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# THE USE OF VIDEO CAMERA TO CREATE METRIC 3D MODEL OF ENGINEERING OBJECTS

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**Keywords:** 3D model, video camera, engineering objects, videogrammetry

**Abstract**

The article presents the possibilities of using a video camera to create a 3D metric model of engineering objects using Agisoft and CloudCompare software. Traditional photogrammetry technique does not always match up with production urgency needed by the market. Complexity is seen when used in huge objects leading to rise of cost, time and tediousness of the work. The use of Video Camera technique here termed as videogrammetry technique is comparable to taking pictures, however, it allows to speed up the process of obtaining data, which in many cases is a key element in anyb any project or research.

The analysis of the quality of 3D modelling of the three filmed objects was performed, which allowed the authors to refine the procedure for acquiring images for spatial analyses. The applied technique of "videogrammetry" is comparable to taking pictures, but allows the data acquisition process to speed up, which in many cases is a key element in field research. 3D objects videos from no-metric camera were processed by Agisoft Metashape. To be able to assess the accuracy of the videogrammetry data, a well-established Laser scanner technique's data was used for comparison. The laser scanner data were pre-processed in Autodesk Recap. Manual registration was performed utilizing 14 points from the three scans. The two 3D models were exported to CloudCompare software for comparison and further analysis. An analysis of the quality of 3D modelling of the three objects filmed was performed, which allowed refining the procedure for obtaining images for spatial analysis. The article presents the possibilities of using a non-metric mobile phone video camera "videogrammetry" to create a metric 3D model of engineering objects using Agisoft and CloudCompare software.

In CloudCompare a registration, cloud to cloud (C2C) and profile to profile analysis was performed to determine the uncertainty of the 3D model produced from videogrammetry data determined as distance of separation between the two models. Results show average distance of separation between laser scanner and videogrammetry derived 3D model point cloud to be 34cm, the average profile separation was 25 cm in XY plane and 1.9 cm in Z-plane. Using Cloud to Cloud PCV the average difference of 84 cm was determined.

## WYKORZYSTANIE KAMERY WIDEO DO STWORZENIA METRYCZNEGO MODELU 3D OBIEKTÓW INŻYNIERSKICH

**Słowa kluczowe:** model 3D, kamera video, obiekty inżynierskie, wideogrametria

**Abstrakt**

Artykuł przedstawia możliwości wykorzystania kamery wideo do stworzenia metrycznego modelu 3D obiektów inżynierskich przy użyciu oprogramowania Agisoft i CloudCompare. Tradycyjna technika fotogrametryczna nie zawsze odpowiada pilności produkcji potrzebnej na rynku. Złożoność jest widoczna w przypadku dużych obiektów, co prowadzi do wzrostu kosztów, czasu i żmudności pracy. Zastosowanie techniki Video Camera, zwanej tu wideogrametrią, jest porównywalne z robieniem zdjęć, jednak pozwala przyspieszyć proces pozyskiwania danych, które w wielu przypadkach są kluczowym elementem każdego projektu czy badania.

Wykonano analizę jakości modelowania 3D sfilmowanych trzech obiektów, co pozwoliło na dopracowanie procedury pozyskiwania zobrazowań do analiz przestrzennych. Zastosowana technika „wideogrametrii" jest porównywalna do wykonywania zdjęć, jednak pozwala przyspieszyć proces pozyskiwania danych, co w wielu przypadkach jest elementem kluczowym w badaniach terenowych. Filmy z obiektami 3D z kamery niemetrycznej zostały przetworzone przez Agisoft Metashape. Aby móc ocenić dokładność danych wideogrametrycznych, do porównania użyto dobrze ugruntowanej techniki skanera laserowego. Dane skanera laserowego zostały wstępnie przetworzone w programie Autodesk Recap. Rejestracja ręczna została przeprowadzona z wykorzystaniem 14 punktów z trzech skanów. Dwa modele 3D zostały wyeksportowane do oprogramowania CloudCompare w celu porównania i dalszej analizy. Przeprowadzono analizę jakości modelowania 3D trzech filmowanych obiektów, co pozwoliło dopracować procedurę pozyskiwania obrazów do analizy przestrzennej. W artykule przedstawiono możliwości wykorzystania „wideogrametrii" niemetrycznej kamery wideo telefonu komórkowego do tworzenia metrycznego modelu 3D obiektów inżynierskich przy użyciu oprogramowania Agisoft i CloudCompare.

W CloudCompare przeprowadzono rejestrację, chmurę do chmury (C2C) i analizę profilu do profilu w celu określenia niepewności modelu 3D utworzonego z danych wideogrametrii określonych jako odległość separacji między dwoma modelami. Wyniki pokazują, że średnia odległość separacji między skanerem laserowym a chmurą punktów modelu 3D uzyskaną z wideogrametrii wynosi 34 cm, średnia separacja profili wynosiła 25 cm w płaszczyźnie XY i 1,9 cm w płaszczyźnie Z. Używając Cloud to Cloud PCV, określono średnią różnicę 84 cm.

## 1. INTRODUCTION

Creation of the 3D objects is an area of broad application at least in all the engineering and related disciplines in this industrialized world. The duplication of the engineering objects, architectural designs, mining inventories and monitoring, terrain assessment for construction and erosion studies are some of the key areas where more research for the creation of accurate 3D models highlight their importance.

The correctness of the surface representation depends on the number of certain 3D i.e. X,Y,Z coordinate points, point distributions and interpolation methods. Undoubtedly, convenient distribution and much more points provide better representation of the surface. However, much more points means much more time and higher costs. Sometimes obtaining geodetic points can be risky or even impossible. For this reason, surface can't be represented or can be represented incorrectly.

Convectional surveying techniques have been widely used to determine shape and surfaces of the engineering objects. The use of these techniques doesn't give a very good representation of the real surface of the object. The smoothness of the defined shape is always associated with how close the measured points are and what interpolation technique is applied. If the required object is huge and complex it will be much work-consuming and the task will be almost impossible. The case is worse in the risky areas and sometimes objects are totally inaccessible. (Yakara, H. & Yilmazb. M 2008).

Laser scanning-based surveying techniques are accompanied with relatively expensive hardware and there are difficulties in extracting information when it comes to indistinct data cloud (Girardeau D., 2005).

Close Range Photogrammetry employs a technique to compute coordinates at every less than ten millimetres distance to redefine the object surface that is very zine representation of the related object.

## 2. LITERATURE REVIEW

### 2.1. Close range photogrammetry technique

Photogrammetry techniques allow to convert images of an object into a 3D model. Using a digital camera with known characteristic (lens focal length, imager size and number of pixels), you need a minimum of two pictures of an object. If you can indicate the same three object points in the two images and you can indicate a known dimension you can determine other 3D points in the images (Atkinson B., 1996; Cooper R. and Robson S., 1996; Lawson L., 1977).

