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Creating 3D Objects Using Photogrammetry

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Abstract: Nowadays there is an increasing demand of creating accurate 3D models of various object. Visualization of these models allows the user to get the realistic impression of the object. 3D visualization has many applications in the areas of architecture, engineering, medicine, tourism, education etc. This paper presents the creation of 3D objects using photogrammetry technique. During our research, we have generated 3D model of various small objects. However, the focus was on generating 3D model of a human body, using Meshroom software. The lessons learned, during the data acquisition, as well as 3D reconstruction are presented in this study.

Keywords: photogrammetry, 3D reconstruction, 3D model, Meshroom.

I. INTRODUCTION

One of the many lessons learned during Covid-19 pandemic, is the need to incorporate technology into education systems. This require reorganizing teaching and learning processes, by creating flexible and enriched educational environments, that will help teachers in conducting the teaching activities, while increasing students' motivation and engagement, at the same time. The transformation of teaching and learning by the utilisation of technologies has certainly provided an exciting opportunity to design various learning systems and environments, that are realistic, engaging and fun [1, 2, 3, 4, 5, 6].

Nowadays, one of the technologies that is showing great potential in education system is Augmented Reality (AR). Using AR technology in education has a number of advantages. AR can: significantly improve students' level of content knowledge, enhanced engagement, enjoyment, motivation and participation improve students' outcome, promote exploratory behavior and develop a positive attitude [7]. The advantages of AR in education indicates that there is good potential to integrate AR in teaching and learning, especially for the subjects that require the students to visualize. The virtual objects used in AR, appear to coexist in the same space of the objects in the real world. Augmented reality (AR) combines real and virtual world, supplementing the real world with computer-generated virtual objects in real-time [8, 9]. AR uses pre-determined target points in real world by connecting virtual objects and interpreting the results through certain programs. However, the virtual

objects used in AR, should be created previously, using various technique and specific computer programs.

This paper presents the creation of 3D objects using photogrammetry technique. During our research, we have generated 3D model of various small objects (like vase, ceramic glass, little statue etc.) However, the main focus of this paper is generating 3D model of a human body. For photo processing we used Meshroom - an open source software 3D reconstruction software based on the AliceVision framework [10]. To clean up and refine our 3D mesh, Meshlab software is used [11].

II. WHAT IS PHOTOGRAMMETRY?

Photogrammetry is a technique to obtain reliable data of real-world objects in the environment by creating 3D models from photos [12]. The technology is practically as old as the photography itself. During the years, it has evolved from analog optical-mechanical technique to analytical methods based on computer/software applications involving complex mathematical algorithms and finally, nowadays, to digital photogrammetry based on digital imagery and computer vision. Photogrammetry is primarily concerned with making precise measurements of three-dimensional objects and terrain features from two-dimensional photographs. Photos should be taken from different positions and angles, allowing for appropriate calculations. 2D and 3D data is extracted from an image and, with overlapping photos of an object, building, or terrain, converted into a digital 3D model.

The fundamental principle used by photogrammetry is triangulation. A line of sight (or ray) can be constructed from the camera location to the point on the object. It is the intersection of these rays that determines the three-dimensional location of the point [12].

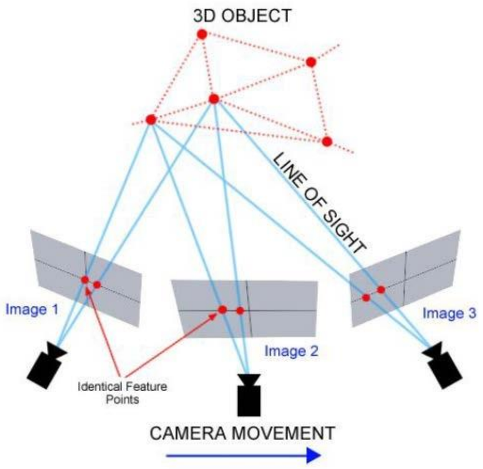

Figure.1 The concept of photogrammetry

III. TYPES OF PHOTOGRAMMETRY

Photogrammetry can be classified based on camera location during photography. On this basis we have aerial, terrestrial (or Close-Range) and space photogrammetry [13].

In aerial photogrammetry, the camera is mounted in an aircraft (or drone or unmanned aerial vehicles-UAVs) and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the vehicle flies along a flight path. Traditionally these photos were processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view) but now are often processed by automated desktop systems. The photogrammetry software will take the images (and potentially GPS position data, along with any camera information or calibration) from the flying vehicle and produce a set of 3D points or surfaces that describe the surface (the ground or object) being modeled.

