experiments, © Z+F 5006h

The point cloud produced is dense enough to represent the object, but in some areas of the object space there are parts where reliance on proper measurements is limited due to their close proximity to the edges. Data from scanners are not trustworthy in places where the angle between the normal surface vector and the laser ray vector has a value far from zero degrees. For this research, a set of referential orientation points were chosen for the measured surfaces. Figure 3 presents the laser scanning data in terms of intensity; the brightness scale depends on the strength of the reverse signal after reflection. Numbers and crosses represent points used as the basis for transformation (ground control points).

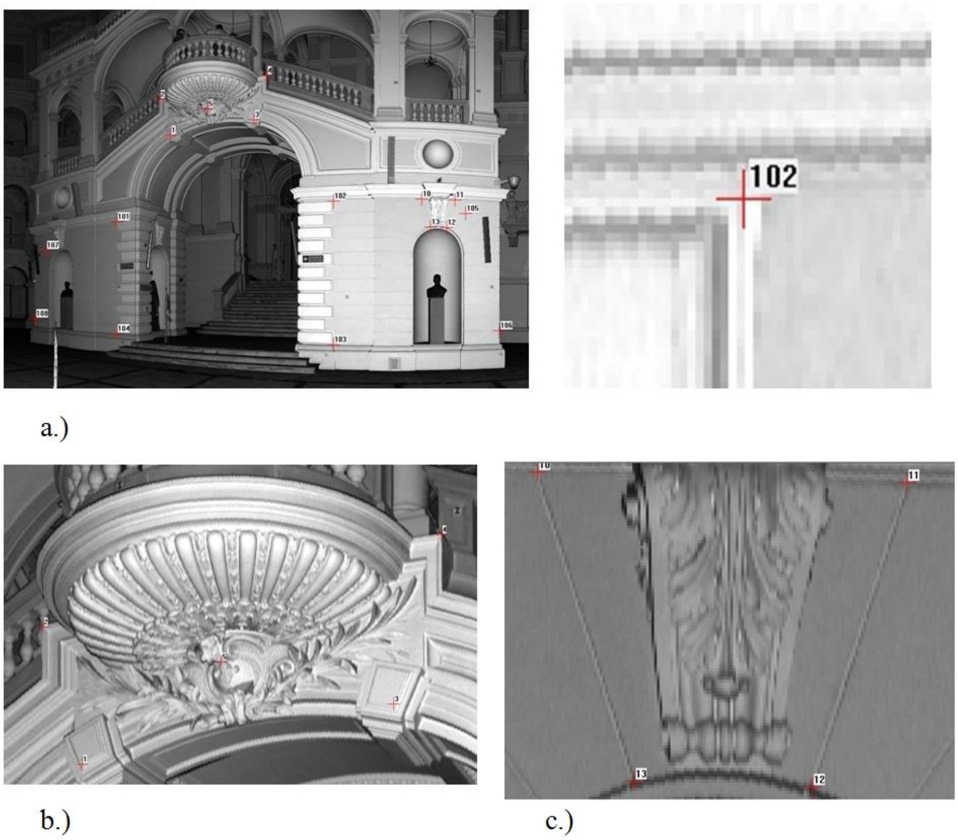



Figure 3. Laser scanning data used in the research and the chosen ground control points with an enlarged example, a.) wall, b.) detail 1, c.) detail 2.

## 4. REGISTRATION OF THE SCENE USING LOW-COST CAMERAS

The experiments were conducted using a Samsung S3 smartphone and a Pentax K-50 SLR camera with a Tamron 28-75 mm lens and an aperture factor of 2.8. The widest possible viewing angle was set. For the purposes of the research, a collection of stills taken from a video sequence were used, acquired using identical operational parameters in orderto make both cameras comparable. The number of pixels per frame was set as 1920 x 1080 pixels, writing the data as mp4 codec standard, or progressive recording, i.e., line by line for each image taken.

