Innovative Methodology for the 3D Reconstruction of Body Geometries using Open-source Software

Javier Tuesta-Guzmán[1][a], William Solórzano-Requejo[1,2][b], Gustavo Grosso-Salazar[1][c], Carlos Ojeda[1][d] and Andrés Díaz Lantada[2][e]

[1]*Department of Mechanical and Electrical Engineering, Universidad de Piura, Piura, Peru*

[2]*ETSI Industriales, Universidad Politécnica de Madrid, Madrid, Spain*

Keywords: 3D Scan, Reverse Engineering, Meshroom, Open-source Software, Photogrammetry.

Abstract: Bioengineering teaching has limitations in developing countries due to the inaccessibility of expensive technology like scanners and commercial software, which holds back progress in the biomedical area because of a lack of resources. In this work, a new methodology is presented with the aim of obtaining a 3D model of body part by open-source software: Meshroom®, Meshmixer®, Ultimaker Cura®; and a cell phone camera. The procedure is based on three methods which were tested: images taken for a short time, burst mode and video-to-frames. Through the process of reverse engineering photogrammetry, an arm and a foot were obtained from images and for comparing the model with the real body part, 3D printing was used. The outstanding method is video-to-frames thanks to the high quality of the generated models and the shortest reconstruction time it presents. The technique developed can promote the education of engineers in the biomedical area, also providing an advance for developers with low economic resources, allowing them to have a new possibility of research.

1 INTRODUCTION

Medical Reverse Engineering (MRE) is highly used to treat fracture problems, obtaining hurt body parts in 3D format as STL (Stereo Lithography) or OBJ (Object) file (Bhatti et al., 2018). MRE is also fundamental in any medical device personalization strategy (Ahluwalia et al., 2022). Computer-aided design software tend to be expensive, which may limit equal accessibility to personalized healthcare technologies. Fortunately, different open-source hardware and software solutions are being developed, which synergize with the "maker's movement" and promote equity in all fields of product development. These technologies allow getting the affected zone, necessary for the design and manufacture of custom medical devices. The usage of open-source software is a proposal for the education framework of engineering students due to remote education as a consequence of the COVID 19 pandemic, which forced to change the techniques used to teach (Pokhrel & Chhetri, 2021). Any researchers already focused their attention on the development of technologies that could assist students in anatomy remote education (Iwanaga et al., 2021) as Qlone® for 3D scanning.

Scanning in the biomedical area is a method to obtain an external body part like legs, arms, hands, face; necessary to design an external fixation for closed fracture (Alqahtani et al., 2021) or help relieve articular injuries (Munoz-Guijosa et al., 2020) but for this, designers need a special camera to scan it, and this is a limitation for the developed of personalized medical technology due to the high cost (Le et al., 2010). Fortunately, Meshroom® (Griwodz et al., 2021) and COLMAP® (Schonberger & Frahm, 2016)

[a] https://orcid.org/0000-0002-6923-7263
[b] https://orcid.org/0000-0002-2989-9166
[c] https://orcid.org/0000-0002-7570-5609
[d] https://orcid.org/0000-0001-6163-5382
[e] https://orcid.org/0000-0002-0358-9186

Tuesta-Guzmán, J., Solórzano-Requejo, W., Grosso-Salazar, G., Ojeda, C. and Díaz Lantada, A.
Innovative Methodology for the 3D Reconstruction of Body Geometries using Open-source Software.
DOI: 10.5220/0010870200003123
In *Proceedings of the 15th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2022) - Volume 1: BIODEVICES*, pages 162-169
ISBN: 978-989-758-552-4; ISSN: 2184-4305

exist, whose principal function is to do the object reconstruction from images. This technique is called photogrammetry and is less common for 3D reconstruction but a MRE useful tool to get the base for the biodevices design (Struck et al., 2019). The photogrammetry for 3D surface scanning allows good visualization of the objects and people without a high knowledge about photography can do a reconstruction (Grabherr et al., 2016).

