3D TECHNOLOGIES FOR INTANGIBLE CULTURAL HERITAGE PRESERVATION: CREATING 3D MODELS OF LACQUER ART THROUGH PHOTOGRAMMETRY

HOANG-SY NGUYEN[1], KHANH-DUY HO HOANG[2], CONG-DANH HUYNH[3], QUOC-PHU MA[4], JAKUB MESICEK[4]

[1]Becamex Business School, Eastern International University, Binh Duong Province, Vietnam

[2]Research Construction Technology Institute, Thu Dau Mot City, Binh Duong Province, Vietnam

[3]Thu Dau Mot University, Thu Dau Mot City, Binh Duong Province, Vietnam

[4]Department of Machining, Assembly and Engineering Technology, Faculty of Mechanical Engineering, VSB—Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic

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e-mail to corresponding author: danhhc@tdmu.edu.vn

In recent years, close-range photogrammetric scanning systems have become increasingly popular due to their low-cost hardware, components, and user-friendly software. These systems utilize high-resolution cameras and advanced algorithms to produce accurate and precise 3D models, which are essential for analyzing, documenting, and preserving cultural heritage. While there are various methods for creating 3D models, minimizing cost and time is a primary concern. This paper focuses on photogrammetry as an option for surface reconstruction that might be used to make 3D representations of transparent objects. The objective of the research is to investigate the feasibility of creating appropriate 3D models for surface reconstruction and units of transparent objects through photogrammetry, utilizing open-source photogrammetry algorithms.

KEYWORDS

3D model, photogrammetry, surface reconstruction, cultural heritage, Meshroom

1 INTRODUCTION

The practice of 3D digitization is now commonly used in museum settings for study [Hassett 2017], Preservation [Lopez-Martinez 2018], and dissemination [Gonizzi 2013] purposes. The use of spectral and 3D imaging in conjunction for cultural assets has recently been the subject of more and more efforts, such as highlighting features [Webb 2017], recognising substances [Liang 2014], documenting the wavelength of light reflected by the object [Kim 2012], and generating a more precise representation of the object's colors [Brusco 2016], evaluating the state of preservation or decay [Simon 2013].

There are various techniques available for creating 3D digital versions of museum objects, including CT imaging, laser scanning, and photogrammetry. Among these methods, photogrammetry is a regularly used and cost-effective approach for producing 3D models [Mathys 2014], [Delpiano 2017]. However, some materials, such as featureless surfaces like polished metals or varnished ceramics often produce unwanted "noise" in the model [Mathys 2015]. Prior research on digitization suggests adding a coating to lessen reflections, such as spraying a developer, glare-reduction spray, talc dust, spraying dulling, chalk spray, cyclododecane spray, or paint, and accurately scan transparent, shiny, or reflective objects [Valinasab 2014]. While laser scanners are known to be more precise compared to image-based systems, the latter is often favored due to its affordability, user-friendliness, and time efficiency. As noted in [Kwon 2017], laser scanning has some drawbacks such as generating many blind spots and taking a significant amount of time to collect data.

3D optical surface reconstruction can be achieved without physical contact with the object being reconstructed [Xu 2020]. Optical surface reconstruction techniques are categorized into two types: active and passive with active methods projecting structured light onto the object and passive methods using images of the object itself [Mirota 2011], [Close S. Rohl 2012], [Zhang 2018]. However, both types of techniques face difficulties when dealing with transparent objects, which have sparse textures that cannot be matched easily and only reflect a small amount of projection light. Additionally, the reflection, refraction, and cross-reflection in transparent objects make it challenging to implement the matching process during the binocular reconstruction process. These challenges also apply to the reconstruction of cultural heritage items, such as ceramics and lacquerware, which require special attention to maintain their exceptional beauty and quality.

To make this happen, large volumes of data, including 3D models of the relevant objects, must be converted into digital form in order for this to be possible. However, creating these 3D models requires extra resources, which prompts companies to search for ways to improve the process and increase its efficiency and quality, according to [Gregor 2018], [Horvathova 2019]. With the introduction of new computer applications and software, there are now more opportunities to optimize the creation of 3D models, as noted by [Buckova 2019].