The films of the wall and selected details were separately recorded while walking along the face of the building, and each film was recorded twice – once for each camera. This basic approach was applied due to its cost-cutting potential, and is commonly used by archaeologists and art restorers. The configuration of the camera positions are shown in Figures 4, 5 and 6 as an orthogonal projection on the xy plane.

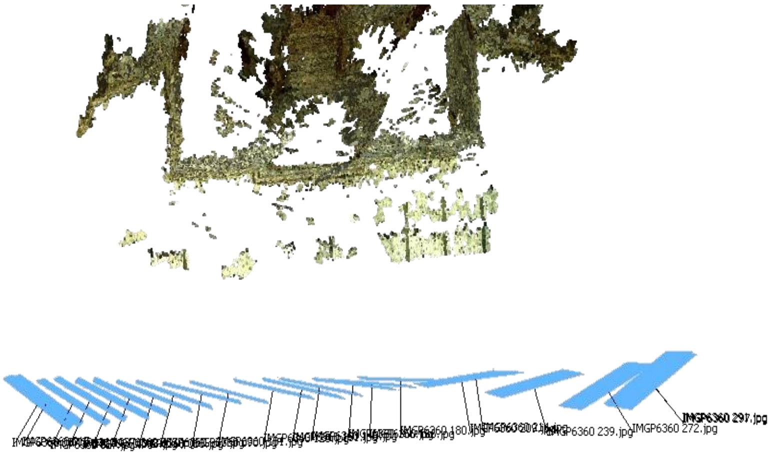



Figure 4. Camera positions for the selected frames: wall, view from the top.

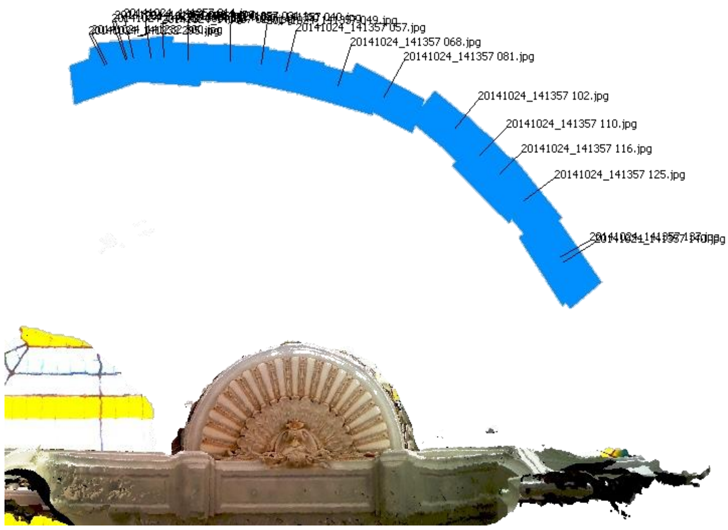



Figure 5. Camera positions for the selected frames: detail 1,view from the bottom.

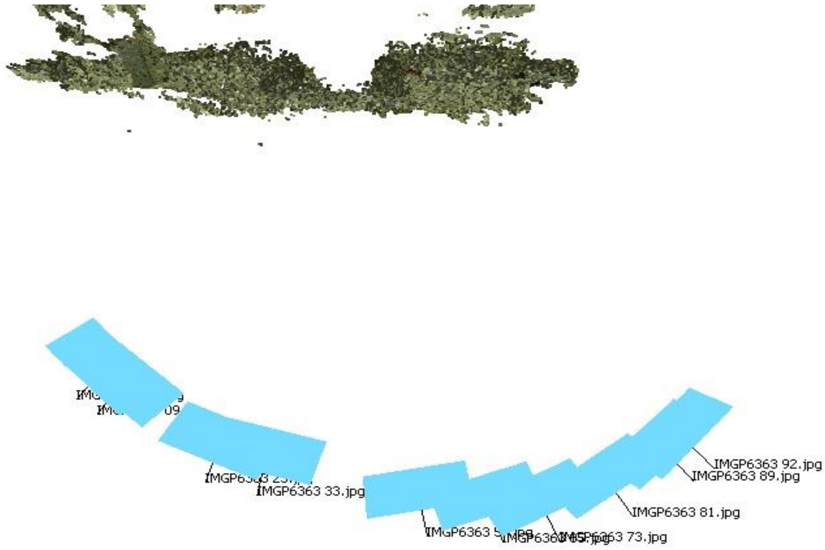



Figure 6. Camera positions for the selected frames: detail 2,
view from the top.

