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A Framework for Using Photogrammetry in 3D Scanning

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Abstract
The paper presents the necessary steps to be completed in order to obtain a 3D model through photogrammetry as an alternative to 3D scan. The methodology described in the paper does not aim to present photogrammetry as a substitute for 3D scan but as a low-cost alternative and/or for occasional use. The framework presented is highlighted by tests performed on an object that has most of the "disadvantages" for the photogrammetry operation. The results are analysed from a technical point of view and correlated to the duration of each stage. This analysis is performed in order to underline the methods and means of improvement. At the same time, the paper presents a structured approach in order to obtain a working 3D model that could be further improved in any CAD software.

Keywords
photogrammetry, 3D scan, accuracy

1. Introduction

There are a variety of non-contact technologies used to capture the shape of a 3D object, the best-known being 3D scanning. This method is ideal for measuring and inspecting complex surfaces and bodies that require huge amounts of data for their accurate description. Generally, a 3D scanner collects information about the distances at which surfaces are positioned to the in their field of view. In short, the "image" produced by a 3D scanner describes the distance to a surface. This method allows identifying the three-dimensional position of each point in the image.

Passive non-contact technologies such as photogrammetry are based on the detection of radiation reflected by the environment [1, 2]. These technologies can be very low cost because, in most cases, it is not involving a particular hardware component but simple digital cameras. The method used in this article is called close-range photogrammetry. This type of photogrammetry is a measurement technology that can be used to extract 3D points from images [3]. Moreover, these 3D points are useful for both 3D modeling and visualization.

Photogrammetry method generates the three-dimensional model by matching similar points in two or more photos. The algorithms used in the construction of the three-dimensional model compare the relative displacements of the object between the different pictures [4, 5].

2. Photogrammetry Framework

2.1. Preliminary activities

In order to reduce the number of errors that may occur in the process of obtaining the 3D model by photogrammetry, it is important to choose a suitable location. Thus, a place with strong natural or artificial lighting is recommended. If this is not possible, it is recommended that the object be positioned so that the lighting creates as few shadows as possible, as they make it difficult the extraction of the 3D model.

In both cases, it is beneficial to place the object in an area with a background of a different colour from that of the object, as this will eliminate the risk of the software confusing the placing surface with the actual object, and thus choosing common points in a wrong way.

Precisely, for this research, an artificial light source was used and the object was placed on a black surface because, as indicated, this reduces the number of shadows that could interfere in the process.

2.2. Object preparation

Regardless of the 3D scanning method, even photogrammetry will have problems if the object being photographed is phosphorescent and strongly reflects the light from the place where it is located. Under such conditions, the methods of preparing the object used in 3D scanning can be used, such as the use of a matte, easily cleanable powder spray or certain stickers that will stick to the surface of the object on surfaces with details that are determined to be important. If the object is black, it is inappropriate to place it in a place with a black background, because the software would have difficulty distinguishing the object from the background. Thus, without enough points chosen from the object, the processing that will follow would be very difficult, maybe even impossible.

Specifically, because the object analysed in article was initially black, the decision was to paint it, using a spray of matt white paint, to facilitate the process of model extraction. This painting process is in turn divided into the following stages: preparing the surface for painting, the actual painting, and drying.

The preparation of the painting surface involves both the preparation of the object and the preparation of the space in which the painting is done. It is very important that the object to be painted is clean and dry because otherwise, the paint powder will not adhere to its surface, and thus the paint will flow and the process will need to be repeated. The space where the painting is performed needs to be very well ventilated and the operator to be properly protected because the spray, if inhaled, can cause certain respiratory syndromes. The recommended distance between the spray and the object is 250-300 millimetres. Figure 1 shows a comparison of the object before (left) and after painting (right).