The environment and materials can make it difficult to generate point clouds, even with proposed solutions. However, there is potential for new advancements to overcome limitations. The resolution of a point cloud is determined by the user's demands and the intended use in cultural heritage [Nocerino 2017], but high-quality results are always important. Traditional laser scanning methods fail to reconstruct transparent objects, but photogrammetry offers a solution by creating 3D models from a set of photos. This technique is becoming more accessible to a wider range of users due to user-friendly software, increased computing power, and better cameras [Kaufman 2015]. By taking photographs of an object from different angles, photogrammetry can determine the position of visible points and calculate their 3D coordinates to create a 3D model of the object. This is the fundamental principle of photogrammetry and how it enables object reconstruction in a virtual space.

In addition to that, photogrammetry is becoming more integrated with other technologies such as Virtual and Augmented Reality, allowing for more immersive and interactive experiences for users. The use of drones for aerial photogrammetry is also becoming more prevalent, making it easier to capture large and hard to reach objects or structures. As the technology continues to advance, it is likely that photogrammetry will become even more widely used in a variety of fields including archaeology, engineering, construction, and more. Particularly, photogrammetry is a flexible technique that has been utilized in different sectors such as cultural heritage preservation [Remondino 2011], prosthetic socket design [Ismail 2020], geoscience studies [Westoby 2012], and automotive industry for car body deformation assessment [Luhmann 2010]. The technology can scan objects of varying sizes and is straightforward to set up and calibrate, producing superior quality 3D models that can be customized and automated [Percoco 2015].

Furthermore, to maximize the potential of photogrammetry, it's essential to have a foundational knowledge of the process. This will allow users to make the most of the tools and achieve the desired outcomes. Previously, photogrammetry was considered a difficult and complicated technique, but modern software has made it much more user-friendly and accessible. Now, even those with limited experience can benefit from photogrammetry and produce high-quality results for the 3D digitization of cultural heritage.

Hence, photogrammetry is a strong tool for reconstructing an object's position, form, size, and orientation using photos. Depending on the user's demands and project objectives, the result of this technique might be numbers (coordinates), drawings (maps), or 3D models with textures. This technique provides a non-contact method of analyzing and reconstructing objects, which is a key advantage of photogrammetry. The results of photogrammetry can be used for a wide range of purposes, from engineering and surveying to cultural heritage preservation and virtual reality. By understanding the basics of photogrammetry, users can take advantage of this technique to achieve their desired outcomes, as noted by [Kraus 2007].

2 THE PHOTOGRAMMETRY-BASED PROCESS OF CREATING A 3D MODEL

The structure-from-motion (SfM) photogrammetry method is widely used for creating 3D models of objects using overlapping images captured from multiple viewpoints. Specialized software automatically calculates camera position and orientation, facilitating the 3D model creation and texturing process. Photogrammetry involves obtaining precise measurements using photographs and creating 3D models of objects by aligning multiple photos with overlapping features in software [Westoby 2012]. Meshroom is a recommended companion software for photogrammetry, known for its ease of use and automatic processes. It is open-source and freely available, making it a great option for beginners or those on a budget. The user's main responsibility is to provide the photos, with minimal post-processing required. The below cautions should be taken into when working with photogrammetry:

- The key to properly photographing an object for photogrammetry is to use a well-lit area with a solid black background that is free of any patterns or designs.
- At least two sets of photos must be taken with a minimum of 33% surface overlap to fully capture the object.
- To ensure complete coverage of an object using photogrammetry, take photos every 30 degrees as the object is rotated 3-4 times from different angles, and then flip the object and repeat the process.

In summary, generating a photogrammetric 3D model with the Meshroom software is a straightforward process. The user simply needs to provide the photos and perform some post-processing cleanup, while the software handles all the underlying tasks automatically. However, for more complex photogrammetry projects, the user may need a deeper understanding of the software's capabilities. It is important to note that a flowchart can be a useful tool in visualizing the photogrammetry workflow, as it shows the tasks performed by the software and the tasks requiring human intervention. The flowchart in Fig. 1 depicts this process and represents the tasks that will be completed automatically by the programme with little user participation in the red region. More experienced users, on the other hand, may adapt the procedure to meet their individual requirements.

2.1 The object's talking photos

The first step in building a 3D model with photogrammetry is to photograph the item. In this scenario, the purpose is to produce a 3D model of lacquerware (surface reconstruction). Since the object is large in size, it is important to make sure the room is well-lit or, if photographing outside, to choose a cloudy day to minimize direct sunlight. Rough surfaces are easier to process while glossy surfaces may cause issues. To increase the chances of successful reconstruction, it is recommended to reduce light reflection by covering the object with a powder such as flour.

