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Photogrammetric 3D digitization of the human head

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Abstract: The paper deals with the use of photogrammetry in the digitization of living objects, specifically it is focused on creating a 3D model of the human head by the walk-around method with the using 1 camera. The RealityCapture software (CapturingReality, Slovakia) was used to create the digital model, the output of which is a head model with a realistic texture with sufficient details. Using the GOM Suite 2019 software (Carl Zeiss, Germany), selected anthropometric measurements of the model were carried out before comparing them with those obtained using traditional measurement of a living subject, which we considered the reference. According to the results, the obtained head model contains sufficient details (face surface, texture). The results show that the values obtained from the 3D model differ from the reference values from 0.1 to 1.8 mm with average value 0.637 mm and standard deviation 0.471 mm. The differences between physical measurement and 3D model are lower than 2 mm. Photogrammetry is applicable for field of anthropometry, medicine, technical orthopedy and other, because the results of measurement do not differ significantly from the reference measurements.

1 Introduction

It is possible to digitalize humans or human body parts for various reasons, for example, for use in medical training and education process (anatomical models) [1]; defects or deformities detection, in the orthopedics (disease diagnosis, monitoring of treatment), creation of orthopedic-prosthetic devices (materials for orthoses, prostheses) [2-7]; anthropometry (human morphometric parameters) [8] and others. The current trend of digitization offers various possibilities how to obtain a 3D digital model. These methods can be structured light scanning, triangulation laser scanning, photogrammetry and more. Photogrammetry is the applied science of using photographs to represent an object in 3D (three-dimensional reconstruction of an object in digital or graphic form), which combines the advantages of photographs, videos, and computerized models while avoiding most of their drawbacks. The basis of photogrammetry is the image, which is, under certain conditions, the exact central projection of the photographed image. In photogrammetry, 2D photographs of an object are taken at varying angles and then overlaid using computer software to generate a 3D reconstruction. The software is used to identify common points between images taken at differing angles and then to overlay the images by matching their common points [1]. This method can be used as an alternative to conventional 3D scanners.

Photogrammetry offers several advantages for creating digital 3D models. First, this process is relatively inexpensive and available to the public, with mobile phone and freeware solutions being sufficient. Second, photogrammetry creates authentic models by generating 3D images from digital photographs. This authenticity surpasses most computer models, which often simplify fine anatomical features. Third, photogrammetry does not damage physical models, nor rely on grayscale or cross-section data to create 3D models. Finally, photogrammetric models are digital and can therefore be distributed indefinitely and do not degrade over time [1].

The following basic rules must be observed when taking photos for photogrammetry:

1. Focusing and zooming - It is recommended to use a fixed focus lens, zoom lenses are less stable than fixed focal length lenses. If a zoom lens is used a constant focal length must be maintained.
2. Lighting - Affects shutter speed and ISO value. In the case of lower light intensity, it is advisable to increase it with artificial lighting. Proper lighting reduces noise and reduces the time it takes to take a picture. It is recommended not to use the flash due to inhomogeneous light distribution, possible reflection on the surface of the subject and the formation of shadows [10].
3. White Balance - White balance ensures accurate interpretation of the object's surface by correcting the chromaticity temperature of the light.

4. Photo Overlap - It is recommended that adjacent photos overlap by 20 to 50% to correct for optical system errors and identify tie points.
5. Shooting distance - depends on the dimensions of the subject and the lens used.
6. Scanning method.

The size, shape, color and surface of the object have a significant effect on the sensing and the result of the reconstruction. The size of the subject affects the shooting distance and the lens used. The amount of detail (fragmentation of the object's surface, chamfers, rounding, holes of different diameters and depths, etc.) affects the number of images needed to digitize the object. The color and surface place the requirements on the lighting of the object and a sufficient contrast with the background must be ensured.

In addition to the light intensity and the background also affects the shooting. It is suitable to provide a one-color and contrasting background (most often green).

