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RESEARCH ARTICLE

Comparative Assessment on the Use of Videogrammetry and Photogrammetry for Rapid and Low-Cost Three-Dimensional Modeling

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Abstract. The current activities in photogrammetry technology such as the permission to apply non-metric cameras, development of Structure from Motion (SfM), and potential usage of videogrammetry are part of the answers to the need for low-cost camera-based mapping. Therefore, this study aimed to test and compare the accuracy of photogrammetry and videogrammetry methods for three-dimensional (3D) modeling obtained using a non-metric camera with SfM processing. Terrestrial Laser Scanner (TLS) was used to obtain comparative data and the results showed a degradation of photo resolution in videogrammetry method, causing a reduction in the number of point clouds produced compared to photogrammetry. Moreover, the point cloud test showed that the surface variation results for both methods were identical to 3D modeling with a higher point density recorded in photogrammetry and the relative distance was different by 0.125 meters. The average difference in point cloud between photogrammetry and TLS was 0.062 meters while videogrammetry and TLS had 0.106 meters. The absolute test produced an RMSE value of 0.022 meters for photogrammetry and 0.032 meters for videogrammetry at a 95% confidence interval, indicating the two methods produced similar data quality. The results led to the conclusion that videogrammetry had satisfactory values and could be used as an alternative in 3D modeling but was not considered better than photogrammetry.

1. Introduction

The development of photogrammetry is inseparable from the advancement in mapping science and technology. Moreover, the legalization of non-metric cameras and the potential use of videogrammetry for three-dimensional (3D) mapping purposes has made photogrammetry a quite affordable method. This is based on the ability of the non-metric cameras in video-based photogrammetry to produce spatial data at sub-meter values for orthophoto needs, DEM (Digital Elevation Model) data production, 3D reconstruction, and cadastral (Elkhrachy, 2021; Murtiyoso, Grussenmeyer, et al., 2017; Murtiyoso, Koehl, et al., 2017; Murtiyoso & Grussenmeyer, 2021; Rokhmana et al., 2019; S Sai et al., 2019).

Structure from Motion (SfM)-photogrammetry has been developed to be capable of supporting low-cost 3D mapping and reconstruction (Eltner & Sofia, 2020; Rogova, 2020; Zhang et al., 2019). The method is a branch of computer vision and photogrammetry with the ability to obtain 3D data from different photo-taking perspectives (Al Khalil, 2020). SfM has showed quality results in the production of 3D data compared to standard photogrammetry and real-world situations (Agüera-Vega et al., 2023; Fabris et al., 2023; Ishida, 2017; Peña-Villasenín et al., 2019). This is associated with several advantages when applied in 3D mapping such as quick and accurate production of models and an increase in processing efficiency (Deliry & Avdan, 2023; Kovanič et al., 2024; Siong et al., 2023). SfM only requires overlap between photos and does not require complex criteria or the strict procedures often identified in traditional photogrammetry. Furthermore, the model accuracy can be calculated through a comparison with the reference or by measuring the control point deviation (Deliry & Avdan, 2023; Iheaturu et al., 2020). The quality of SfM is influenced by several factors because the process is based on automatic digital image matching. Some of these factors include digital camera resolution which affects texture detail, the number of photos related to overlap as well as the target, lighting, focal length, and lens quality influencing the automatic digital image matching process (Deliry & Avdan, 2023; Javadnejad et al., 2021; Parente et al., 2019; Siong et al., 2023).