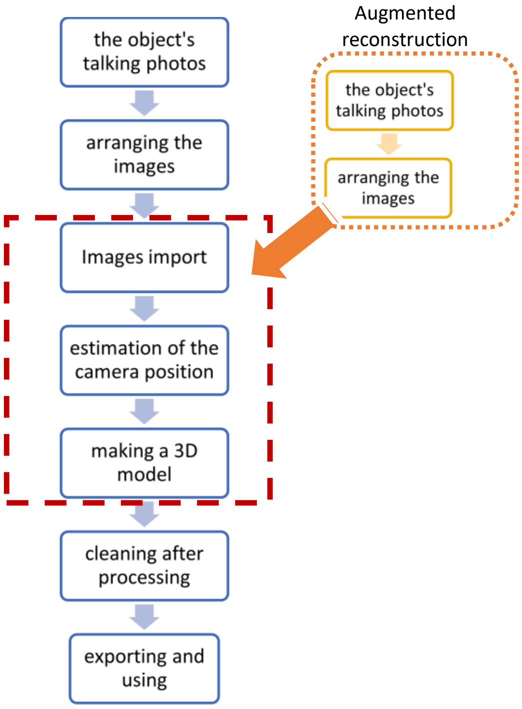

Figure 1. The flowchart of creating a 3D model using photogrammetry.

The capturing of images can be achieved by utilizing a Digital Single Lens Reflex (DSLR) camera. However, the utilization of a smartphone is also an available option. When using a DSLR, it is crucial to correctly adjust the aperture in order to maintain the entire object in focus. To ensure capturing of a sufficient amount of detail, it is recommended to take a minimum of 60-100 images, which may vary based on the size and level of detail of the object. It is imperative to keep the object stationary during the photography process. Additionally, reducing or removing any moving objects in the background of the images can minimize potential problems during reconstruction [Zuza 2018]. It is advisable to capture the object from various perspectives and to fill the majority of the frame with the object. The optimal approach is to move around the object while capturing images. Rotating the object while keeping the camera stationary may not provide satisfactory results, especially for larger objects.

2.2 *Arranging the photos in order*

After completing the photography process, it is crucial to inspect each image to guarantee that they are in focus and meet the established criteria (lighting, position, etc.). Discarding a significant number of photos may necessitate the need to take additional images, making it advisable to take extra pictures initially. The Meshroom software can import suitable images after they have been checked.

2.3 *Estimating the camera position through partial 3D reconstruction.*

Once the pictures have been imported, the reconstruction process can commence. The software used for 3D modeling will undertake multiple tasks and sub-tasks to produce the final 3D model. The completion of the reconstruction process may require a significant amount of time. To avoid potential issues with the reconstructed model, it is advisable to stop the reconstruction process at a certain point, rather than allowing it to be fully complete. This way, any potential shortcomings in the model can be identified and addressed before proceeding further.

Creating a 3D model requires a crucial step called camera reconstruction. In this process, the software calculates the position of the camera for each image captured to generate the 3D points for object reconstruction. It is recommended to only perform camera reconstruction at first, as it is quick and provides a rough visualization of the future 3D model, allowing any potential issues to be identified. If parts of the point cloud appear sparse or have limited points, additional photos can be taken for augmented reconstruction, according to [AliceVision 2020].

2.4 *Augmented reconstruction*

In the event that a large number of photos were discarded and there is insufficient data for a quality reconstruction, augmented reconstruction can be utilized to resolve this issue. To perform augmented reconstruction, additional photos must be taken. The quantity of photos required for augmented reconstruction is typically smaller than that required for a standard reconstruction (as few as 10 photos may be sufficient). However, if the object has been moved since the initial photography, augmented reconstruction may not be possible. The new photos will fill in the gaps and provide additional camera positions, leading to an improvement in the overall quality of the reconstruction, or allowing the reconstruction to proceed to the next stage.

2.5 *Creating the 3D model and textures*

Assuming that there are enough data and no complications, the project can move on to complete the reconstruction of the object. This process involves several stages that the software performs automatically. The software utilizes camera positions and 3D coordinates to create a mesh of the object and its textures. Before this process, there are a few sub-stages that generate the necessary data for the final outcome. Fig. 2 demonstrates the process of creating a 3D model through photogrammetry and Meshroom software.

Figure 2. Generating a 3D model through the utilization of photogrammetry and the Meshroom software.