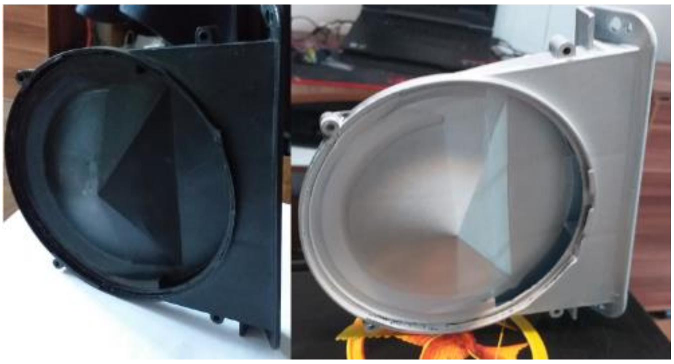

Fig. 1. Photo taken before painting (left) and after painting (left)

2.3. Digital photography stage

The most important stage of the whole process is taking pictures of the object. This will be done by placing the object followed by rotation of the object or camera with a fixed increment, while maintaining, as far as possible, the same distance between the object and the lens. This incremental movement is important because, in order to obtain a 3D model, it is necessary for the software to obtain common points of the object from the photos taken.

Specifically, two sets of photos were taken. One when the piece had the initial black colour, set consisting of 79 photos, the equivalent of posing the object in two complete rounds. The second 37 pictures were made after painting the piece, the equivalent of posing the object in one complete round, including a few more pictures taken in the sections where the details are considered more important. This step will be repeated as often as necessary in order to obtain a 3D model as close to reality as possible.

Is important to mention that in addition to the light conditions in the room where this stage is performed, of particular importance is the camera with which the actual photos are taken. The better the camera, the clearer the pictures will be, and this will greatly simplify the model extraction process. The photos were captured using a Huawei P20 Pro camera, in auto mode. Each photo was taken at 10 Mega pixels in 4:3 format and saved in .jpg format. Characteristics of a three-photo module camera are 40 MP, f/1.8, 27mm (wide), 1/1.7", PDAF, Laser AF, OIS, 8 MP, f/2.4, 80mm (telephoto), 1/4.0", PDAF, OIS, and 20 MP B/W, f/1.6, 27mm (wide), 1/2.7".

2.4. Photos pre-processing

After obtaining the set of photos, the pre-processing stage of the photos to be introduced in the photogrammetry software follows. No matter how much previous preparation has been done to ensure the highest possible shooting quality, the human eye will always perceive more detail than a camera, so there is a need to change certain parameters of the pictures in order to allow the software to identify points more easily.

In the most general way, the main parameter that will have to be modified is the exposure. In this way is increased the brightness of the areas whose shadows are prominent. In the same time, for areas with too much light, the level will be reduced. No matter what changes are done for each image, it is very important to avoid changes that could distort the images, as this will lead to corruption of the data that will be used for the photogrammetry process. Is relevant to mention that this stage it can be long lasting because the manual changes for each photo rise the duration of the whole process.

For this stage, the any photo-editor software can be used but, in order to speed-up the activities, a feature like "batch processing" is necessary. With this, all the settings from one picture could be applied to all the others. In this way, it is not necessary to edit each photo separately, but only one of them, and the changes will be transferred, finally, to all the photos in that group by using batch processing feature. In the vision of minimal costs, a free and open-source photo editor was used, namely GIMP, version 2.10 [6].

It is obvious that previously it is necessary for the photos taken at the previous stage to be downloaded to a computer in order to facilitate the process of selecting the images to be used. This step of importing photos can be seen in Figure 2.