Digital close range photogrammetry is a technique for accurate measuring objects directly from photographs or digital images captured with a camera at close range. Multiple, overlapping images taken from different perspectives, produce measurements that can be used to create accurate 3D models of objects. Knowing the position of the camera is not necessary because the geometry of the object is established directly from the images (Yakara H. and Yilmazb M., 2008).

Object point reconstruction in close range photogrammetry is often associated with a simple famous device called the "pinhole camera". Close range photogrammetry is able to get three dimensional (3D) data of an object from images similar to triangulation conventional survey techniques. It is based on the intersection between two or more optical rays (redundancy) called colliniality straight lines in photogrammetric terminology. Interior orientations establish the geometric characteristics of a bundle of rays, the Exterior Orientations establishes its position and orientation with respect to the object space coordinates system (Chen Q., 2009).

(Abdel I. and Karara M., 1976) proposed a simple method for close range photogrammetric data reduction with non- metric cameras; it establishes the Direct Linear Transformation (DLT) between the two-dimensional coordinates, and the corresponding object – space coordinates. The Direct Linear Transformation (DLT) between a point (X, Y, Z) in the object space and its corresponding image space coordinates (x, y) can be established by the linear fractional equations. This has been one of the early studies to simplify the complex task paused in the need to calibrate the non-metric cameras when a person wants to use close range photogrammetry technique.

With the current state of development and the proposed technology for the use of non-metric camera, it is possible to carry out photogrammetric works with satisfactory accuracy in a particular way (Ersilia O. et al., 2016). In close range photogrammetry in particular surveying and architectural works in surveying façades, completing the established demands with accuracy at lower cost (Barnardo R. et al., 2008). Currently non-metric cameras are used even in cadastral surveying studies (Catur A., et al. 2019)

This paper deploys and gives procedures for 3D modelling of engineering objects by using non metric video cameras (videogrammetry) instead of photos with the application of Agisoft and CloudCompare software.

## 3. RESEARCH PROBLEM AND METHOD

3D shape reconstruction by close range photogrammetry takes much time, human resources, higher expenses and risk in some areas but still do not match up with production urgency needed to the market. Complexity of the technique arises when dealing with huge objects leading to rise of cost and tediousness of the work. Capturing hundreds of individual photos can take hours or days and requires extensive training in the software. It also has to make adjustments manually in dealing with the percentage of overlap, ground sample distance, and photo resolution. Although close range photogrammetry-based software expanded the use of 3D modelling throughout many industries, still it is complex, painstaking, and therefore its use has been relatively limited.

Video camera technique provides much more data than photos (Hossam F., 2015). The video frames, which are naturally shot in sequence, provide much more usable data than still photographs taken individually. From a recording perspective, the entire process is much faster, because speed to record video is faster than taking individual photographs of the same engineering object hence saving time in capturing the scene. Data capturing to processing of the 3D model takes relatively less time compared to close range photogrammetry of the same object, and the results actually appear clearer than photogrammetry-based models. It means that it takes less time, effort, and less or no risk on site in getting a model, and moving on for further works.

## 4. METHODOLOGY

### 4.1. Materials

The moving mobile phone iphone 8 plus camera was used to record the movie (table.1). Faro Focus 3D Terrestrial Laser Scanner was used for 3D laser scanning of the tunnel (table.2). Point makers and targets on objects were used for alignment and registration of photos. Agisoft Metashape Professional, and CloudCompare Software were the major software used for processing. See table 1&2 for equipment specifications.

### 4.2. Methods

This section shows procedures from 3D object video acquisition, processing to producing the 3D object models from Non-metric Video Camera. To examine the usefulness of the video camera as simple, fast and lower cost equipment; the point cloud model of a tunnel created by non-metric video camera in Agisoft Metashape

**Tab. 1.** Video Camera specification
**Tab. 1.** Specyfikacja kamery video

| MODEL | IPHONE 8 PLUS VIDEO CAMERA |
|---|---|
| Technology | A11 Bionic chip, Neural Engine |
| Camera Stability | Continuous autofocus video |
| Resolution | 12Mega Pixel with up to 6x zooming |
| Scan Rate | Optical image stabilization for video |
| | 4K video recording at 24 fps, 30 fps, or 60 fps |
| | 1080p HD video recording at 30 fps or 60 fps |
| | 720p HD video recording at 30 fps |
| | Slo-mo video supprt for 1080p at 120 fps or 240 fps |
| Camera Lens | Wide: *f*/1.8 aperture<br>Telephoto: *f*/2.8 aperture |
| Weight | 202 Grams |
| Dimensions | 158.4 mm × 78.1 mm × 7.5 mm |

**Tab. 2.** Laser Scanner specification
**Tab. 2.** Specyfikacja skanera

| MODEL | FARO FOCUS 3D × 130 |
|---|---|
| Technology | Phase Shift |
| Scan rate | < 976,000 points/sec |
| Scan density | < 1 mm |
| Error | < 2 mm @50m |
| Range | 120m @90% reflectancy |
| | 0.6 mm @10m @90% reflectancy @122,000 points/second |
| Beam Diameter | 3 mm @exit |
| Weight | 5Kg |
| Dimensions | 240 × 200 × 100 mm |

was compared by the point cloud model created by Laser Scanner of the same object (tunnel) in CloudCompare software. The video recorded was converted into photographs by utilizing the capabilities of VLC software refer diagram 1. VLC was used to cover a missing function in Agisoft Photoscan version1.3 that was prepared to be used in this project. However later on it was updated to Agisoft Metashape which has this function, so this step can be done straight within Agisoft Metashape in the future exercises.

Photo alignment was done on Agisoft Metashape Software to produce object surface continuation followed by 3D Points cloud, mesh, textured, solid model creation and Normal construction by Agisoft Metashape and Autodesk Recap Software. All the model analyses were done in CloudCompare Software.