In addition to SfM-photogrammetry, some methods can be used to record objects based on video (Ahmad et al., 2019). An example is video-based photogrammetry or videogrammetry which focuses on calculating 3D position of objects by extracting photos from the video recording process. It has been identified as another alternative for reconstructing 3D objects (Kaiser et al., 2022; Murtiyoso & Grussenmeyer, 2021; Pepe et al., 2022). The advantages include time management related to the process of acquiring data (Herráez et al., 2016) and the lack of overlapping due to the process of photos from a video recording by frame (Ortiz-Coder & Sánchez-Ríos, 2020; Ramirez et al., 2022). Videogrammetry processing is based on the methods in photogrammetry which include extracting point clouds from several photos and performing image matching through triangulation (Kurniawan et al., 2017; Torresani & Remondino, 2019). The method has benefited greatly from the development of digital video sensors and photo-orientation algorithms but is still considered unable to compete with conventional photogrammetry due to the inherent reduction in photo resolution during the conversion from video to photo (Murtiyoso & Grussenmeyer, 2021; Torresani & Remondino, 2019). Videogrammetry can be a practical option for taking photo data for 3D mapping purposes despite the setbacks. Potential technological developments such as SfM, Non-Metric Cameras, and Videogrammetry can be used to support low-cost and accurate mapping. Video methods can also be combined with SfM processing by focusing on the precision and accuracy of the process and product. Therefore, this study aimed to analyze the potential of combining videogrammetry with photogrammetry in 3D point cloud production using non-metric cameras for modeling. The intention was to explore the capabilities of videogrammetry in producing SfM-based 3D modeling with planning controls that suppressed the inherent weaknesses. This led to the combination of SfM method with non-metric cameras as the central point in the data collection process to support the need for low-cost mapping. The aim was to prove that the application of different non-standard and low-cost methods could provide high-quality spatial products.

2. Methods

This study was conducted using 3D modeling object located at the Heritage Path of the 1883 Eruption of Krakatoa - Krakatoa Monument, South Betung Bay, Bandar Lampung City, Lampung, Indonesia. The specific location of the object is presented in the following Figure 1.

Krakatoa monument used as the study objected is located at latitude 5°26’44.26”S and longitude 105°15’43.80”E. Moreover, data were collected using two methods, including photo and video. The methods were subjected to similar three stages, including a distance of 6 meters from the object to take the entire shape, 1 meter from the object, and above for the detailed relief. It is important to state that the photos and videos are taken with the same camera specifications and shooting path. The camera used was the Xiaomi Yi Action with a resolution of 16 Megapixels and a sensor size of 1/2.3 “CMOS capable of recording video at a maximum resolution of up to 2K and a frame rate of up to 30 fps. The stages used for the study are presented in the following Figure 2.

The monument objects were acquired through photos and recording videos followed by the extraction of the data to be used as input in SfM-based processing. The video data was obtained through a frame extraction process to obtain overlapping photos. This was followed by data processing from both photogrammetry and videogrammetry using the basic SfM. 3D point cloud and mesh models for each method were compared. There was also a comparison of the products with the data acquired through Terrestrial Laser Scanner (TLS) which was considered the best model reference. The data analysis methods adopted were relative and absolute