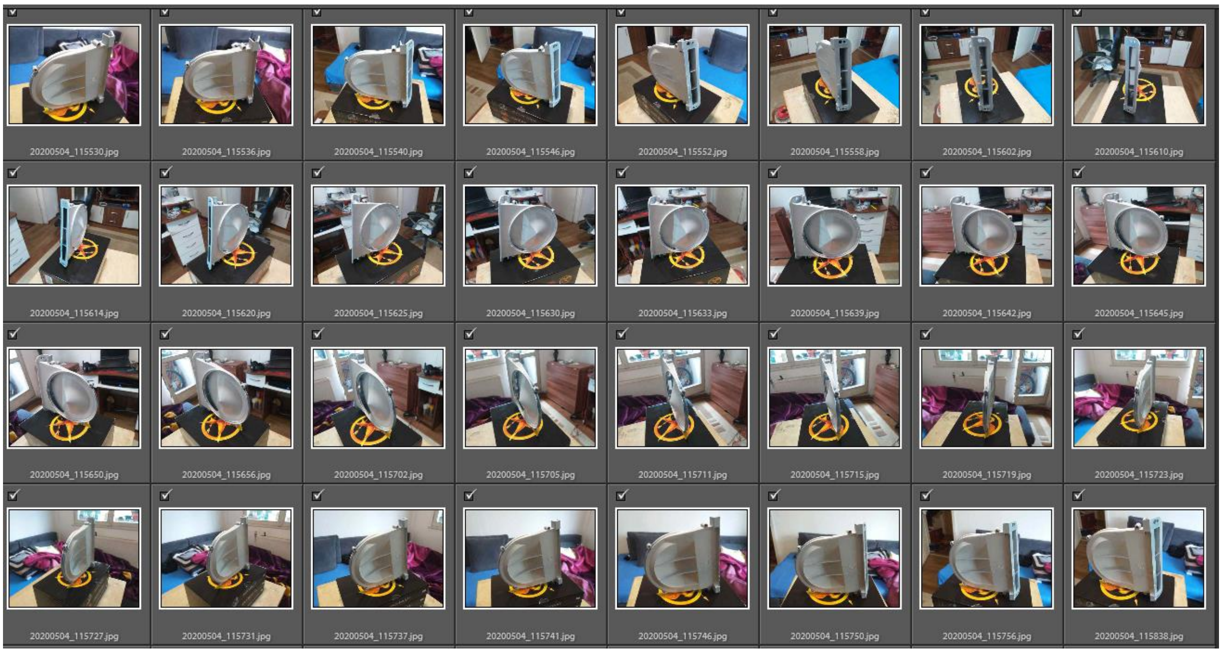

Fig. 2. Photo set

The most important parameters that can be changed through the photo-editing program are exposure, shadows, texture, and saturation. It is recommended to use the auto-retouch facility in the program. In case it does not offer the desired results, it is possible to intervene manually over the previously mentioned parameters. Due to these changes, the photogrammetry software will be able to obtain common points of the object in the pictures, in an easier and more precise way compared to the simple introduction in the respective software of original pictures, without these pre-processing.

A comparison between a picture before and after automatic processing can be seen in Figure 3, where, before processing the picture was darker due to the light source used and more blurred. After processing, it is brighter and certain details and contours are much clearer, thus focusing the object more efficiently. The final picture may not look artistically appropriate, having with an unnatural touch, but the goal is to highlight the photographed product.

Fig. 3. Photo before (left) and after pre-processing (right)

By means of another photo editor software, like Adobe Lightroom Classic [7] it is possible to use histograms that describes the current state of the photo, in terms of parameters such as black, shadows, exposure, highlights, and white. An example of such histograms, along with the parameters that generate it, before and after automatic photo processing, can be seen in Figure 4. It aims to correct errors caused by the artificial light source and possible blurring effects caused by erroneous shooting due to external sources of disturbance. As can be seen, the main adjustments made by the program were in the area of black, which is prominent due to light falling directly on the object, and as a result, its intensity was reduced. The shadows have also been accentuated, and as a result, certain contours can be seen more clearly.

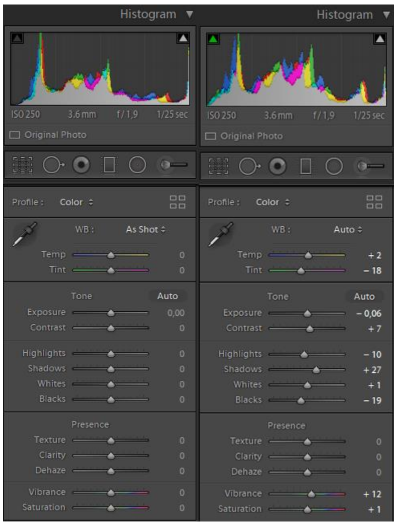

Fig. 4. Photo parameters before (left) and after (right) automatic processing

Once the photos have been brought to a stage considered optimal for what is to come, the export option will be used to save the batch of edited photos. The activities within this stage can be resumed whenever it is considered necessary.

2.5. Obtaining the primary 3D model

3D model of the object is based on the set of previously processed photos. Turning photos into a 3D model is done by uploading them into a dedicated software, such as Autodesk ReCap Pro [8] or 3DF Zephyr [9]. Depending on the software used, the optimal number of photos used to extract the 3D model varies. For example, although the maximum limit of photos supported by 3DF Zephyr is 50, after repeated attempts it was observed that satisfactory results are obtained using somewhere around 30 photos. Although it allows an unlimited number of photos, ReCap Photo works best with a number above 40 photos. These values were obtained based on initial tries used to establish an optimal number for the photo set. Empirically, it can be said that a larger number of photos can generate better results. In practice, this translates into a considerably longer processing time of the photo transformation software.. In addition, a larger number of photos may not add something to the accuracy of the 3D model.