Agisoft Metashape uses a well implemented algorithm to analyse each input image for special features in order to create relation between images of the entire scene. Photogrammetric operations like bundle adjustment are used to solve the inner and outer orientations to each camera, reconstructing their spatial orientation to each other. Once the camera alignment is solved then a dense cloud and a textured 3D model of the captured scene can be computed and exported in the e57, U3D or

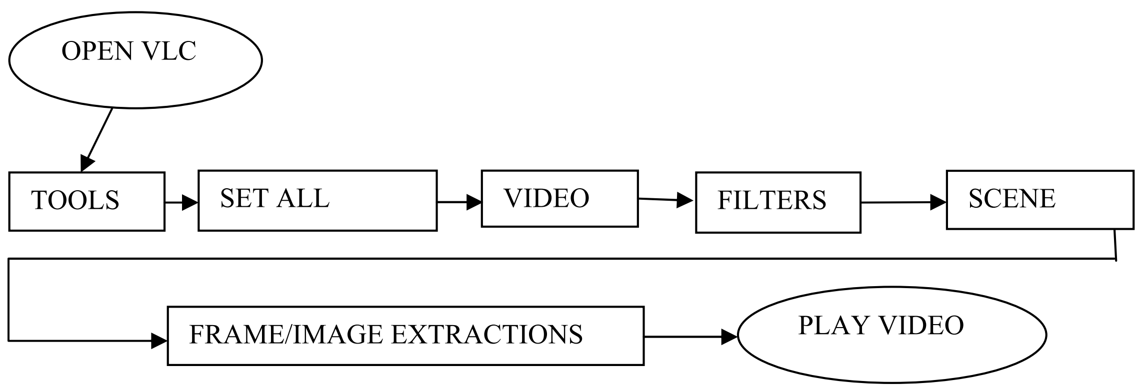



**Diagram 1.** Flowchart for photo extraction from videos
**Schemat 1.** Schemat blokowy do ekstrakcji zdjęć z filmów

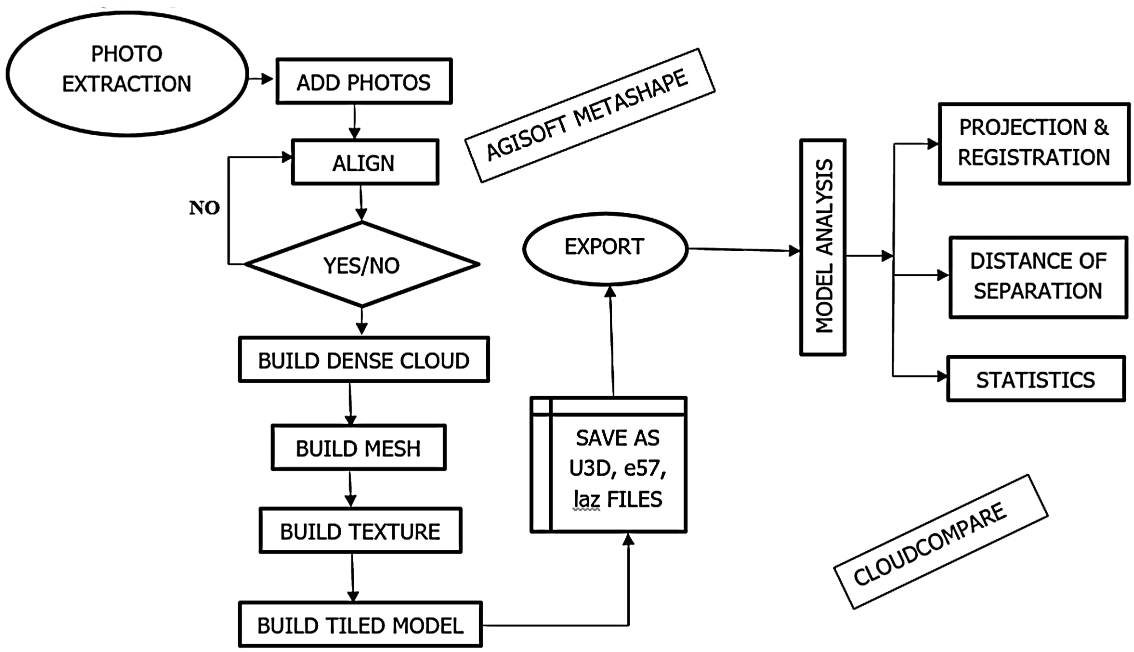



**Diagram 2.** Complete applied Methodology Flow Chart Diagram
**Schemat 2.** Schemat blokowy zastosowanej kompletnej metodyki

laz file formats (Agisoft Metashape-case studies, 2019). See diagrams 1 and 2 for flowchart for 3D model creation by Agisoft Metashape Professional and analysis in CloudCompare software.

## 5. EXPERIMENTAL APPLICATIONS AND RESULTS

Before the targeted object of the study, two more objects were used to experiment the possibility of creating 3D model using non metric camera by Videogrammetry technique in Agisoft Metashape, refer experiments 1&2.

### *Experiment 1*

This object was chosen due to its well defined markers to simplify automatic alignment by the software.

A 3D object (photo 1 and 2) made of metal at the campus of AGH University of Science Technology, was tested. A video was taken by a moving camera in two rounds revolving the object of interest and it took 6.26 minutes.

Using VLC software the video was converted into 418 photos obtained with resolution of 1920*1088 at 24fps at a recording ratio of 20.


**Photo 1.** Experiment 1: Front View
**Fot. 1.** Eksperyment 1: widok z przodu

**Photo 2.** Experiment 1: Back View
**Fot. 2.** Eksperyment 1: widok z tyłu

This model reconstructed only three faces out of six, refer photo 3. The back three faces couldn't be created may be due to light rays interference from the reflecting surfaces from the cars parking in this direction.

### *Experiment 2*

This experiment was conducted to test the applicability of the technique to a bigger engineering object. The emphasis was still on the use of automatic alignment towards creation of different objects.

A hill located within AGH Campus between the swimming pool building and the University Hospital was used, refer photo 4. Black and white printed paper marks were placed randomly upward the hill. A video was taken by a moving camera in two rounds revolving the hill and it took 8.51 minutes. From video using the same techniques as in experiment 1., a total of 1362 photos were obtained. All the photos were successfully aligned and reconstructed and a point cloud with 13,564,183 points was used for 3D model creation.