## 5. RESEARCH WORKFLOW

Several configurations of the images taken by both cameras were used to create the models. The Agisoft software produced camera position and orientation. The subsequent stages consisted of matching images to build dense point clouds and to produce a textured model. Furthermore, the acquired collection of object points was scaled and oriented to the scanning data by utilizing some of the characteristic points shown in Figure 3. Finally, the comparison between the two was accomplished using the CloudCompare freeware program. Table 1 describes the number of experiments.

Table 1. Number of research photos taken for each set.

| Object \ Camera | smartphone photos | SLR camera photos |
|---|---|---|
| wall | 23 | 11, 22 |
| detail 1 | 5, 9, 18 | 2, 3, 5, 9, 18 |
| detail 2 | | 3, 5, 10 |

### 5.1. Experiment stages

The following scheme presents the tasks undertaking to obtain a comparison between laser scanning and classic photogrammetrical results - Figure 7.

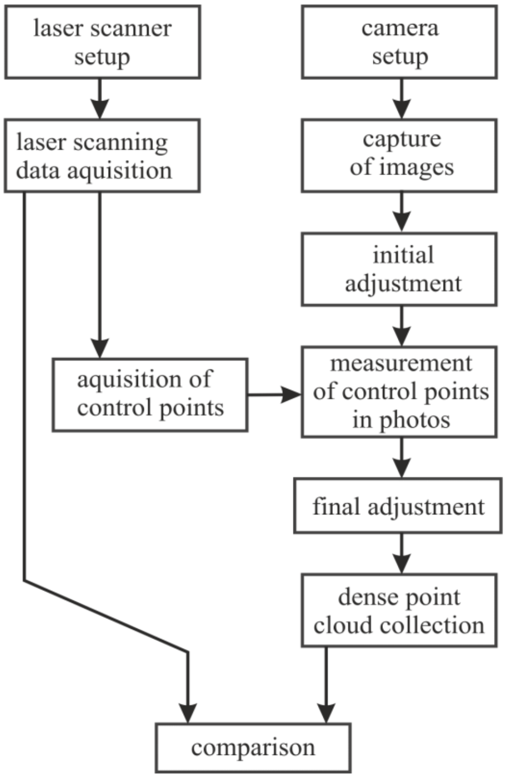



Figure 7. Stages of the experimental process.

### 5.2. Orientation of the models

For each set of photos, residuals were determined in the object space that represented the difference between the coordinates from the laser scanning dataset and those of the oriented model. Those residuals are based on characteristic points. Table 2 presents the results depending on the number of photos used and their points. In the table cells, the first number means the number of photos used (pho), the second number represents the number of points (poi) and the third is the value of the residual as a root mean square error in metres (res).

Table 2. Orientation errors

| Object \ Camera | smartphone pho, poi, res [m] | SLR camera pho, poi, res [m] |
|---|---|---|
| wall | 23, 5, 0.021 | 11, 7, 2.456<br>22, 7, 0.026 |
| detail 1 | 3, 5, 0.183<br>5, 5, 0.012<br>9, 5, 0.009<br>19, 5, 0.012 | 2, 4, 8.308<br>3, 4, 0.013<br>5, 5, 0.014<br>9, 4, 0.010<br>18, 4, 0.017 |
| detail 2 | - | 3, 4, 0.318<br>5, 4, 0.011<br>10, 4, 0.018 |

Table 3 presents the results of the camera calibration parameters under similar conditions, determined by the application of a self-calibration process (Hobruk *et al.*, 1996a; Sawicki, 2000) in the Agisoft PhotoScan software. Both of the cameras show instability in terms of interior orientation, although the smartphone performed somewhat better. The zoom lens in the SLR camera could have an influence on the repetitiveness of the determined parameters (Viley *et al.*, 1992a). Tilting of the camera probably vertically shifted the position of the principal point - value of y0 (Shortis *et al.*, 1998).