Regarding the performance of software used to obtain 3D model there are also some criteria to take in consideration, namely processing time and accuracy. Sometimes it is preferred a longer processing time if this is leading to an accurate model. The processing of the primary 3D model takes a long time because this stage involves multiple interventions on the surfaces of the object. Specifically, the ReCap Photo software was used, because the quality of the extracted models is much higher than those in Zephyr, and thus the user will be exempted from a lot of work when it comes to finishing the digital model. The processing time is much longer; it generally lasts around 60 minutes, as opposed to 15 minutes Zephyr software.

Pre-processed photos are introduced into the software, which will automatically upload them on a cloud platform, called the A360. An image processor is implemented in the platform that will transform the uploaded files into a 3D model. As mentioned, the quality of the model obtained strongly depends on the clarity of the details in the batch of pictures. For this research, there have been two tests, a model made using the 79 photos of the black piece and a model made using 37 photos of white piece.

Although the first model contained more pictures, so implicitly a larger number of references from which software to choose the common points, the model made from the batch of 37 photos has a better clarity. As consequence, this is an important conclusion regarding the minimal set of captured photos, which are the equivalent of a single rotation around the object. The second conclusion is related to colour of the object. The initial object, being black is not offer enough details. In Figure 5 a and b are presented the two models obtained.

a. Model obtained from 79 photos of the black piece

b. Model obtained from 37 photos of the painted piece

Fig. 5. Model generated from different number of photos

From the pictures presented, the model obtained from the photos of the black piece has a very detailed front, and is free of distortion in general. The back face has many errors of shape and size, and its repair could take a very long time. In addition, unnecessary points are closely related to the object, and their elimination would be very difficult.

Instead, the model obtained from the photos of the painted piece has a shape much closer to the real one and unnecessary dots will be much easier to be removed than in the previous case, because they are near only to one part of the object. Although it has holes on its surface, they can be covered after the model is extracted.

2.6. Post-processing of the model

After obtaining the 3D model, the post-processing stage is necessary in order to bring it into its final shape. This stage starts by removing unnecessary points from the model. Once the unnecessary points have been removed, the program allows the model to be exported in various specific formats such as .stl or .obj.

Specifically for this part, in order to facilitate the post-processing stage, due to the symmetry offered by the object, the model will be sectioned in half and will be exported in this way, as can be seen in figure 7. Generically, this is done using a function implemented in the software, such as "cut" or "slice". In the case of ReCap Photo, this function is "slice" and involves working with a cutting plane placed properly by the user. An example of a sectioning plan, correlated with the part, can be seen in figure 6.

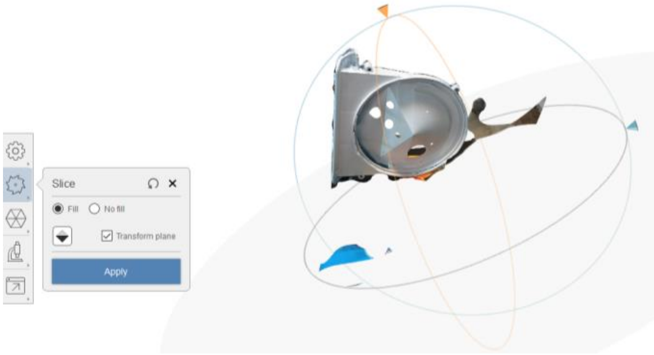

Fig. 6. Slice function and section plane

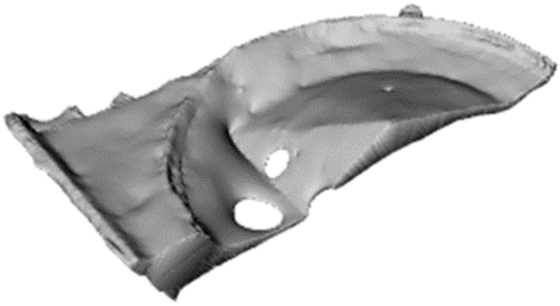

Fig. 7. Half model

The final model will be generated and repaired by using TinkerCAD online platform [10]. The sectioned model, in .STL format, will be uploaded and then processed. In order to obtain a complete model, the section will be inserted in the work surface and then duplicated. The mirror effect will be applied to the duplicate and after that, the Group command will be used on the two sections in order to obtain a single object. In addition, to cover the holes will be used the Basic shapes type objects that are implemented as commands within software. Figure 8 shows how the model looks before and after filling the majority of defects.