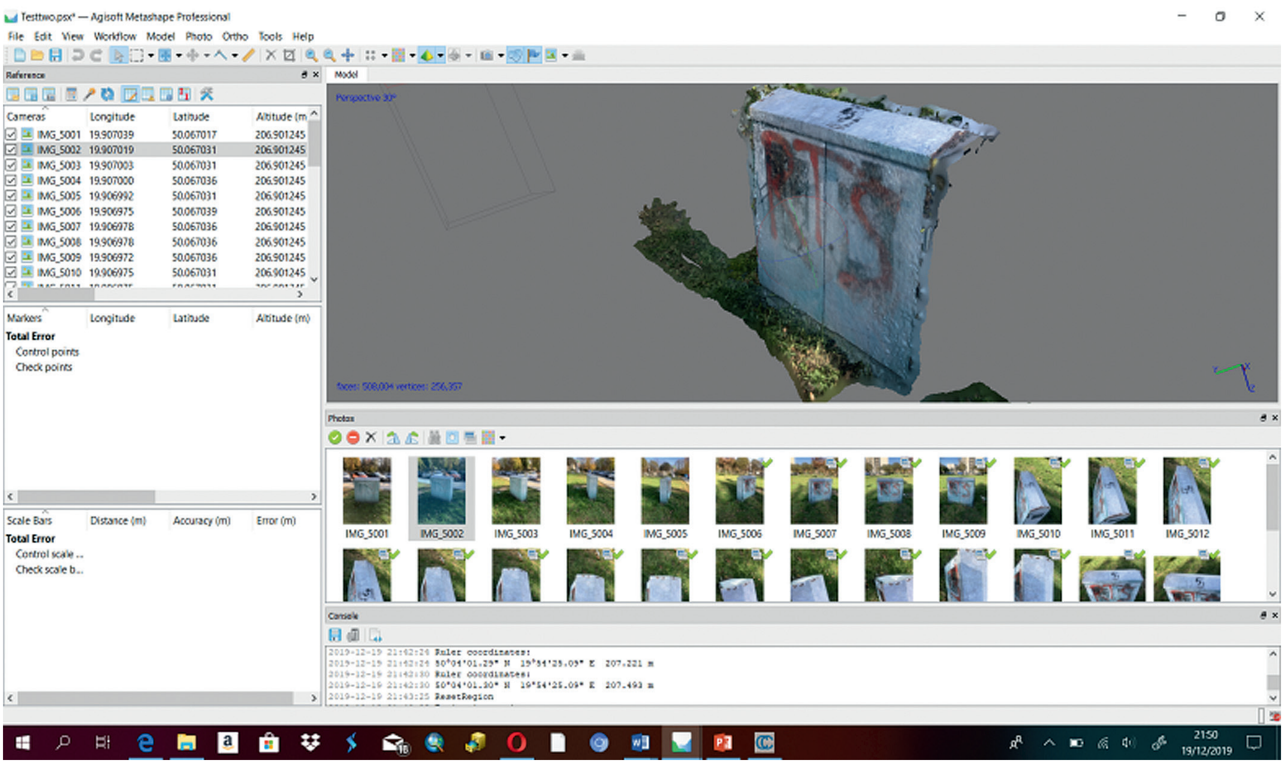



**Photo 3.** Experiment 1: Point Cloud Model
**Fot. 3.** Eksperyment 1: chmura punktów modelu

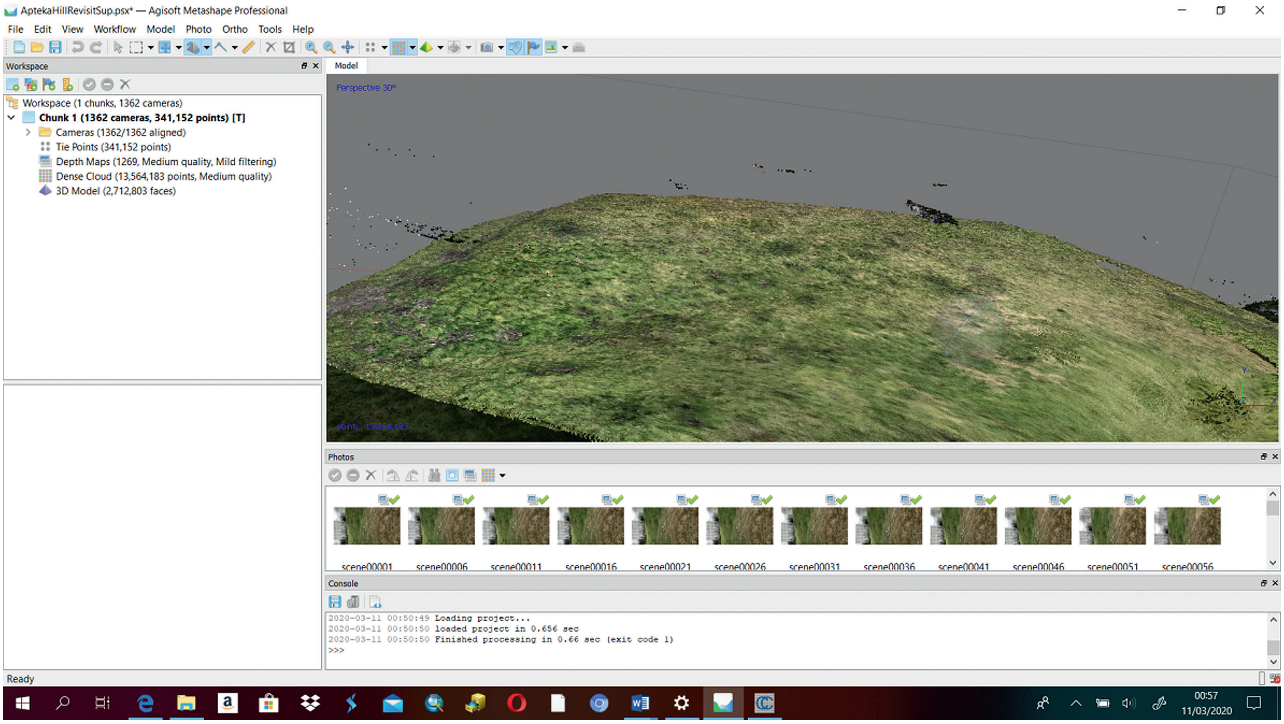



**Photo 4.** Experiment 2: A Mound 3D Model reconstructed from a video camera in Agisoft
**Fot. 4.** Eksperyment 2: Usypisko 3D – model zrekonstruowany przy użyciu videokamery i Agisoft