Table 3. Results of the constant values of the self-calibrated cameras and the principal point position in reference to the corner of the image.

| Parameter \ Camera [pixels] | smartphone 5, 9 photos | SLR camera 5, 9 photos |
|---|---|---|
| $c_k$ | 1639, 1596 | 2620, 2537 |
| x0 | 960, 942 | 1015, 1003 |
| y0 | 554, 563 | 859, 656 |

### 5.3. Comparison between collections of points

After properly preparing the orientation of the point clouds from the laser scanning data, a comparison was then performed using the CloudCompare software as a final step. The results are presented to scale from Figure 8 onwards.

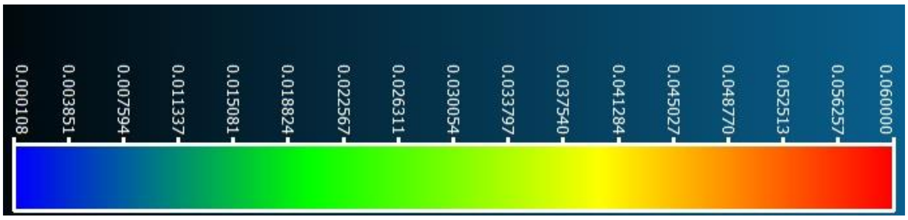



Figure 8. Scale bar presenting the distances between points from one compared set to another; values given in meters.

Next. Figures 9-13 describe some experimental cases, using a diverse number of photos to create point sets. Blue (darker) parts represent small differences (below 0.010m, which is acceptable for architecture registration). Green and yellow (lighter) parts are unacceptable for use for this purpose (G-3.4, 1981) due to the given size of the analysed object (0.020-0.040 m).