In terrestrial photogrammetry, the camera is located on the ground, and hand-held, tripod or pole mounted. Usually this type of photogrammetry is non-topographic - that is, the output is not topographic products like terrain models or topographic maps, but instead drawings, 3D models, measurements, or point clouds. Everyday cameras are used to model and measure buildings, engineering structures, forensic and accident scenes, mines, earth-works, stock-piles, archaeological artifacts, film sets, etc. In the computer vision community, this type of photogrammetry is sometimes called Image-Based Modeling.

One step forward from aerial and terrestrial photogrammetry is space photogrammetry (photogrammetry on large scale). It is conducted with cameras that are positioned on the Earth surface or on a satellite. It is used in space exploration, for mapping the space around us, giving accurate information

about cloud patterns, producing more accurate maps of the Earth itself and the objects positioned into the space.

A. *Classification of photos*

Aerial photographs can be classified in to two main categories: vertical photographs and tilted photographs. Vertical photographs are done when the camera axis is strictly vertical. The lens of the camera is pointed down to the ground (bird-eye view). Most common approach for this type of pictures is when the camera is put on a drone or airplane. When pictures are taken with camera axis near (but not fully) vertical or when the camera axis is unintentionally tilted from the vertical (while positioned on a drone or airplane) we speak about tilted photos. If tilt of the camera axis from the plumb line is less than 3 degree the photograph is called vertical. For tilt more than 3 degree, it is called tilted photograph. Tilted photograph may again be classified in two categories: high oblique - in which the apparent horizon appears, and low oblique - in which the apparent horizon does not appear (Fig. 1).

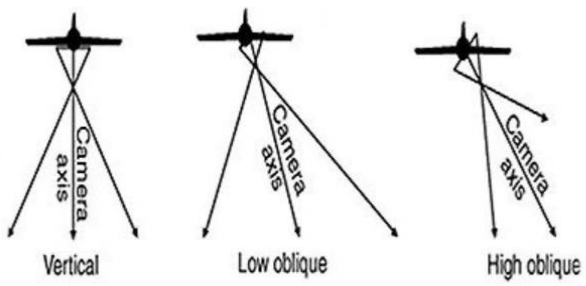

Figure 2. Aerial photography principles

When applying photogrammetry on a small sized object, the possibility to choose among different acquisition strategies is one of the greatest advantages. Several important factors have to be considered in this scenario. The shape and geometry of the object is very important. Thus, it is necessary to calculate two very important parameters: tilt angle (Ψ) and step angle (θ) values. Tilt angle identifies the inclination of the camera respecting the xy object pane. Step angle identifies the rotational angle step when turning around the object and within the same tilt angle determines the number of images taken. It also determines how much the images will overlap between each other (bigger step angle – smaller overlapping).

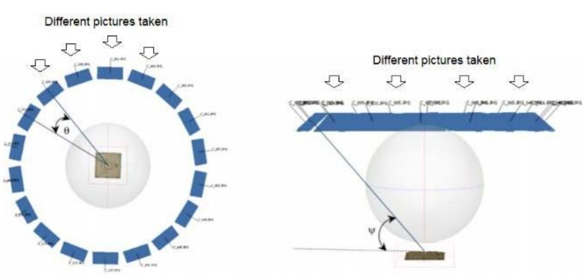

Figure 3. Step and Tilt angle

In general, if photogrammetry software application is available, several steps need to be followed in order to build a 3D model of an object using photogrammetry:

1. Photo acquisition - taking photos from different angles, following the prerequisites for photo shooting;
2. Processing of photographs - loading the images into the photogrammetry software;
3. 3D Model generation - choosing the method, if it is not automatically, and setting the features of the software application before processing the images;
4. Texturing and visualization.

IV. PHOTOGRAMMETRY OF A HUMAN BODY

The focus of this case study is generating 3D model of a human body. The human body is one of the most complicated objects to model because of its complex features, non-rigidity, and the time required to take body measurements. In body scanning, large errors occur due to the non-static nature of the human body and to the occurrence of displacements during the scanning process, such as small movements, breathing, and blinking. For example, just during quiet breathing in healthy subjects, the breathing amplitude is one-third of a deep breath (approximately 3 cm) based on the average 3D distances of the chest and abdominal wall [14]. To avoid large errors, the scanning time has to be as short as possible, in order to freeze the scene.