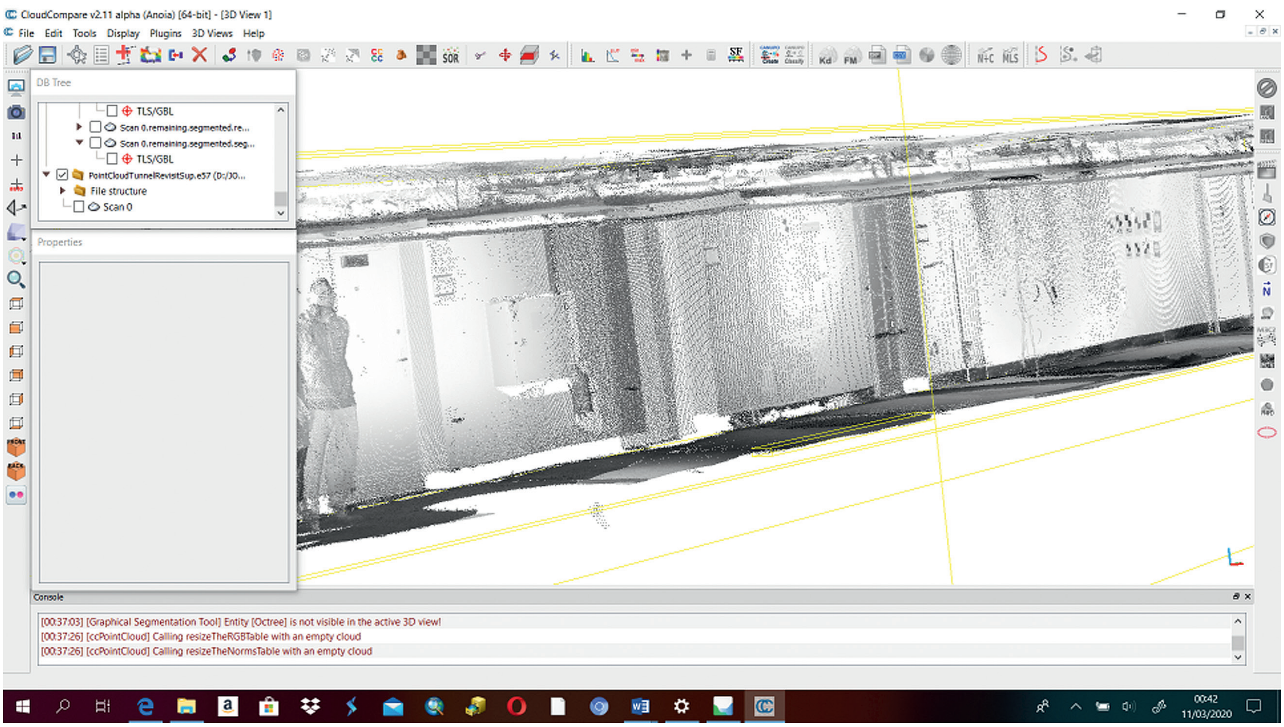



**Photo 5.** Cloud of corridor points obtained from laser scanning
**Fot. 5.** Chmura punktów korytarza uzyskana ze skaningu laserowego

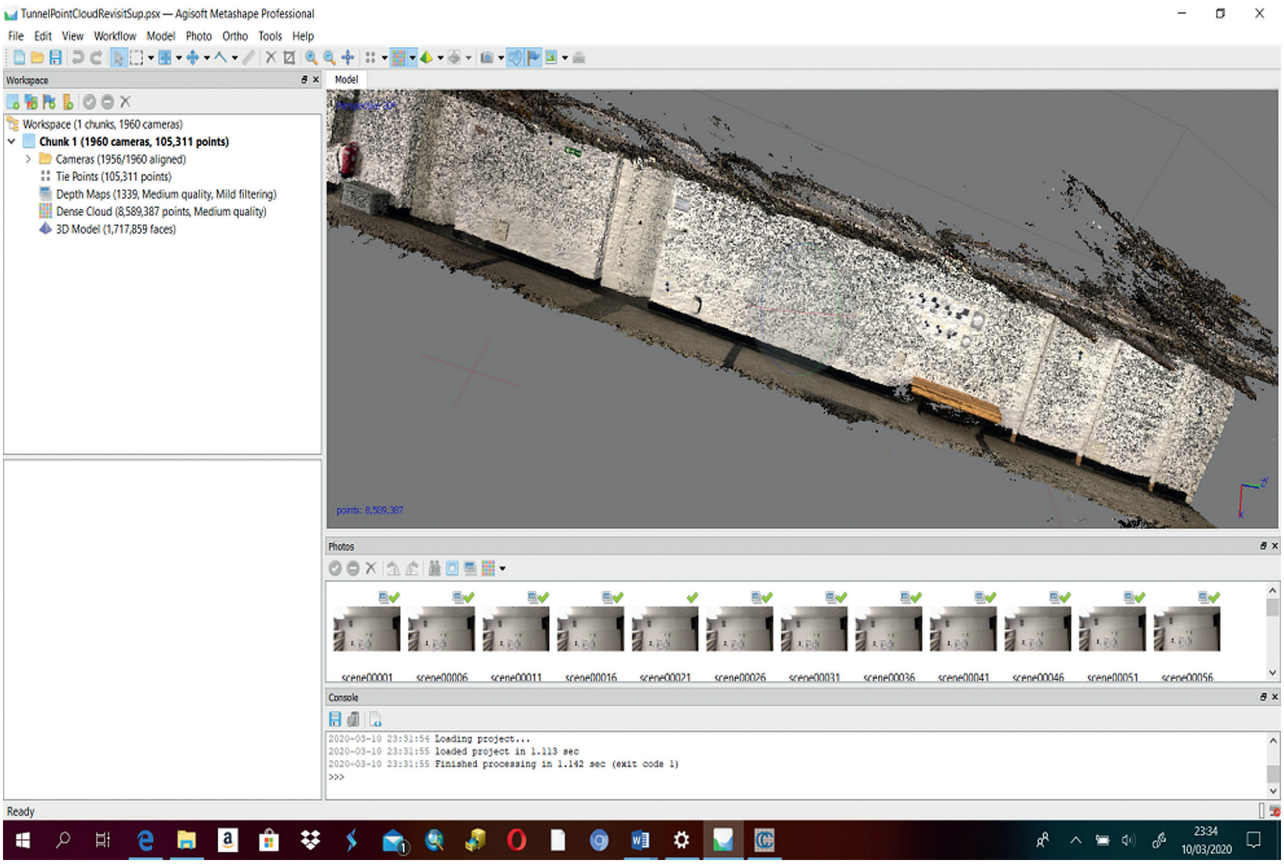



**Photo 6.** Video camera point cloud 3D Model in Agisoft window
**Fot. 6.** Chmura punktów z kamery wideo – model 3D w oknie Agisoft

***Experiment 3***

This was the main experiment carried out to collect data for 3D model comparison between laser scanner and videogrammetry. The 3D model from videogrammetry was created by Agisoft Metashape while the 3D model from Laser scanner was created by Audesk Recap. The comparison of the two 3D models was done in CloudCompare.

An underground tunnel used by the faculty of Mining Surveying and Environmental Engineering of the AGH-University of Science and Technology for training was used. A total length of about 72m with a single minor branch was used. The tunnel is marked with several special targets and markers placed randomly in all of the four surfaces of the entire tunnel. The video camera and 3D Laser Scanner were used to create 3D model of the tunnel and compared to assess accuracy of the Video cameras derived models against the well-established laser scanner surveying technique.

Experiment 3(a). Laser scanning to create point cloud of the same area of the tunnel was done by occupying four stations ensuring proper overlapping of the adjacent scans refer photo 5. A laser scanning of the area took 34 minutes. Laser scanning point clouds registration were done in Autodesk Recap software producing tunnel point clouds with a total of 12,965 points for 3D model creation with a total of 14 check points.