This project explores innovative approaches to promote MRE through open-source software. A procedure relying on the combination of varied software, including: VLC Media Player 3.0.16 Vetinari®, Meshroom 2021.1.0®, Meshmixer 3.5.474®, and UltimakerCura 4.8.0®, is presented. To the author's knowledge, this combination is innovative and reported for the first time. It is illustrated through a set of case studies.

The goal is to promote collaborative work, inspired in projects as UBORA (De Maria et al., 2020), wanting to reinforce the techniques used for remote study and have an important impact in developing countries for people with few resources, focused on the formation of students, engineers and doctors who want to research in the biomedical field.

This work is organized as follows: first, materials and methods used to obtain the arm and foot models will be explained; secondly, the results and discussion of the quality of models, and finally the conclusions of this project.

2 MATERIALS AND METHODS

Figure 1 shows the roadmap to obtain the 3D model, as a base for designing personalized medical devices, from images of the body part employing open-source software. This research assesses the influence of the method to get the images, in the mesh given by the programs.

Figure 1: Roadmap.

External devices need a geometrical body obtained through photogrammetry, which needs images around the body part, then they are imported to Meshroom® which reconstructs the scene and generates an OBJ file, different tests will be done to define which is the best method together with the correct number of images. Subsequently, Meshmixer® was used to optimize, crop, and repair the 3D model that finally is prepared and printed through Ultimaker Cura®.

2.1 Reverse Engineering

2.1.1 Photogrammetry

Photogrammetry can be understood as a methodology to determine distance relations between different bodies in space from images. One image provides two-dimensional coordinates of each point of the photo, and if it is complemented by a second image from a different position, so a three-dimensional coordinate could be calculated for each point (Linder, 2009). It is a powerful tool for reverse engineering to obtain models of inanimate objects, also could be used to reconstruct body parts with the correct steps.

Meshroom® is an open-source software for 3D reconstructions based on the AliceVision framework. The software works in a base of photogrammetry, and to make a reconstruction is necessary to configure nodes that Meshroom® offers. The environment nodes by default receive the inputs (images), separating them into groups and highlighting the most notable features, then generate a points cloud of the scene in 3D, filter the inconsistencies and finally generate a mesh and project the textures in the model (Dong et al., 2021). Meshroom® will be used for the experiments of bodies part reconstruction adding a new node to establish the actual scale.

Their minimum requirements are RAM: 8GB, GPU: NVIDIA CUDA, CPU: Intel or AMD and works in any operating system.

To take the pictures, it is necessary to use a camera or multiple cameras (Peyer et al., 2015) which allows obtaining a detailed view of the body reconstructed. The cell phone used was a Samsung A50 which has a triple camera. The primary camera has a resolution of 24.9MP with an aperture of f/1.7. The second (ultra-wide) and third (depth sensor) ones have an aperture of f/2.0 with 8MP and 5MP respectively.

2.1.2 Meshroom and Animated Objects

Through Meshroom®, different models can be obtained of all types of inanimate things as vehicles (Matys et al., 2021), ship structures (Shah et al., 2021), and more if given it images of the object from 360° degrees as shown in Figure 2. Meshroom® uses these images to establish measure relations between the background and the main piece. For this reason, while more images are given, the detail of the final model should be better, but not all is quantity because if blurred images are used, the final model will be affected. The difficulty is obtaining a 3D high-quality model of a self-moving object.

Figure 2: Images surrounds the body.

For example, arm, face, foot, hand, and functional body parts are considered as self-moving objects, if someone tries to take images surrounding them, it is a fact that exists minimal involuntary movements because of the tired of maintaining these parts in a special position, necessary to do the images for 2 minutes or more. If these images are given to Meshroom®, the final model will have all the background: walls, floor, and other objects minus the body part. An idea could be to eliminate the background and only have the body part in the pictures; the result will be an amorphous model because distance relations are eliminated, which are essential for Meshroom® works. Therefore, it is necessary that the interaction with the participants be the minimum to avoid these unwanted movements (Peyer et al., 2015).