2.6 *Finalizing the process with cleaning up.*

The final stage of post-processing clean-up is significant because the reconstructed 3D model can be too intricate and contain numerous unnecessary vertices. Furthermore, some parts of the environment that were captured in the photos may have been reconstructed as part of the primary object and must be removed to decrease the vertex count. To achieve this, 3D modeling software such as Blender or Maya is required. These modeling tools enable the modification of the reconstructed mesh, including the removal of unnecessary parts and simplification of the mesh. Even though individuals with little modelling experience can accomplish these tasks, it is vital to recognize that reconstructed models can have over a million vertices. Therefore, it is recommended to use a powerful computer to ensure accuracy and avoid slow processing. The degree of mesh simplification will depend on the intended use of the reconstructed model, but it should be streamlined as much as possible without compromising the model's quality.

3 CASE STUDY: THE SUITABILITY OF PHOTOGRAMMETRY FOR CREATING 3D MODELS OF LACQUER ART

The experiment will consist of taking photos of traditional lacquer art from various angles, importing the photos into Meshroom, and performing camera reconstruction and fully 3D model reconstruction. The results of the experiment will be evaluated based on the quality and accuracy of the 3D model, as well as the time and effort required to create it. This experiment aims to determine the suitability of photogrammetry for creating 3D models of lacquerware. The results of the experiment will provide valuable information for industries and researchers, who are looking for efficient and cost-effective ways to create 3D models of large and complex objects.

3.1 *Creating a 3D model of lacquer art using photogrammetry*

As previously discussed, the initiation of 3D reconstruction through photogrammetry entails capturing images of the object of interest, which in this case was a traditional lacquer art utilized for short-distance transportation in a metal stamping workplace. The images were taken from a range of angles and heights to ensure all parts of the object were captured. This was carried out outdoors during overcast conditions, which is a desirable setting for this procedure. The movability of the traditional lacquer art made the process more manageable. A total of 155 photos were taken using a mid-range device. The photos were then evaluated and any that were out of focus, poorly lit, or did not meet the criteria were discarded. Ultimately, three photos were excluded.

The following stage involves importing each photograph into the photogrammetry software Meshroom. This is accomplished through a straightforward drag-and-drop process. Before proceeding with the full 3D reconstruction, a final quality control step was conducted to ensure that no low-quality photographs were missed. Once all photographs were successfully imported, the 3D reconstruction process was initiated. However, due to its lengthy nature, it is essential to conduct a partial reconstruction beforehand to confirm that the software is capable of estimating the camera position for each photograph. In the event that the software discards an excessive amount of photos (due to an inability to determine the camera position) or lacks sufficient data for certain areas of the object, the issue can be addressed through the use of augmented reconstruction. The process of photo import and camera estimation is depicted in Fig. 3.

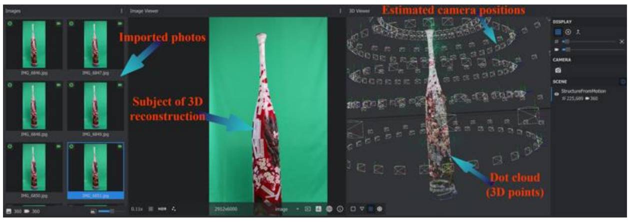

Figure 3. 3D point cloud generated

In this instance, the software was able to accurately estimate the camera position for 150 out of the 152 photos imported. This resulted in a sufficient amount of 3D points covering the entire traditional lacquer art object, eliminating the need for augmented reconstruction. However, if an object is a surface reconstruction that can be stationary for an extended period, then augmented reconstruction can improve the final model's quality. Nevertheless, the potential challenge in the case of lacquer art is the difficulty in affording to keep the object stationary for the duration of camera estimation. Additionally, even if the object's exact location is marked, there may still be small differences in position, raising questions about the software's ability to handle such variations.

After the successful estimation of camera positions and preview of the dot cloud, the next stage was to complete the entire 3D rebuilding process. This procedure took longer than anticipated by the camera but resulted in a comprehensive and detailed 3D representation of the lacquer art, along with a portion of the environment. However, the 3D model of the environment needed to be removed. This session explains that a 3D model was cleaned and simplified using Blender software. The 3D model had an excessive number of vertices and contained unnecessary parts of the environment, which could cause performance issues in other industrial engineering applications. To simplify the mesh and reduce the number of vertices from 1,654,733 to 46,219, Blender was used. A visual representation of the reduction process can be seen in Fig. 4.