Laser scanner point cloud data were exported to CloudCompare in an e57 format for further processing and analysis. The tie point picking method was used to register the two different models for comparisons. Different analyses were done, so that cloud to mesh and mesh to mesh comparison could be performed, but for this report a cloud to cloud distance of separation, profile and PCV statistical analysis is presented.

Experiment 3(b). A video was taken by a non-metric moving camera in two rounds covering the entire tunnel and it took 10.39 minutes. From video using same

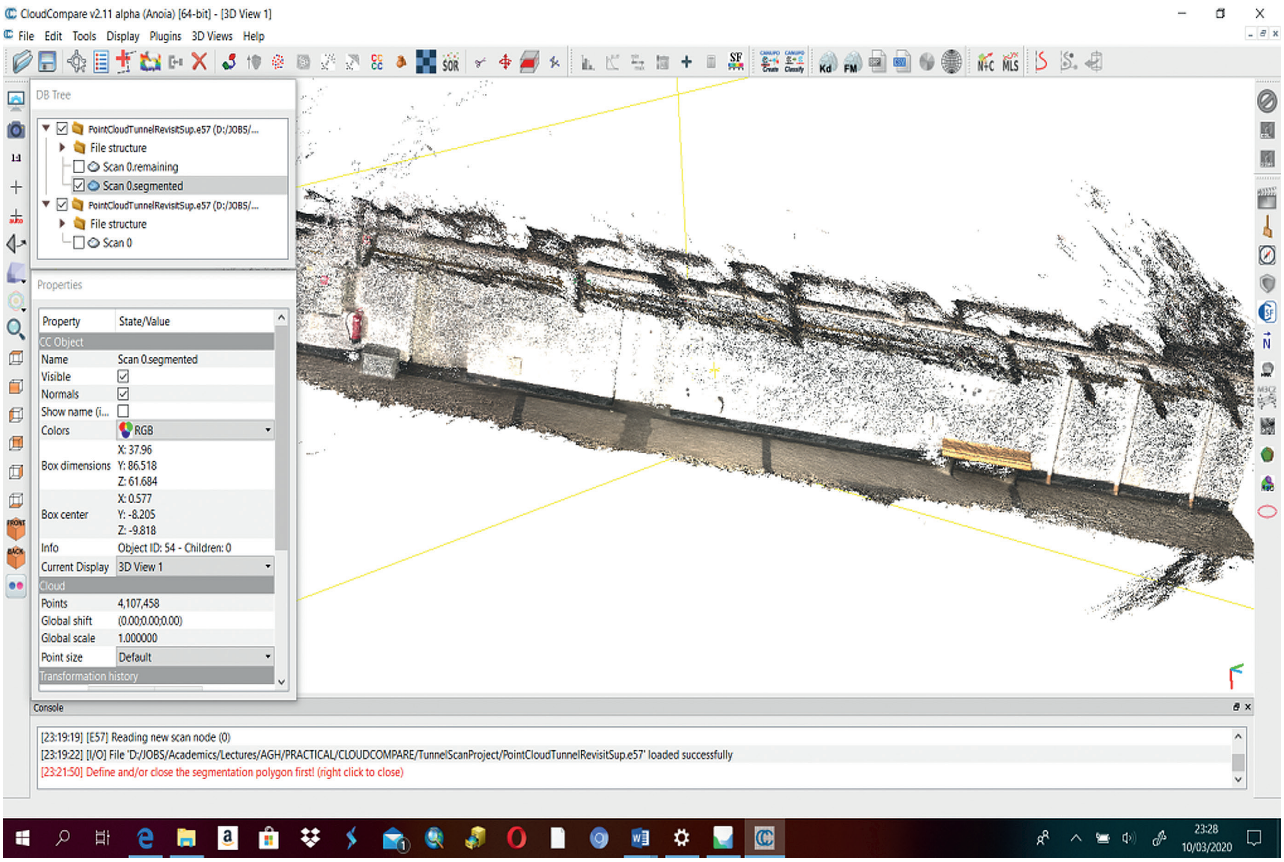



**Photo 7.** A point cloud 3D model in CloudCompare window
**Fot. 7.** Model 3D chmury punktów w oknie CloudCompare

techniques as in experiment 1&2, a total of 1960 photos were extracted at 24 frames per second. In Agisoft Metashape 1956 photos were successfully aligned and the model reconstructed, which is 99.8% refer photo 6. A model was reconstructed with total of 8,589,367 points of a 3D point cloud, refer photo 7.

## 6. RESULTS ANALYSIS AND DISCUSSION

3D objects videos from a non-metric camera were processed by Agisoft Metashape. The laser scanner data were processed in Autodesk Recap. Manual registration was performed utilizing 14 points from the three scans. Two 3D models were exported to CloudCompare software for comparison and further analysis. As the Terrestrial Laser Scanning is a well-established method in surveying, it was used as a reference for comparison with the 3D model created by the new technique, videogrammetry.

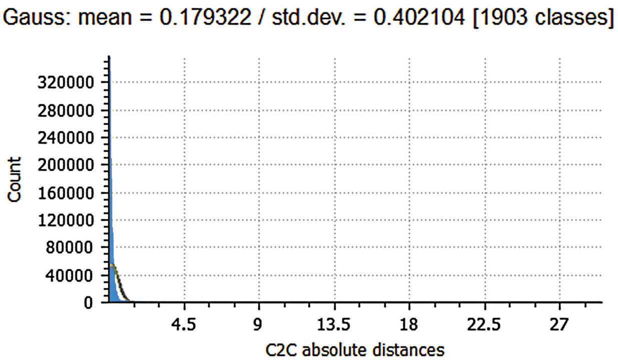
As the CloudCompare doesn't handle units, some analyses were done to observe relationship between real 3D object to its corresponding distances on 3D model. Distances were measured by a ruler on the real 3D object and tabulated against the distance units obtained from the 3D model to obtain the scale/relationship of units.

**Tab. 3.** Distances measured on a 3D object against same distances on 3D model
**Tab. 3.** Odległości rzeczywiste w stosunku do wyznaczonych na modelach 3D

| Distance | Distance on 3D object | Distance on 3D model | Scale |
|---|---|---|---|
| 1 | 100 cm | 44.60 Units | 0.446 |
| 2 | 75 cm | 34.80 Units | 0.464 |
| 3 | 33.5 cm | 16.00 Units | 0.477 |
| 4 | 18 cm | 8.18 Units | 0.454 |

Scale = (Distance on 3D model) / (Distance on 3D object)

**Tab. 4.** Cloud to Cloud separation distance statistics (Implicit Units)
**Tab. 4.** Statystyka odległości między chmurami (jednostki niejawne)




The average scale obtained was found to be 0.46, refer table 3.