Compared to acquisition of inanimate objects, capturing a 3D image of a human head is more critical; in fact, it is necessary to "freeze motion", that is, to avoid the breathing and movement effects. If images are captured at different moments, errors may occur due to large movements (change of head position) or minor movements (muscle activity, change of skin or hair surface) [11, 12]. Also, the head area is the part that is rich in hair (hair, tertiary hair), which can cause additional problems in modeling.

The aim of the paper is to determine the suitability of photogrammetry for human head scanning and to determine the accuracy of scanning using the methodology and equipment for its subsequent use to obtain anthropometric data for other applications, e.g., technical orthopedics, education, medicine, etc. This article demonstrates the entire process of creating a 3D model through photogrammetry using only 1 camera by the walk-around method, highlighting the economic relevance of this method of creating 3D models.

2 Methodology of experiment

The experiment was carried out on a living object, which was a young Caucasian woman who was acquainted with the conditions of the experiment and signed an informed consent. The experiment procedures involved non risk to participant therefore research ethics committee approval was not necessary. The object of measurement was the human head, the facial area and the brain part of the head. This area of the human body has been chosen for its wide range of sizes, textures, shapes and contours. The position of the subject's head during capturing is oriented in the Frankfurt horizontal. The subject's face without any make-up during the experiment and relaxed without significant facial expressions, the view is forward. The hair was adjusted so that it did not cover the face and so that the hairline and the ear were visible. Before scanning, it is recommended to remove from the scanned area all objects (jewelry, glasses, etc.) that could affect the scanning, data processing and evaluation.

A Canon EOS 70D digital SLR camera (Japan) with a Canon EF 50mm f1 / 4 USM lens (Japan) with a fixed focus was used to capture the subject. RealityCapture software (CapturingReality, Slovakia) was used to process the images and generate the 3D model. The measurement of the model created by photogrammetry was performed in GOM Inspect 2019 software (Carl Zeiss, Germany) certified by PTB and NIST. The physical object was measured with a Somet caliper (Czech Republic).

Capturing was performed outdoors with natural lighting (bright sunny day) and without artificial additional lighting. When taking craniofacial parameters, the subject sat on a 45 cm high chair and the position of his head was oriented in the Frankfurt horizontal. Due to the shape of the object and its texture, control points were placed on the irises of the eyes (Figure 1). The face parts were photographed after the moment of person blinked. Throughout the shooting were used ISO 100, f8 aperture, and a shutter speed of 1/80.

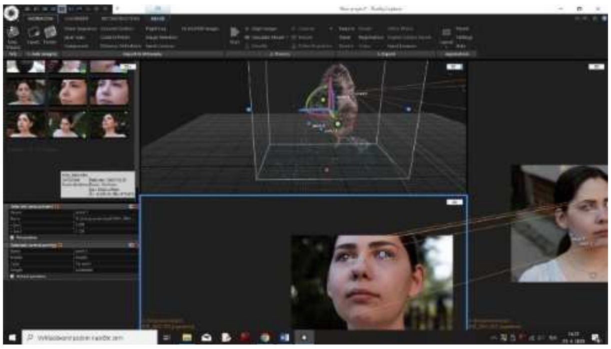

Figure 1 Checkpoints located on the irises of eyes

The person was photographed using the object walk-around method (Figure 2). To ensure stability, the camera was placed on a tripod. The images were created in three levels. In each level, 4 images with a spacing of approximately 90° were taken around the circumference of the imaginary circle. In the first level, the axis of the camera was horizontal to the ground and the camera was at head level at a height of 120 cm. In the second level, the camera was 145 cm high and the camera axis was rotated 30° downwards. In the third level, the camera was 95 cm from the ground and the camera axis was moved 30° upwards. At the same time, the approximate distance of the camera to approximately 100 cm from the subject was maintained. In this way, 12 photographs of the head were taken. In order to capture the details, 6 more photos were taken, which focused on the ear area and more complex removable areas of the neck and chin.