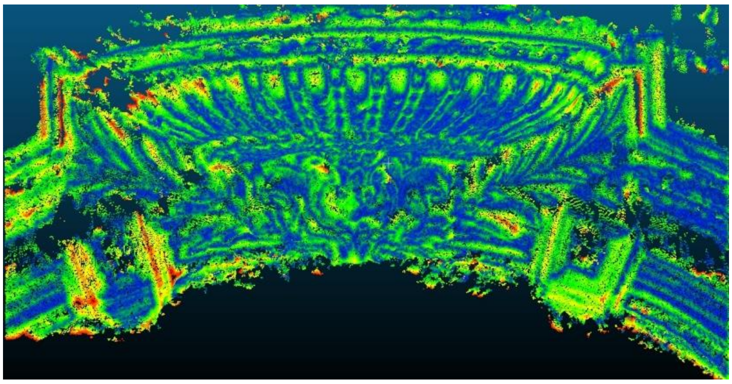


Figure 9. Object: detail 1, number of photos: three, SLR camera

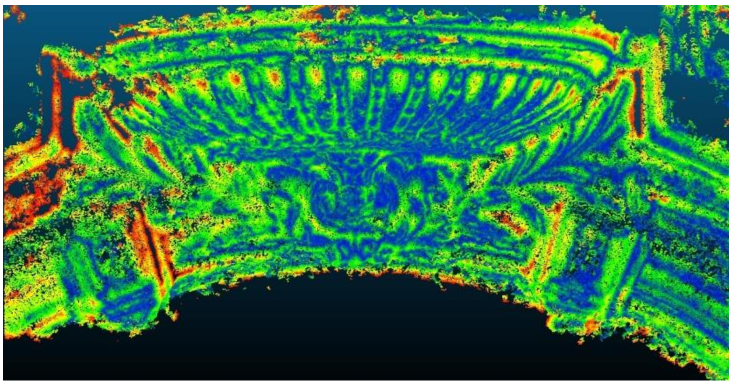


Figure 10. Object: detail 1, number of photos: five, SLR camera

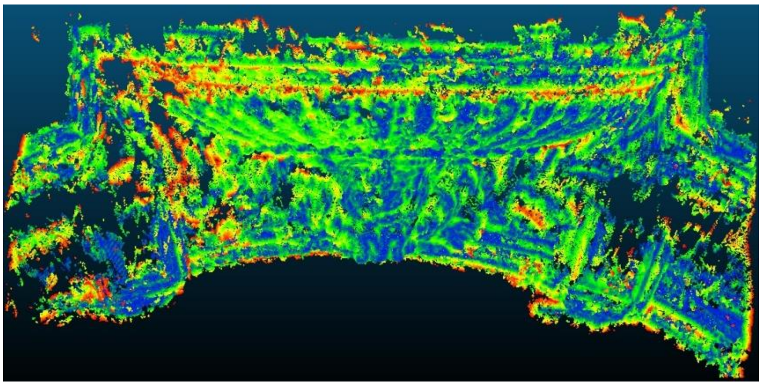


Figure 11. Object: detail 1, number of photos: five, smartphone

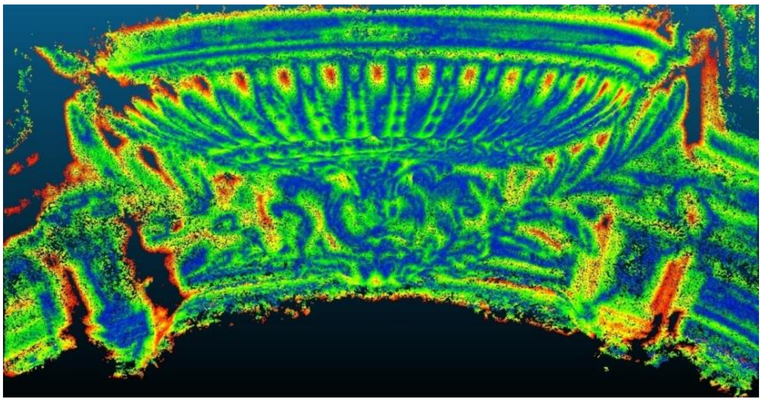


Figure 12. Object: detail 1, number of photos: nine, SLR camera

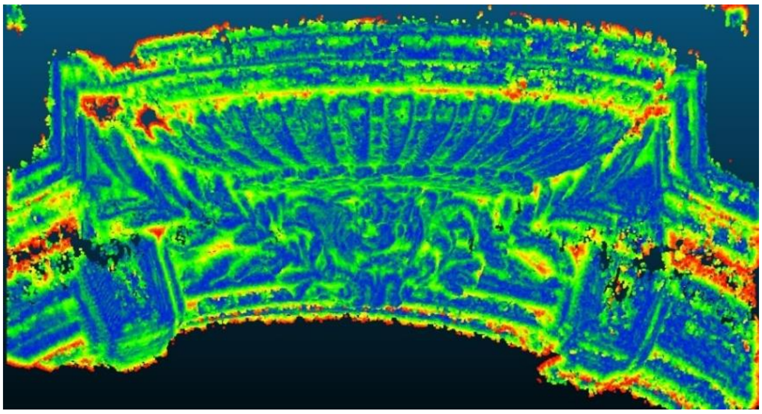


Figure 13. Object: detail 1, number of photos: nine, smartphone

The above results were obtained using similar, but not exactly the same, image configurations. The sensitiveness of the smartphone registration when using a small number of photos can be observed. With a large number of images, the smartphone solved this task better than the SLR camera. Histograms of these residuals are presented in Figure 14. The vertical axis represents the point count.