In CloudCompare a cloud to cloud (C2C) analysis was performed to determine the distance of separation between the two models (photo 8). Table 4. and Photo 7 show the average distance of separation between laser scanner and video 3D model point cloud to be 17 Implicit Units which equals to 34 cm, refer average scale in table 3.

Table 4, Cloud to Cloud PCV gives average difference of 42 Implicit Units equals to 84 cm, it shows point clouds' intensities difference for illumination. It colours point as a function of their relative depth and provide good relief to the micro-geometry.

The PCV algorithm (inspired from ShadeVis) is simulating the ‚natural' illumination of the scene as if there were spotlights sampled all over hence a cloud lying at the centre (Sikos, L., 2016). It was used to compare the quality of clouds from scanner and videogrammetry. The technique relies upon light theories and hence light reflectance plays a big role in defining the quality of video and photos. The interference of the reflective light from nearby or background surface will hinder quality of the photos. In experiment 1 the rear side of the metal object was not reconstructed. This may be a result of the interference of the light reflected from the high reflective surfaces behind the target object. The study suggests that dull surface objects are better than reflective surfaces. The placement of markers on the target object helps the Agisoft software to make automatic alignment easier and model reconstruction even more correct.

Profile comparison: A longitudinal profile across x-axis through a noted markers on the back wall for

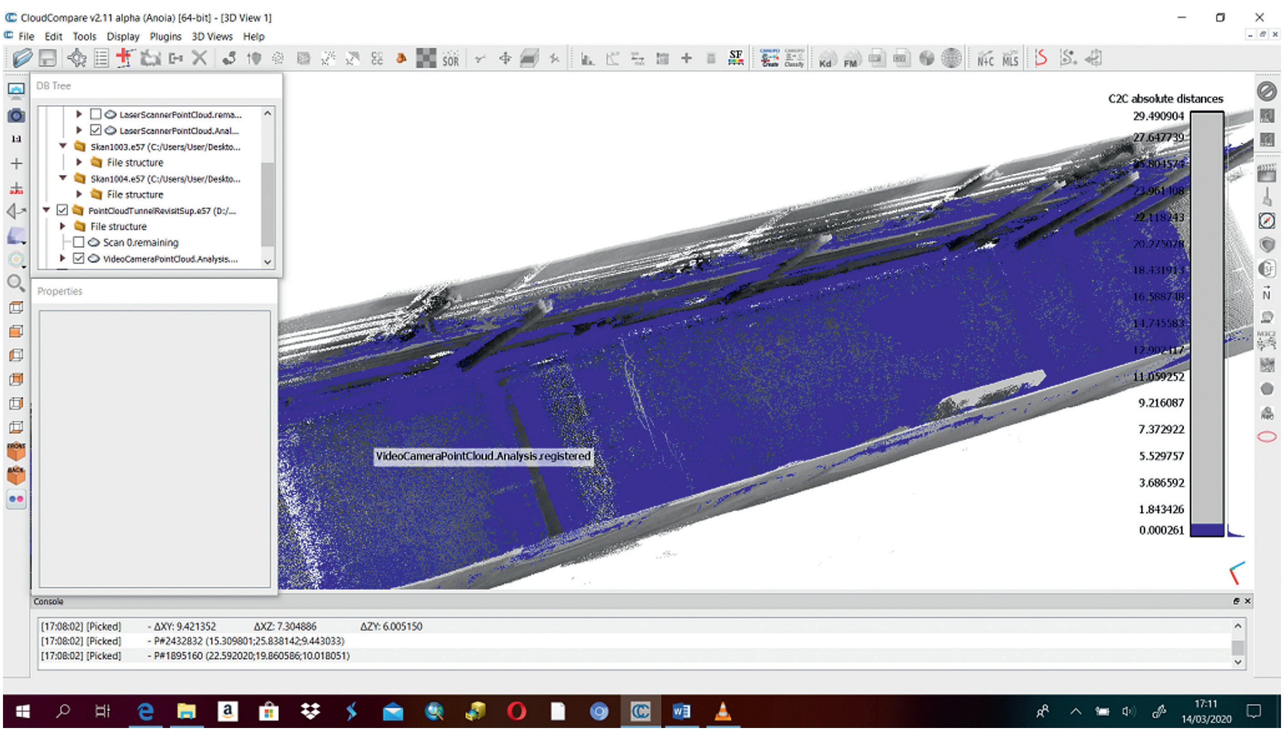
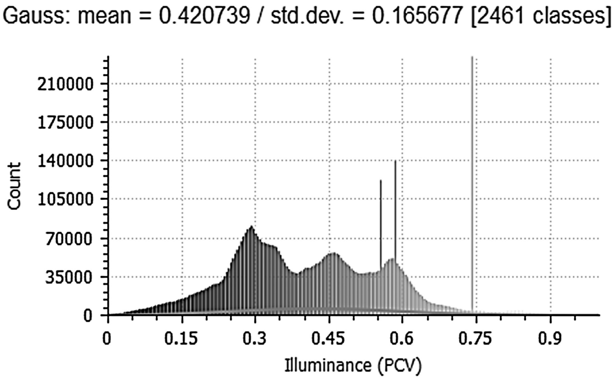



**Photo 8.** Distance Separation analysis between models on CloudCompare (Implicit Units)
**Fot. 8.** Analiza odległości między modelami w CloudCompare (jednostki niejawne)

**Tab. 5.** Cloud to Cloud PCV difference (Implicit Units)
**Tab. 5.** Różnica PCV między chmurą a chmurą (jednostki niejawne)




both Laser Scanner and Videogrammetry cloud data were produced. Analysis of the average deviation between the two profiles was done at several points producing a mean of 25 Cm in X-Y plane and 1.9 cm in Z-plane, refer photos 8&9. The computation scale used was 0.46 as approximated from table 3. to give standard units from CloudCompare analysis. This can be considered as a satisfactory result, allowing for the improvement of the proposed technique towards quick geometric inspections, especially in places inaccessible for precise measurements.

## 7. CONCLUSIONS

In this industrialized world, the engineering techniques to reconstruct 3D models become of more importance. The quest to produce, reproduce, visualize and analyse within 3D models of environment plays a big role in engineering projects design, implementation, control and monitoring.

With the future of engineering shifting to Artificial Intelligence, the sophisticated means for creation of 3D models of engineering objects bring even more sense. The evolution of 3D printers is one of the examples for such need.

The development in science and technology can serve into simpler, faster and more cost effective means of creating 3D models of engineering objects. The use of cheap equipment like cameras and cheaper resources like Agisoft Metadata Professional demo, CloudCompare software brings the quest into reality.

The results suggest video cameras, VLC or another video frame grabber, Agisoft Metadata Professional and CloudCompare can be used to make 3D models within few minutes with just smartphones producing a relative accuracy of 34 cm. It no longer requires extensive training, time, or resources to process it.