B. Methodology

The methodology used in this research includes several steps with different degrees of automation: 1) photo-capturing in short-time intervals with minimum light variation (indoor); 2) denoising; 3) edges improvement; 4) determination of matching features/points (characteristic points); 5) generating mesh.

Steps 2-5 are integrated and automated within Meshroom processing nodes scheme. For the fourth step, FeatureExtraction node was included in the processing, working with Scale-Invariant Feature Transform (SIFT) algorithm, while DescriberPreset value was set to High.

Multiple scenarios were conducted in slightly different conditions (outdoor - with indirect lighting, as well as indoor scenarios - with different lighting conditions). These scenarios were also applied on other small objects (like vase, ceramic glass, little statue etc.) in order to draw certain conclusions. Ten scenarios used in this research are shown in Table1.

Table1. Scenarios used in the research

N	Dataset	Node structure	N of p	Processing time	I/O
1	Male_1	General scheme	74	53 minutes	Outdoor
2	Female_1	General scheme	80	51-52 minutes	Indoor
3	Female_1	General scheme +: 1. Camera sensor width added to sensor db 2. Denoising filter (node) included 3. Decimate node included	80	53-54 minutes	Indoor
4	Female_2	Out of the box nodes + additionally: 1. Camera sensor width added to sensor db 2. Feature extraction / Describer preset = High	103	93 minutes	Indoor
5	Female_3	General scheme	47	61 minutes	Indoor
6	Female_3	General scheme _: 1. FeatureExtraction / DescriberPreset = High 2. MeshDenoising node included	47	78 minutes	Indoor
7	Female_4	General scheme	64	65 minutes	Indoor
8	Male_5	General scheme + additionally: 1. FeatureExtraction / DescriberPreset = High 2. MeshDenoising node included	92	91 minutes	Indoor
9	Male_6	General scheme + additionally: 1. FeatureExtraction / DescriberPreset = High 2. MeshDenoising node included	103	110 minutes	Indoor
10	Male_7	General scheme + additionally: 1. FeatureExtraction / DescriberPreset = High	155	98 minutes	Indoor

General scheme includes nodes shown on Fig. 4.

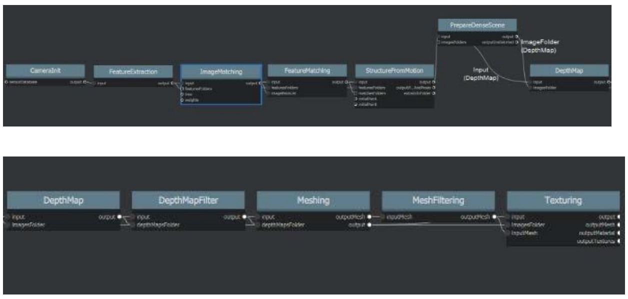

Figure 4. General node scheme

The technica0l details about the hardware and software used in this research are as follows:

- **Camera:** Samsung S9, sensor size: 1/2.55’’
- **Computer:** Intel(R) Core(TM) i7-7700U CPU @ 4.20GHz 4.20 GHz , RAM: 16GB / NVIDIA GeForce GTX 1060 6GB. As for hardware requirements, the Nvidia GPU (with compute capability of at least 2.0) is generally required for the dense high quality mesh generation. 32GB of RAM is recommended for the meshing. Of course, it can run with lower parameters also, but it will increase the processing time.

- **Operating system:** Windows 10 64 x86.
- **Photogrammetry software:** Meshroom 2020.1.1.
- **3D editing software:** Meshlab.

C. Data acquisition

Photographs of the subjects were mainly taken indoor, in an empty room with white walls and indirect solid daylight. Photographs were taken from different angles around the subjects. The positions of the camera were carefully planned for the geometric accuracy of photogrammetric reconstruction of the project and to identify all points on photographs required for determination of the frame of reference and textural data of the object.

Dataset samples, for different subjects and scenarios, are shown on Fig. 5 – Fig. 7

Figure 5. Scenario_3 Part of Dataset Female_1

Figure 6. Scenario_6 Part of Dataset Female_3

Figure 7. Scenario_10 Part of Dataset Male_7

D. Creating the 3D Models and post procesing

The photos, taken by each subject, were imported into Meshroom software, where 3D models were generated. However, these 3D models have a lot of noise, holes, and irregularities that need to be clean up. For this purpose, MeshDenoise and MeshDecimate functions were used. MeshDenoise removes the noise from the meshes, while MeshDecimate reduces the vertex density of a mesh by removing and reconnecting vertices automatically while attempting to preserve the mesh's silhouette and normals as much as possible.