Figure 3 shows the Meshroom® interface; the images generate a point cloud that is exported in OBJ format. The default model scale is not the real magnitude. For this reason, it is necessary to use the CCTAG3 templates (*CCTag /MarkersToPrint at Develop · Alicevision/CCTag*, 2021) that were provided by AliceVision, since Meshroom® needs to set up the real size.

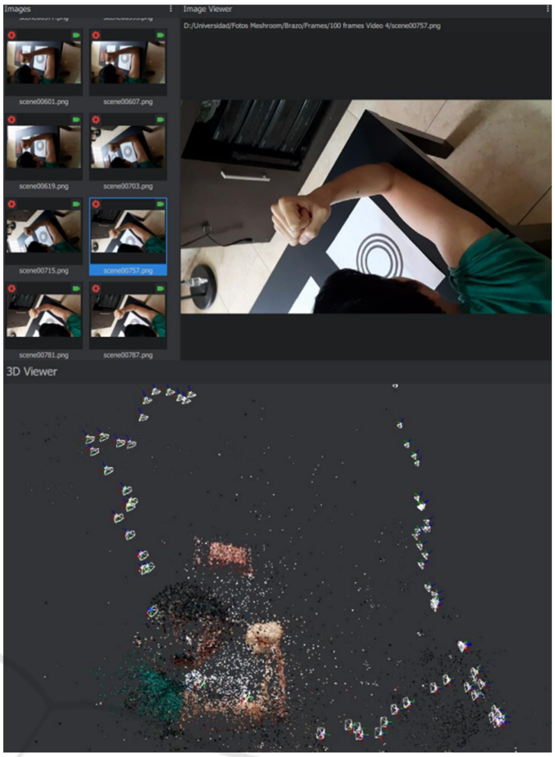

Figure 3: Meshroom® interface.

2.2 Experiments

Six experiments have been performed with different methods and several images to generate the best model as possible. The first method consisted in taking pictures surrounding the body; the reconstructions were made with 100 images taken for 4 minutes approximately, then, this experiment was repeated with half of the images (50) that were taken from the first 2 minutes. As some involuntary movements may exist, another approach to take the pictures should be sought, for this purpose, in the second method the use of the burst mode of the phone was performed. Finally, the third method (video-to-frames), proposed by the authors, is based on recording a 40-second video, since Meshroom® does not use videos for reconstruction it must be converted into frames. To maintain the conditions of each reconstruction, 100 and 50 images were used for each method.

To convert the video on frames, VLC Media Player® was used (Figure 4). This program generates a high number of images according to the recording ratio, for example, 100 frames in 30-second video. Thus, the number of images for the recognition is maximized and the involuntary movements are minimized.

Figure 4: Conversion of video-to-frames through VLC Media Player®.

3 RESULTS AND DISCUSSION

3.1 Arm

To take the images, the person was sitting down with their arm supported on a table where the CCTAG3 templates stay collocated with 30cm of distance and should be visible.

The models were exported from Meshroom® and imported in Meshmixer® to visualize it, for understanding the behavior of the models, a similar sight of the reconstruction will be compared.