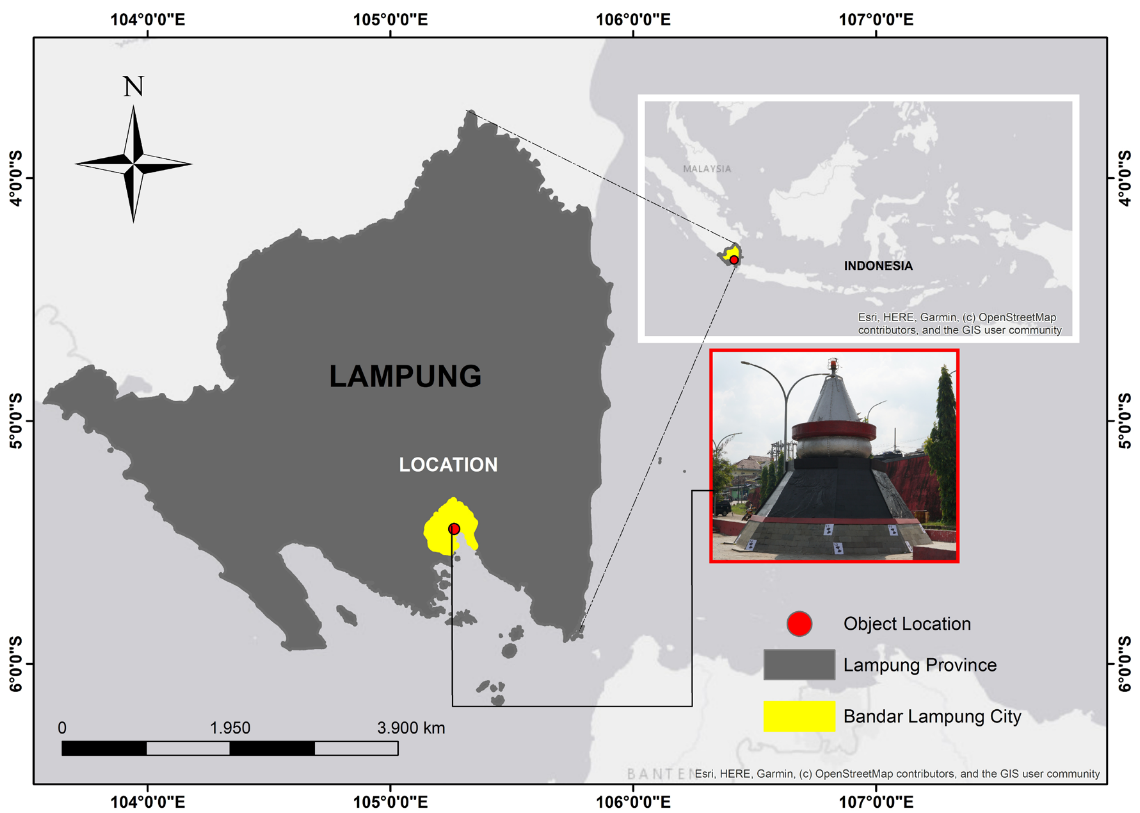


Figure 1. Study Location

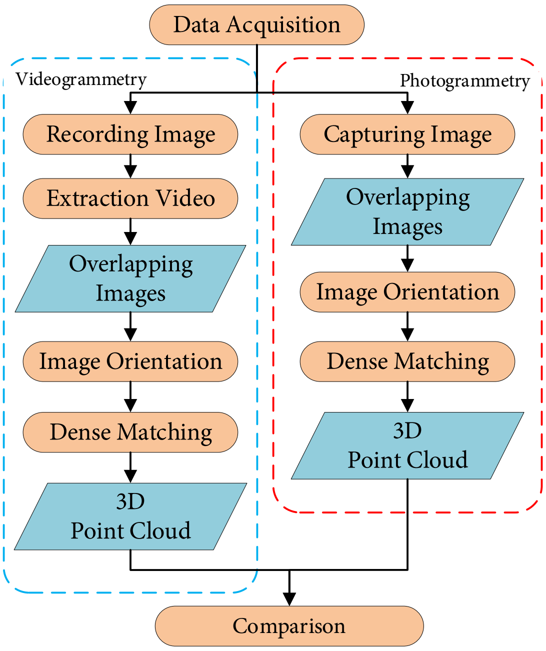


Figure 2. Workflow

Table 1. Lens Calibration Parameter

Parameter	Value for Camera
cx[mm]	-23,692
cy[mm]	3,541
f[mm]	2085,429
k1	-0,239
k2	0,141
k3	-0,098
p1	-0,005
p2	0,001

Source: Primary Data Processing

comparisons. The relative aspect focused on surface variation, volume density, and point discrepancy while the absolute used field size to determine Root Mean Square Error (RMSE) from the results.

3. Result and Discussion

Camera Calibration

The calibration process was applied to the non-metric camera used to determine the quality. This was conducted by photographing a special chessboard with the results presented in the following Table 1.

The values for the radial distortion parameters k1, k2, and k3 as well as tangential distortion parameters, p1 and p2 were very large. The calibration is very important to ensure increased accuracy in photogrammetry process because the Xiaomi Yi Action is an action camera. It was observed that the lens had high radial distortion because the camera had a wider lens designed with a radial effect. The calibration was determined for the purpose of correcting the data acquired. This was achieved by reducing the effect of existing lens distortion to ensure the light propagation data on the camera was obtained at the corrected value. The trend was related to the ability of the calibration parameter information to improve the quality of the point cloud produced. This was confirmed by Rokhmana et al. (2019), Abdullah et al. (2019), and Sobura (2021) through the application of non-metric cameras for mapping and 3D modeling.