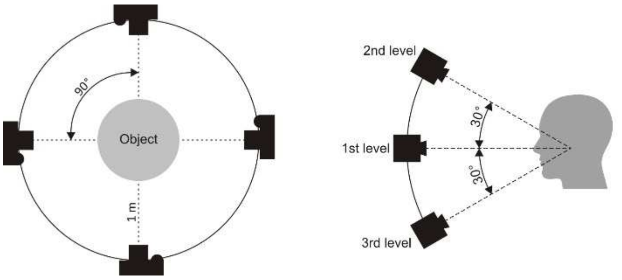

Figure 2 Head scanning scheme, top view and side view

2.1 *Processing of acquired images*

All acquired images were processed and visually evaluated in RealityCapture software, the resulting models were exported to *.obj format for measuring dimensions in GOM Suite.

The resulting model was created from 6,211,995 triangles and 3,106,561 vertices. Figure 3 on the left shows the non-textured STL head model in GOM Suite and the textured head model in RealityCapture. Different orientations of the used software are visible, in GOM Suite obtained surface is visible after merging individual images, in RealityCapture the surface structure is suppressed by the texture of the object.

Figure 3 Display of STL model in GOM (left) and model in RealityCapture software (right)

When creating a textured model in RealityCapture software, there are visible hair reconstruction problems (Figure 4 left), which the software cannot process as very thin objects. Other problematic parts of the model were the chin and neck area, where holes in the model were created due to insufficient number of overlapping points (Figure 4 right). Other problems in the model are in the neck area, which were caused by incorrect alignment of the photos.

Figure 4 Surface defects in hair, chin and neck

In the GOM Suite software, minor defects can be seen all over the surface of the model without texture, resulting from the insufficient number of images and from the errors caused by composing photos or by calculating the geometry (filling the holes) when exporting from RealityCapture software. These errors are reflected in the uneven surface, mainly in the cheeks, chin and neck.

2.2 *Dimensional analysis*

On the basis of the obtained scan was created coordinate system, while the basic conditions for maintaining the position of the head were observed.

Measures of selected anthropometric head parameters (Figure 5) (ear length and width, eye length, internal corners distance, head width, lower jaw width, head height, nose width and height) as reference measures were obtained manually using caliper to verify the accuracy of the scan. Manual measurements were performed three times after that arithmetic average were calculated. The model dimensions were taken using the GOM Suite 2019 software. Surface points were placed on the locations of individual anthropometric points using the "Surface Point" function. The direct distance between the individual points was measured using the "2-Point Distance" function (eg nose width, distance of the inner corners of the eyes), the other distances were measured in the direction of the individual axes and recorded in the table. Obtained values from physical measurements were compared with the values taken from the photogrammetric model.

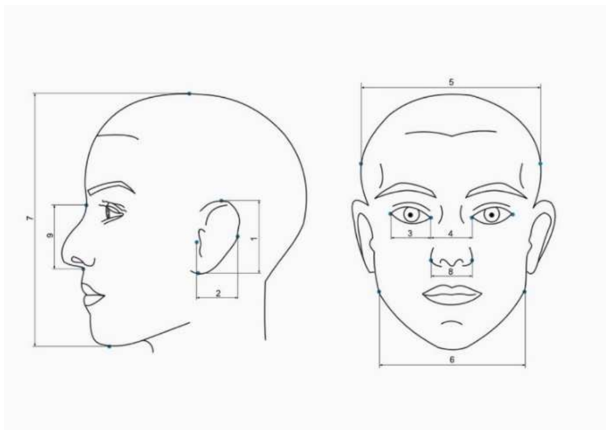

Figure 5 Selected anthropometric measures of the head

3 Results and discussion

Table 1 shows the differences between the physical object (reference model) and the 3D model. The differences are calculated as subtraction of dimensions measured on 3D model and dimensions measured manually.

Table 1 Matrix of length

	Measured dimension	Difference (mm)	
		Right	Left
1	Ear length	0.102	0.516
2	Ear width	0.278	0.456
3	Eye length	0.232	–0.259
4	Intercanthal distance	0.468	
5	Head width	0.835	
6	Mandibular width	–0.951	
7	Head height	1.813	
8	Nose width	–0.820	
9	Nose height	0.924	

The results show that the values obtained from the 3D model differ from the reference values from 0.1 to 1.8 mm. The difference between the values takes on a positive and a negative sign, so it is not possible to claim that the model is neither reduced nor enlarged. Minor deviations came out on the right side of face, the left side is affected by the reconstruction of the surface, where the surrounding hair caused the surface to deform. Dimensions at head width and height could be affected by hair, nose width and height, lower jaw width could be affected by soft tissues or inaccurate identification of anthropometric points.