The remaining unwanted artifacts were removed using the MeshLab software.

Finally, the following 3D models were generated (Fig.8– Fig.10):

Figure 8. Female_1 3D model

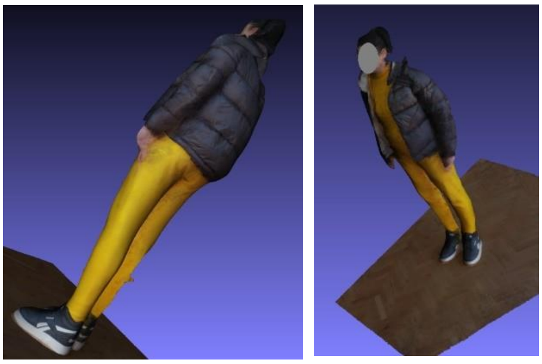

Figure 9. Female_3 3D model

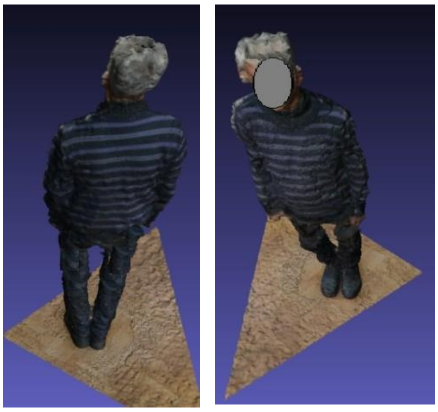

Figure 10. Female_7 3D model

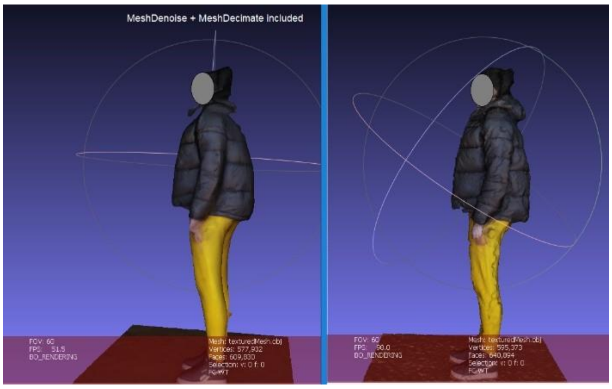

Figure 11. Comparison of using vs. not using MeshDenoise and MeshDecimate

V. Discussion and Conclusions

Digital photogrammetry has become very popular and it is broadly used in variety of fields, like: topographic mapping, architecture, engineering, manufacturing, cultural heritage, medicine, education etc. It requires a series of overlapping photographs, taken of the physical object, from which a 3D reconstruction is obtained using photogrammetry software. Many factors influence the creation of accurate 3D models, such as camera positions, lighting conditions, object reflection, coverage of the scanned physical object, percentage of photos overlapping etc.

In this paper we have presented the creation of the 3D model of the human body. Regarding data acquisition, multiple scenarios were conducted in slightly different conditions in order to draw certain conclusions. Lessons learned during this study are:

- Pictures must be taken from different angles around the object;
- Flashlight should not be used;
- Pictures should be taken in indirect light;
- Consistent ambient light is required, thus the indoor shooting is better that the outdoor;
- It is always better to take more pictures;
- Focal length should be fixed during the photoshoot;
- Overlapping should be within range 60% - 80%;
- The background of the image has a direct impact on the quality of the final model; thus, it should be fixed (non-movable);
- Plain background is recommended;
- Shadows should be avoided;
- Plain and one-colored surfaces should be avoided;
- The human body should fill most of the frame;
- The object should not wear clothes that create reflection;
- Visual color contrast between the background and the object is required.

For 3D reconstruction of the body, the Meshroom software was used. Meshroom contains various functions, as well as wide range of possible nodes that can be included in the reconstruction processes, with a lot of combinations, in order to generate more realistic 3D model. However, for more accurate output, intervention in the source code (Meshroom is a Python application that relies on the AliceVision framework) would be necessary and will be considered for further research.

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