Analysis Product

The point clouds produced through photogrammetry and videogrammetry were compared to identify the capabilities of each method. The triangulation process applied showed that RMSE for photogrammetry was 0.032 meters while videogrammetry had 0.029 meters, indicating a difference of 0.003 meters. The analysis conducted using the Fisher test showed that the values were not statistically different at a 95% confidence interval. This led to the conclusion that the quality of the point clouds produced was the same and an equivalent comparison process could be applied due to the absence of significant triangulation errors. Furthermore, the aerial triangulation results showed that the effects of distortion were suppressed due to the fairly low RMSE value. This is in line with the previous report of Rokhmana et al. (2019), Abdullah et al. (2019), and Sobura (2021) concerning the capabilities of non-metric cameras for mapping needs.

The number and quality of point clouds produced can improve the quality of 3D modeling (Liu et al., 2023). Therefore, the spatial resolution which was more familiar with Ground Sampling Distances (GSD) was compared for both methods. Videogrammetry produced a resolution of 9.57 mm/pix while photogrammetry had 2.56 mm/pix. In comparison with the aerial triangulation result, videogrammetry was observed to have a 3 3-fold reduction in GSD while photogrammetry decreased by 13 times. This was associated with the limitation of GCPs and ICPs in using a total station at an accuracy of fractions of cm. The values relate to Class III on ASPRS Accuracy Standards for Digital Geospatial Data which is categorized as lower-accuracy visualization-grade geospatial data suitable for less-demanding applications. GSD values recorded were observed to be in line with results reported by Murtiyoso & Grussenmeye (2021).

The weakness identified in applying videogrammetry to extract photos from the video is the differences reflected in the resolution. This is observed from the fact that the application of the same method at the same data collection distance using the same camera is expected to produce approximately similar GSD. However, photogrammetry showed more detailed resolution values due to the quality of the input photo. This confirmed that recording with the same camera but using two different methods produced photo outputs with different resolutions. For example, photogrammetry produced images at a resolution of 4608 x 3456 while the photos extracted from videos recorded at 2K 30 fps quality reduced to 1920 x 1080. These highly significant differences in resolution led to variations in the image quality. The trend confirmed that the photos from photogrammetry had better sharpness than those produced using videogrammetry. The observation was in line with the previous results reported by Torresani & Remondino (2019). Moreover, photo quality has a significant influence on the SfM process because a higher quality can lead to better key point detection, leading to the production of more sparse point clouds. The total number of point clouds produced by photogrammetry and videogrammetry are compared in the following Figure 3.

Photogrammetry has a more significant number of point clouds than videogrammetry as observed from 92,600 and 34,295 recorded respectively. Point clouds are data filtered by eliminating those not needed due to high errors or noise. The trend showed that videogrammetric frame extraction process produced more number of photos than photogrammetry with 303 and 243, respectively. Videogrammetry is expected to have more point clouds at the same processing parameters due to the higher number of photos produced. However, photogrammetry had a figure considered to be 3 times more than videogrammetry, showing that the photo data had higher quality than the video data. This showed that the point cloud noise generated in videogrammetry was at a higher level compared to the other method.

The trend was related to the observation of Torresani & Remondino (2019) that the difference in selecting keyframes from the video was a mandatory prerequisite in 3D modeling process to produce precise point clouds. This was considered a challenge in the process of extracting keyframes in video data. Therefore, more point clouds were eliminated in videogrammetry in the gradual selection process due to degraded data sources compared to photogrammetry.

Data for 3D modeling reconstruction are often collected through photogrammetry but there is a need to compare the usage with the application of videogrammetry. This is based on several parameters such as Surface Variation, Volume Density, and Point Discrepancy, and the results are presented in the following Table 2.

The comparison shows that photogrammetry has superior accuracy as observed from the 11.3% data containing errors in the surface variation parameter at a 95% confidence level compared to 17.5% recorded for videogrammetry. It is important to state that surface variation represents the quality of the data against noise and a small value shows the existence of smaller noise. The trend was observed to be in line with the previous report of Jia et al. (2018). The surface variation data processing showed that the point cloud data from videogrammetry contained noise, thereby indicating several weaknesses.