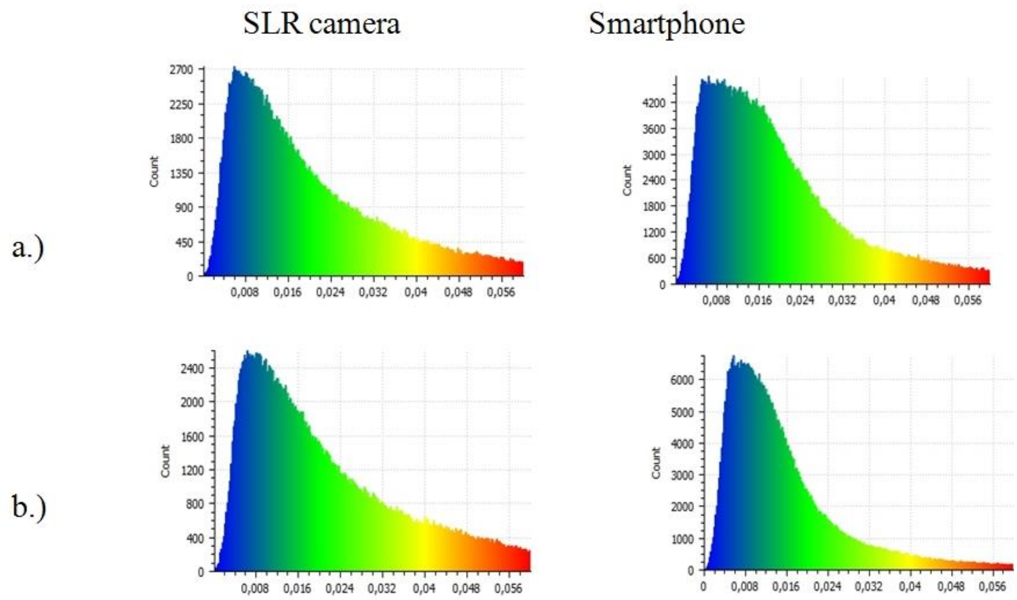



Figure 14. Histograms showing the differences between detail 1, a.) five photos, b.) nine photos; horizontal axis is scaled from 0.000 to 0.060 m.

The results confirm that the smartphone performs better when an increasing number of photos are used. The shift of the curve’s maximum point to the right of the Y axis attests to the orientation error and the difference between the mean distances inside two compared sets of points.

Figures 15, 16, 17 and 18 show similar examples of the differences between the registration of the wall and detail 2.

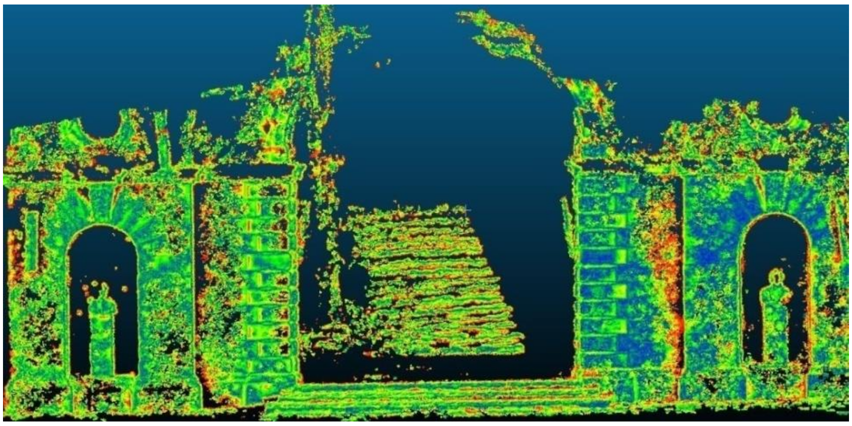


Figure 15. Object: wall, number of photos: 22, SLR camera

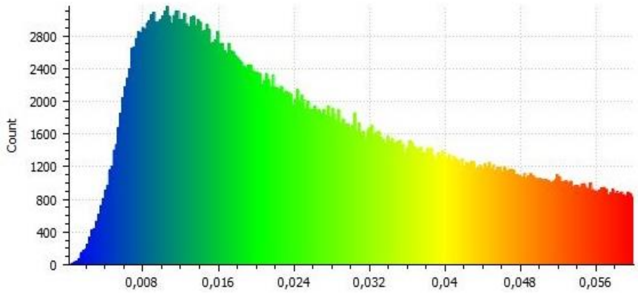



Figure 16. Histogram of difference. Object: wall, number of photos: 22, SLR camera, horizontal axis is scaled from 0.000 to 0.060 m.