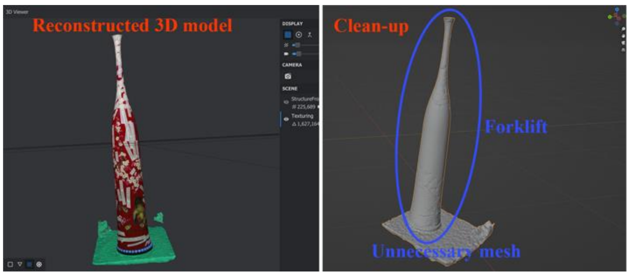

Figure 4. Post-processing adjustment

After the appropriate cleansing, the 3D model of the lacquer art is available for exporting into other software. This work can include 3D simulations, visualizations, or any other operations that are crucial to optimizing transport processes. The model's quality can be improved by using better cameras or creating a better environment for photographing, although the software struggled to reconstruct the translucent parts of the model, which could be removed or improved with further modeling knowledge. Despite being relatively complex, the model can still be simplified for performance optimization, and losing details would not affect the focus of the scene. The 3D model of the traditional lacquer art can be seen in Fig. 5 after the cleanup process.

Figure 5. The 3D model of the lacquer art

3.2 Evaluation of time and cost

In terms of cost-effectiveness, the 3D reconstruction of lacquer art using photogrammetry proved to be a great success. The key factor contributing to this success was the low cost of the tools and equipment required. The software used, Meshroom, was readily available for free on the internet, and a smartphone was sufficient for capturing the photos. This made photogrammetry one of the most cost-effective methods for creating 3D models of cultural heritage. With regard to the assessment of time, Tab.1 provides details about the duration of each stage of the 3D reconstruction process, including capturing images, organizing and bringing in the photos, performing a partial 3D reconstruction for camera positioning, conducting a comprehensive 3D reconstruction, and completing the procedure with a post-processing cleanup.

Process	Time consumption (minutes)
Taking pictures of the object.	30
The process of organizing and bringing in the photos into the software.	10
Estimating camera position with a partial 3D reconstruction.	10
The process of creating a complete 3D model of the object.	60
Post-processing adjustment	20
Process	**130**

Table 1. Time evaluation

In summary, the 3D reconstruction process using photogrammetry took 130 minutes in total, making it relatively fast and efficient. However, factors such as the complexity of the object, the quality of the photos, and the photographing environment can impact the speed of the process. An added advantage is that the process is mostly automated, freeing up employee's time for other tasks and saving company resources. Overall, photogrammetry proved to be a suitable method for creating the 3D surfaces of transparent objects. The entire reconstruction process took a little over two hours, with a cost-effective approach as the necessary equipment was just a smartphone. The final product had a high vertex count, but the details could be improved by using a better camera and covering the windows. However, it should be noted that photogrammetry may not be the best option for creating simple models or for models that appear frequently on the virtual scene. The use of photogrammetry can help save company resources as the employees can perform other duties during the process.

4 CONCLUSIONS

In conclusion, photogrammetry presents a viable solution for creating 3D models of lacquerware and units in a fast and cost-effective manner. However, it is important to consider the factors such as the type of object, quality of photos, and quality of the photographing environment in order to achieve the desired results. Additionally, photogrammetry is best suited for complex objects with surfaces of transparent objects. While it may not be the best option for creating simple 3D models, photogrammetry is a useful tool for those with limited 3D modeling experience and can be improved upon with additional experience.

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CONTACTS:

Becamex Business School, Eastern International University, Binh Duong Province, Vietnam; Website: https://www.eiu.edu.vn

Ing. Hoang-Sy Nguyen, Ph.D.

E: sy.nguyen@eiu.edu.vn

Research Construction Technology Institute, Thu Dau Mot City, Binh Duong Province, Vietnam

Khanh-Duy Ho-Hoang, Mr

E: hhkd.1995@gmail.com

Thu Dau Mot University, Thu Dau Mot City, Binh Duong Province, Vietnam; Website: https://www.tdmu.edu.vn

Cong-Danh Huynh, Mr

E: danhhc@tdmu.edu.vn

Department of Machining, Assembly and Engineering Technology, Faculty of Mechanical Engineering,VSB—Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic

Bc. Quoc-Phu Ma

E: phu.ma.quoc@vsb.cz

Ing. Jakub Mesicek, Ph.D.

E: jakub.mesicek@vsb.cz