Different forms/states of the 3D Model can be compared and registered (photo 9). The computation of dis-

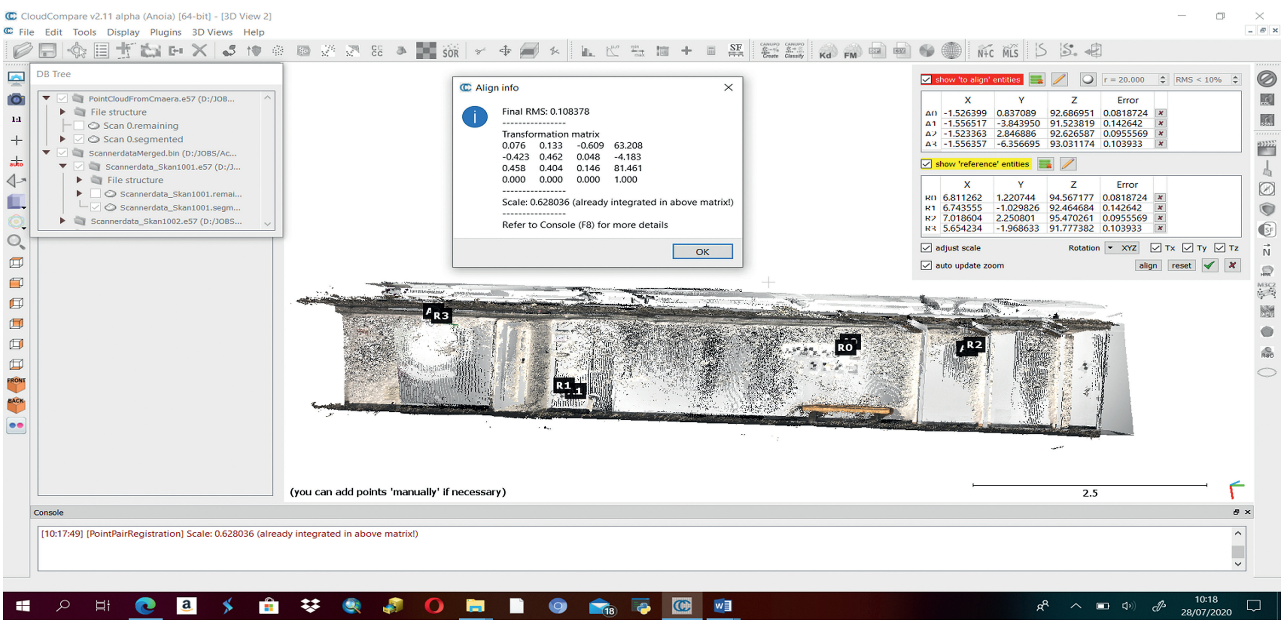



**Photo 9.** Videogrammetry – Laser scanner clouds registration
**Fot. 9.** Wpasowanie chmur punktów z wideogrametrii i skaningu laserowego

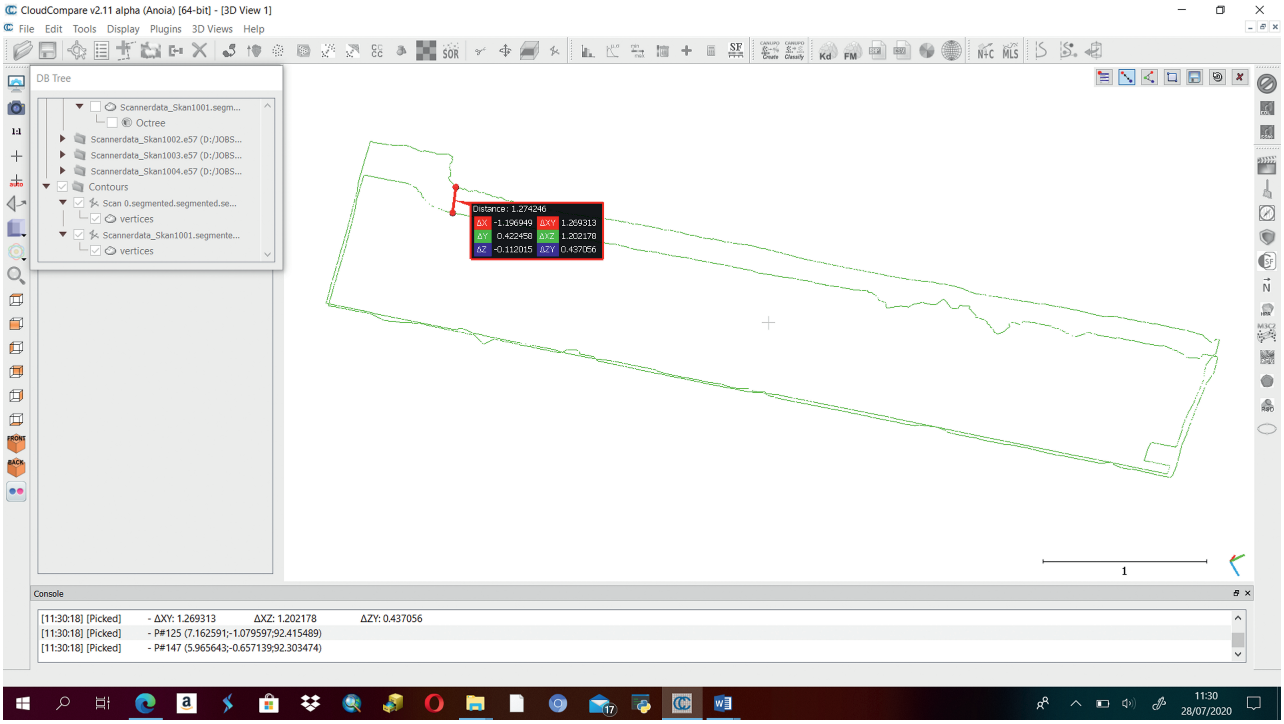


**Photo 10.** Videogrammetry – Laser scanner clouds profile comparison
**Fot. 10.** Różnice położenia profili poziomych uzyskanych z wideogrametrii i skaningu laserowego (jednostki niejawne)

tance from one cloud point to another cloud point, their separation, rescaling, profile comparison, projection to the intended coordinate system referencing to the set of control points and segmentations of the point cloud were possible (photo 10). Further studies give the possibility of finding volume of the reconstructed model in the point cloud, mesh/wireframe and solid models either by a closed model or by segmenting at a cross section point of interest.

The speed, convenience, and simplicity of video camera mean that this technology is more affordable compared to photogrammetry in making 3D modelling available for all.

With different tools and techniques video can be captured within minutes without halting any activity on the site. It can reduce time spent in gathering data and increase productivity in commercial operations.

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