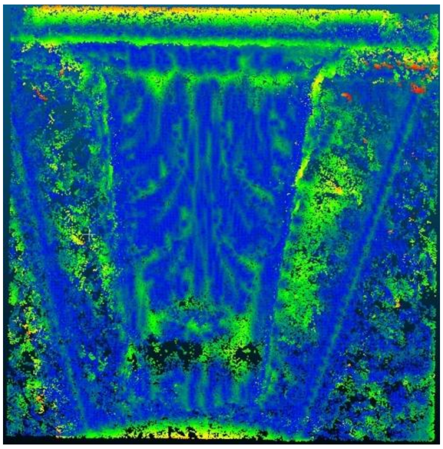


Figure 17. Object: detail 2, number of photos: 10, SLR camera

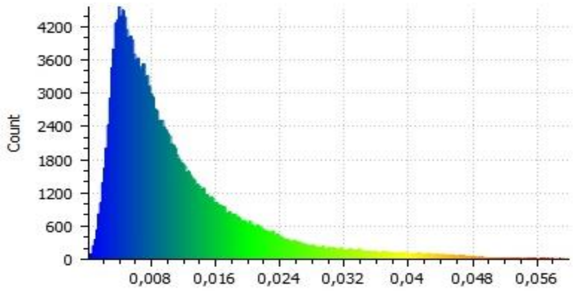


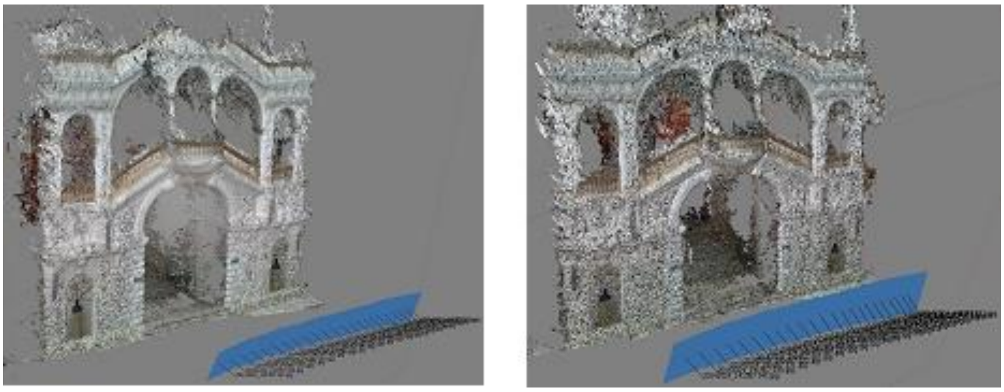

Figure 18. Histogram of difference. Object: detail 2, number of photos: 10, SLR camera, horizontal axis is scaled as above from 0.000 to 0.060 m.

The figures presented concerning the wall provide information on the instability of determining coordinates, especially on smooth surface areas. It is necessary to mark these areas using proper signalization, for example, by projecting texture or placing signalized targets. This last proposal is usually impossible because of architectural legal restrictions.

The situation appears to be much better in the case of detail 2. A large amount of photos supported the determination of a sufficient number of points. The histogram shows also better results; the maximum is moved to lesser error values and it has more points than the wall example. The shape of the curve is steeper.