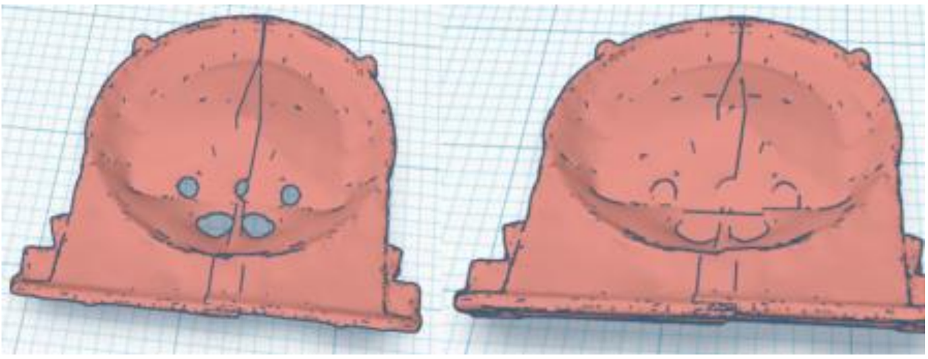

Fig. 8. Model before and after the holes were filled

Holes and cavities finishing will be done in the same way as described above by using hatch box and cylinder shape corresponding to material removal. These shapes will be dimensioned according to the negative of the hole it will process. This stage will last more as the preliminary model obtained in the previous stage is of a lower quality. After completing the process, the platform allows to export the models in the same digital formats that ReCap Photo allows .stl and .obj. The editing process could be more refined if the software could natively processes .stl models or that it allows their transformation into solid type bodies. Then, being in solid form, this model could be edited like a true 3D design. Because the idea was to carry out these activities at the lowest possible, applications were chosen that do not bring additional costs, even if they have inferior functionalities.

An operations summary and their associate times can be seen in Table 1.

3. Conclusions

By photogrammetry, the digital model was obtained in 3.25 hours, of which the largest stages are the sub-operation of software processing, with a duration of 60 minutes, and the post-processing operation of model with a duration of 90 minutes. The high value of the post-processing operation of the model is due to the fact that the model obtained in the previous operation is not optimal because certain pictures, although pre-processed, maintained some faults. These high working times are generated by the fact that the photogrammetry cannot reproduce the holes and channels within the objects. Because the software processing sub-operation is platform dependent, this time can only be reduced by using higher performance software.

Table 1. Operations and their related times

No.	Operation name	Time
1	Choosing and preparing the location	5 minutes
2	Object preparation	
	2.1. Surface preparation for painting	6 minutes
	2.2. Painting	5 minutes
	2.3. Drying	10 minutes
3	Digital photography stage	7 minutes
4	Photo pre-processing	12 minutes
5	Obtaining the primary 3D model	72 minutes
6	Post-processing of the model	90 minutes
	TOTAL	195 minutes = 3.25 h

Considering the costs, a factor that determines a high level of labour costs is that the photogrammetry process is relatively long, in this case 3 hours and 15 minutes. Obviously, the duration of the post-processing operation of the model is closely related to the quality of the model obtained in the previous stage, namely obtaining the preliminary 3D model. The fewer imperfections the model has, the less post-processing is necessary, so lower costs. In this context, the higher the clarity of the pictures and the higher the number of details, the more adequate the quality of the model will be. Thus, in order to reduce the post-processing time, it will be necessary to increase the quality of the photos. This can be improved by several methods and the most common are a higher performance camera and using a turntable.

The main advantage of photogrammetry is that the duration of the actual photo shooting does not suffer a major rise as the size of the object increases. Instead, the main disadvantage is that the interior details the interior details need to be done manually if they are not found in the photos.

As a final remark, photogrammetry is recommended when the user does not have a capital corresponding to the purchase of an industrial type 3D scanner. At the same time, photogrammetry is a suitable solution when this activity is only occasional. Nevertheless, photogrammetry could produce remarkable results as long proper hardware and software is used for capturing and image processing.

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