A 3D model of the head was produced using the walk-around method, which presents the disadvantage of increasing labor-intensiveness, since photo equipment must be moved around while maintaining the distance between it and the object. In this way, the object remains stationary, considerably reducing the risk of movement, but it increases the capturing time, that can lead to possibility of increasing the movement risk. To achieve higher quality and resolution of the model and textures, the object could be rotated. By rotating the subject (for example, sitting on a swivel chair), the risk of the subject moving is increased, but the capturing time decreases. However, this is a more expensive solution, as it requires a monochrome background, tripod, turntable and additional lighting.

In practice, the traditional method of direct measurement of anthropometric parameters is still the most used. Measurements done by direct method are simple, noninvasive, and do not require expensive equipment [10]. Certainly, a benefit of this technique is the possibility of palpating individual anthropometric points, but soft tissue compression can cause deviations as well. Inconvenience, time consumption, and experience are disadvantages. On the other hand, measuring with software has the advantage of being non-contact, it nevertheless requires experience, and its major disadvantage is the more challenging measurement of anthropometric points. There is a partial solution in the form of manual palpation and labeling on the skin, which is then followed by scanning.

To improve the connection of the images, it is advantageous to use morphological features on the face (checkpoints). A checkpoint is chosen according to the morphology of the face and the unique identification points. Studies often use the pupil as reference points. In the case of a darker iris, their identification is complicated. For this reason, irises have been chosen as reference points for our purposes. The disadvantage of choosing pupils or irises is their response to environmental stimuli (movement). The solution would be to choose these points on the facial skin.

The control of mimic movements and breathing is essential when scanning the head, as they can significantly affect the composition of individual images. The biggest problem is capturing and then creating a model from an area with hair, because defects on the model and textures occur in these places. The solution could be to fix the hair with a hat or hair net.

Based on 3D scanning experiences of children's faces photogrammetry is more suitable method for scanning children since the flash is not used because of sufficient lighting and child does not respond to flicker as it is at most 3D scanners. Additionally, this scan does not take place in a dark closed environment like some 3D full-body scanners. The above information indicates the suitability of this method for people with various diseases, where the use of 3D scanners is limiting.

4 Conclusion

The living object model provided an effective interpretation of the surface and texture of the subject's face.

The data were processed in the RealityCapture software, where the images were combined into one object. The 3D model with texture was created and the data was exported for measurement in the GOM Suite. Empty areas were showed during processing, due to low number of images (12 photos). For this reason. another 6 images were taken from the problem areas. filling in the empty areas and improving the quality of the details. In order to improve the composition of the images, the irises of the eyes have been designated as control points, but it is necessary to ensure their stability by focusing on the selected point.

An anthropometric map was used to measure dimensions in the GOM Suite program. According to the results, the largest deviation is 1.8 mm compared to the manual measurement.

The differences between manual measurement and the measurement made on the 3D model may be related to soft tissue compression during manual measurement, as well as the ambiguous determination of anthropometric points on the model. There is less than 2 mm difference between the measurements, which is sufficient for most possible uses.

Based on the experience of creating a model using photogrammetry and the results of measurements, photogrammetry appears to be an effective tool for digitizing living objects and performing measurements on the model, provided that the conditions and optimization of imaging are observed. As a bonus, the person can have their eyes open when being photographed, thus capturing the color of their iris. The output model is sufficiently detailed and the obtained surface texture allows the model to be utilized for numerous purposes (medicine, criminology, anthropology, technical orthopedics and others).

The photogrammetric method can be used to scan various parts of the body. However, when it comes to shooting larger areas or the entire figure, the required equipment becomes quite complex.

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