Another comparison was the volume density parameter which could affect the quality of 3D modeling produced. The results showed that the average density in photogrammetry was 3,852,108.00 while videogrammetry had 226,516.547 . This was determined based on the resolution of the camera used and the quality of the photos obtained with subsequent influence on the quality of 3D modeling. The criterion is that a higher density leads to better quality for 3D modeling due to the possibility of a closeness to the real object (Saif

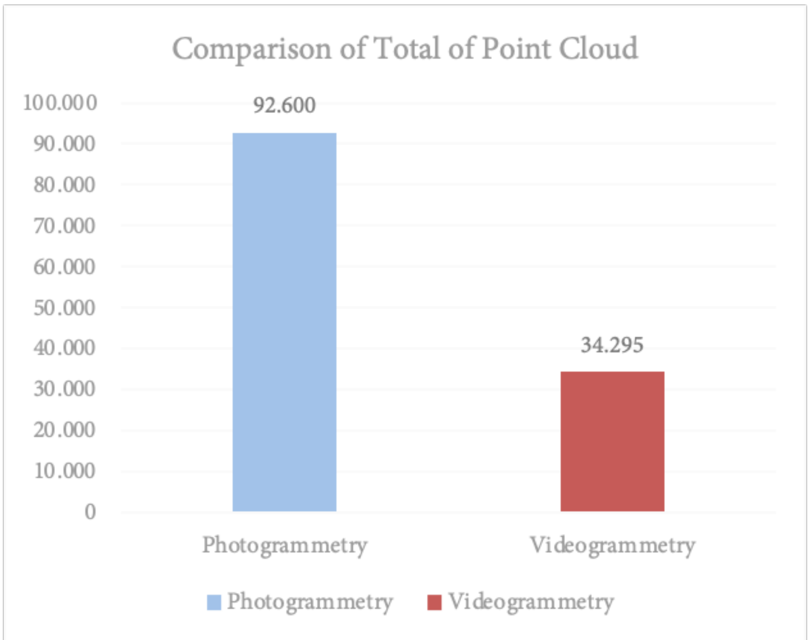
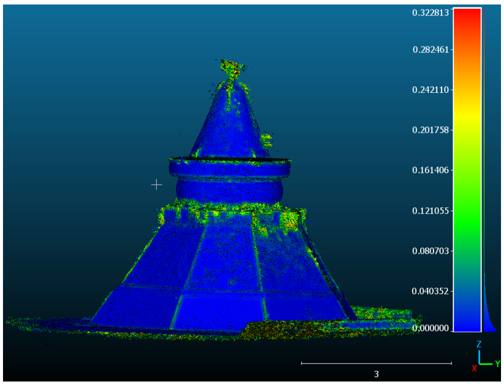
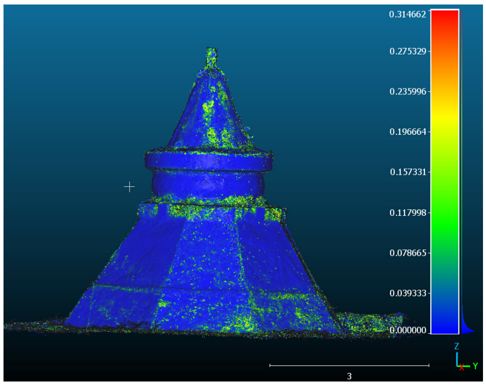
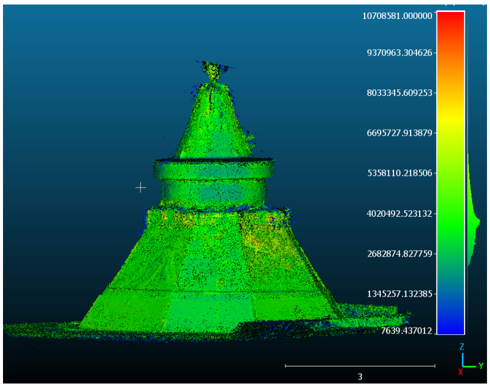
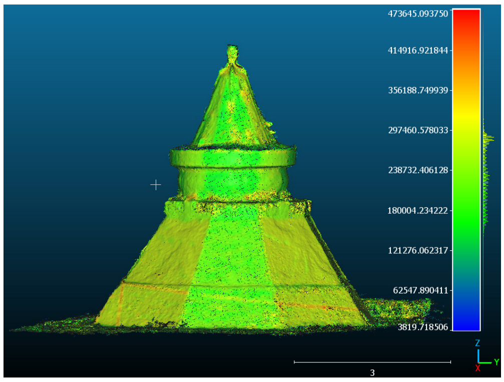
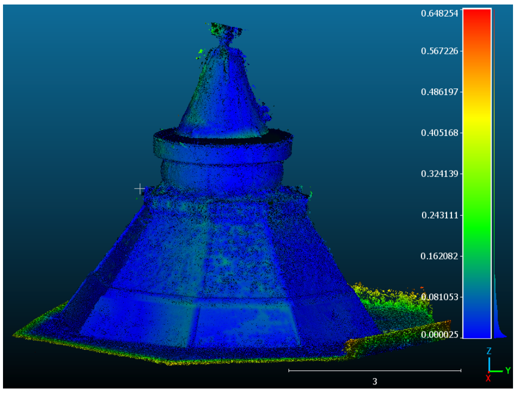