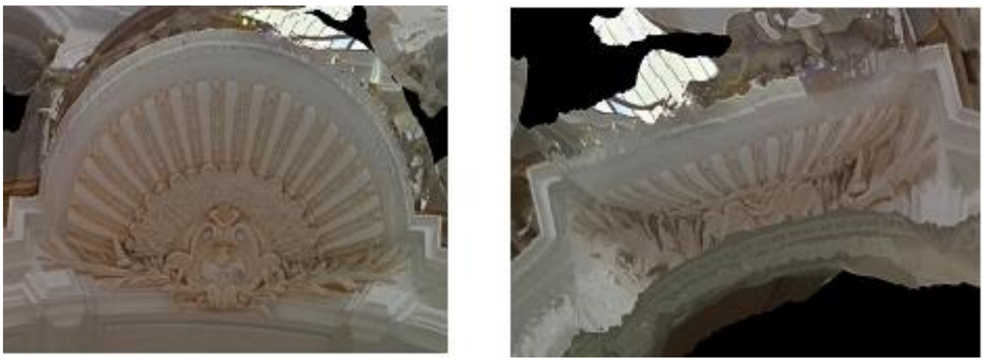
## 6. VIRTUAL MODEL AND ORTHOPHOTO

During the evaluation of the tools under analysis, virtual models were also produced with textures and orthophoto images. Point clouds produced with high density parameter settings, did not provide satisfying results due to the smooth surface. A medium setting gave smoother results when representing the scene, but it was still not realistic. An example is presented in Figure 19.



a.) b.)

Figure 19. Models produced with a.) medium and b.) high point densities.



a.) b.)

Figure 20. Orthophoto produced with: a.) smartphone and b.) SLR camera.

The orthophoto examples only show good results close to perpendicular projection of camera positions to model surface (like nadir point in aerial photogrammetry), presented in Figure 20.

The orthophotos in Figures 20 a.) and b.) are projected on different planes, set right in front of most camera positions, particularly for this experiment.

## 7. CONCLUSIONS

Summarizing the results of the presented research, the proposed low-cost tools produced satisfying results in some cases. For the purpose of gaining a rough outlook, the accuracy of the described products is acceptable. In cases where it is important for an exact registration of architectural monuments to be taken, using the cameras discussed is not a sufficient solution. The software used for the experiment does not work properly in extremely complicated conditions, like for smooth surfaces or large differences in the depth of objects. In these kinds of cases, additional support should be prepared, such as special illumination or a larger number of manual measurements. A minimum number of five photos should be used to properly register the object area to use it in the experiment software.

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## GENEROWANIE MODELI 3D PRZY WYKORZYSTANIU POPULARNYCH KAMER

SŁOWA KLUCZOWE: fotogrametria bliskiego zasięgu, naziemny skaner laserowy, model 3D, porównanie chmur punktów

### Streszczenie

Problem generowania wysokorozdzielczej dokumentacji architektonicznej jest ciągle aktualny i nie został w pełni rozwiązany. Coraz powszechniejsze jest wykorzystywanie chmur punktów z naziemnego skaningu laserowego oraz gęstego dopasowania zdjęć cyfrowych, pozyskiwanych z wysokorozdzielczych sensorów. Alternatywą dla tego typu rozwiązań mogą być niedrogie systemy pomiarowe oparte na telefonach komórkowych, cyfrowych kamerach wideo lub kompaktowych aparatach fotograficznych, które potencjalnie pozwalają na tworzenie wiarygodnych i dokładnych trójwymiarowych modeli analizowanych scen. W artykule przedstawiono wyniki porównania uzyskanej jakości chmur punktów pochodzących z wymienionych źródeł informacji, prostych i popularnych kamer oraz danych pochodzących ze skanera laserowego bliskiego zasięgu. Badane zestawy zdjęć generowały kilka wirtualnych modeli małych detali architektonicznych, obsługiwanych przez oprogramowanie Agisoft PhotoScan. Ocenę końcową przeprowadzono stosując dane, uzyskane dla tego samego obiektu przy użyciu skanera laserowego. Zostały one przyjęte jako wzorcowe przybliżenie jego trójwymiarowego kształtu.

Dane autorów / Authors details:

dr inż. Michał Kowalczyk
e-mail: m.kowalczyk@gik.pw.edu.pl

mgr inż. Jakub Markiewicz
e-mail: j.markiewicz@gik.pw.edu.pl

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