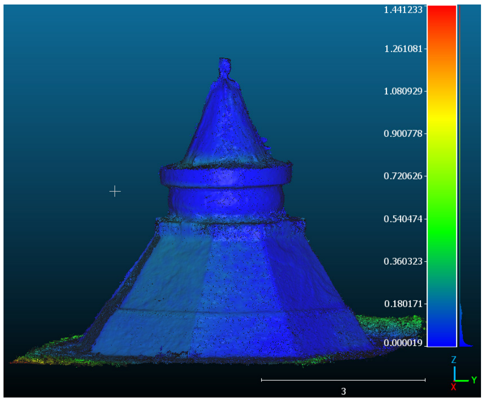
Figure 3. Comparison of Total of Point Clouds

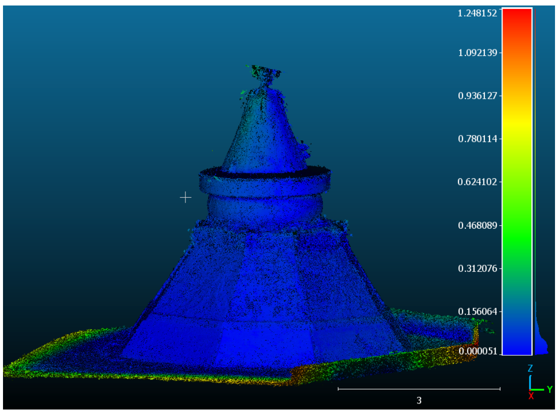
Table 2. Comparing Results

<table>
<tr><th>Testing</th><th colspan="2">Product</th></tr>
<tr><td>Surface Variation</td><td>Photogrammetry


; 11.3% outlier</td><td>Videogrammetry


; 17.5% outlier</td></tr>
<tr><td>Volume Density</td><td>Photogrammetry

</td><td>Videogrammetry

</td></tr>
<tr><td>Point Discrepancy</td><td>Photogrammetry vs TLS


% outlier</td><td>Videogrammetry vs TLS


; 8.4% outlier</td></tr>
<tr><td></td><td colspan="2">Photogrammetry vs Videogrammetry


% outlier</td></tr>
</table>

& Alshibani, 2022). The trend showed that the quality of 3D photogrammetry model could not be surpassed by videogrammetry due to the downgraded photos associated with resolution issues.

Point discrepancy was further compared using TLS data considered to be correct. This was based on the criterion that a farther point discrepancy value was a representation of worse point cloud quality. The results showed that photogrammetry had an average of 0.062 meters compared to TLS at a standard deviation of 0.071 meters and the total points with distances above the 95% confidence interval were 8.5%. Meanwhile, videogrammetry produced an average of 0.106 meters with a standard deviation of 0.131 meters and the total points with a distance above the 95% confidence interval were 8.4%. This showed that the noise point clouds produced by both methods were not statistically different and the result was in line with the previous observation by Murtiyoso & Grussenmeyer (2021). The outlier points were also observed to be approximately the same percentage value and this showed the ability of videogrammetry to compete in producing products less significantly different in quality from photogrammetry.

The final aspect was to compare the quality of the model geometry produced with real-world measurements through RMSE. The results showed that photogrammetry had 0.022 meters while videogrammetry produced 0.032 meters. This showed that photogrammetry had better quality but videogrammetry was also sufficient. The trend was further confirmed by the t-test conducted which showed there was no significant difference in the values produced through both methods at a 95% confidence interval. In terms of the data acquisition process, videogrammetry was superior due to the ability to shorten the time required significantly compared to photogrammetry and TLS. The observation was found to be in line with the results of the previous study by Ortiz-Coder & Sánchez-Ríos (2020). The difference in the photo quality due to resolution degradation is a real challenge to videogrammetry process. However, the results showed the method was able to produce quite high 3D point clouds which were not significantly different statistically from the real form. The trend showed the capability of videogrammetry to produce quality 3D modeling.

This study deliberately did not consider frame splitting in videogrammetry activities to estimate the ideal conditions. The results showed that the products were not significantly affected by the decrease in resolution. This was based on the ability of SfM to remove noise from the point clouds in order to enhance the quality. However, future studies can consider frame splitting to maintain the quality of photo resolution. Another interesting observation was that videogrammetry required 3 minutes 3 seconds to produce 303 photo frames at fixed intervals depending on the method used to break down the frames. Meanwhile, photogrammetry used 50 minutes to produce 243 photos. The observation was in line with the results of Torresani & Remondino (2019) that videogrammetry was beneficial in terms of data acquisition speed. The results showed that the speed was covered by the degradation of the resolution associated with the photos produced.

The assumption that the absence of photodegradation can make videogrammetry very superior in all aspects compared to photogrammetry is not confirmed due to the major weakness identified. The lack of control for the measurement can lead to the production of bad 3D point clouds by videogrammetry but this is also not proven because the mapping is controlled with good planning to ensure both photo and video data have the same parameters during the collection process. The analysis showed that videogrammetry had the ability to produce models with quite high accuracy not statistically different from photogrammetry. The advantage of fast acquisition time could be the reason for the adoption of this method as an alternative for low-cost 3D modeling. However, this benefit cannot be explored efficiently due to the weaknesses associated with the resolution of the photos produced.

4. Conclusion

In conclusion, two non-metric camera-based modeling methods, including photogrammetry and videogrammetry, were compared. This was based on the expectation that videogrammetry could be used as low-cost 3D modeling alternative solution. The results showed that the method was beneficial because data acquisition was approximately 15-20 times faster than photogrammetry. However, the quality of the photo data was reduced and this led to a decrease in the quality of the texturing product. The determination of the solution for the appropriate keyframes can allow videogrammetry to compensate for 3D point cloud accuracy produced by photogrammetry. Moreover, both methods were observed to have similar surface variation and volume density as presented by the lack of significant differences in the noise point clouds. This was further confirmed by the ability of videogrammetry to produce a lower surface variation value and higher point density. Both methods were compared with the discrepancies in TLS data. The results showed that the average difference in photogrammetry was 0.062 meters and the outlier was 8.5% while videogrammetry had 0.106 meters and 8.4%, respectively. In terms of the physical results of the model, RMSE produced was similar statistically as reported by 0.022 meters and 0.032 meters recorded for both methods, respectively.

GSD was very detailed but the control point measurement capability was insufficient for the quality required, leading to a minimum error of 1 pixel in the aerial triangulation process. Empirically, the tolerance value was 3-5 GSD pixels with the consequence that the quality of the control points was in the same metric size fraction. The value was related to Class III on ASPRS Accuracy Standards for Digital Geospatial Data used to represent lower-accuracy visualization-grade geospatial data suitable for less-demanding applications. Videogrammetry generally had the ability to produce accurate 3D modeling even though the method could not outperform photogrammetry. Considering time and cost, it could be an alternative for low-cost 3D modeling needs to produce results not substantially different from photogrammetry in the statistic tolerance of 95% confidence interval.

Further studies are required to use appropriate video frame splitting to avoid significant degradation of photo resolution. This is necessary to explore the potential of videogrammetry properly without considering the possibility of a decrease in photo resolution during the conversion from video.

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