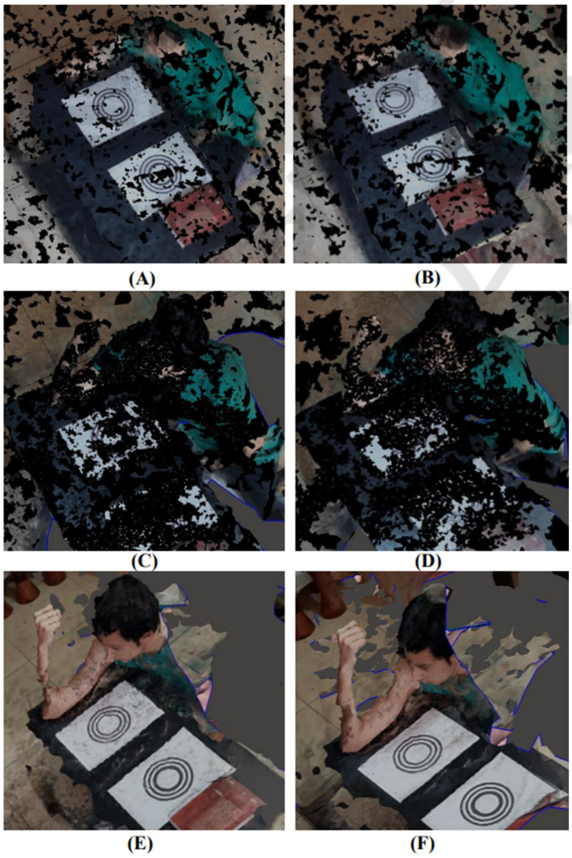

Figure 5: Arm reconstruction with (A) 100 and (B) 50 photos, (C) 100 and (D) 50 burst photos, (E) 100 and (F) 50 frames.

Figure 5 shows the different models obtained through the experiments. In Figure 5A is visible that the arm was not reconstructed but at least obtain a part of the neck, shoulder, and a few of the inanimate objects. In Figure 5B, despite using half of the photos on purpose to reduce the time to take images (4 to 2 minutes), the result was not good, this model does not show the arm too. In Figure 5C appears a form similar to the arm with poorly defined parts (errors in reconstruction), but the shape is noticeable. In Figure 5D, the use of half of the images did a few differences defining better some parts of the body but not enough. Figure 5E presents the arm reconstructed with a void in the last part of the forearm and Figure 5F present the arm with nom-uniform areas. Anyway, the difference with the first four models is noticeable.

In the models from method of photos is notorious that the presence of the involuntary movements is the principal problem, for this reason, images should not be taken for a long time or else not be obtained the desired model, despite this, it is a necessity a large number of images for the reconstruction. Burst mode of phone method presents better models than only taking photos due to reduction of the capture time, but not enough to minimize the effect of the involuntary movements. Also, any images from burst mode could have low quality when trying surround the main piece and as a consequence the final models are poorly detailed and useless. For video-to-frames method was obtained a good reconstruction, first, the model is recognizable, there is no doubt that the reconstruction is an arm; second, the arm was reconstructed completely and with high quality compared with the previous methods, third, the surroundings objects were reconstructed correctly too. It is visible that these models present non-uniform areas due to in frames exist a problem of brightness, the recording place has angles where the arm looks darker, and deformations occur right at these angles. In other words, when existing different illumination, the model will be affected directly, so the lightning must be constant to preserve the quality of reconstruction.

It visualized that the use of half images has fewer errors in the result obtained in each technique, for example, 50 bursts model is better than 100 bursts model; this may be due to if use an excessive number of images, results in oversizing whose inconsistencies are not suppressed in totally in filter nodes.

Table 1 summarizes the results for each experiment through Meshroom®. It is easily noticed that the best model was obtained with the method proposed "video-to-frames", also the number of triangles in Table 1 has a relation with the number of images used, more photos make more reconstruction of the main piece and its environment.

Table 1: Vertices, triangles, and reconstruction time for each arm model.

Model	Vertices	Triangles	Time
100 photos	308672	612916	60m 7s
100 bursts	428034	849489	86m 50s
100 frames	138060	274218	36m 56s
50 photos	232459	461799	28m 8s
50 bursts	366186	727762	45m 57s
50 frames	37695	74290	10m 11s

Models with 50 pictures have fewer triangles than the model with their respective method with 100. It is not possible to compare the number of triangles of the six models only having the arm, cropping the OBJ file, because in some the arm is not completely reconstructed.

The fastest reconstruction for 50 and 100 images was the video-to-frames models, so this method performs a better reconstruction in less time.

3.2 Foot

The experiments were repeated with the foot to analyze the performance with another body region, for comparative purposes. In this case, to took images, the person stood up and placed their leg near to CCTAG3 templates which establishes the real scale.

Figure 6 shows the results of the reconstruction of each technique and the respective number of images. Figure 6A presents an amorphous and incomplete mesh, same problem in Figure 6B but adding that due to the fewer images, the reconstruction presents a gap between the foot and calf. For Figure 6C, the calf zone is visible with protuberances, and it is the same for the model of Figure 6D but with a gap in the leg. In Figure 6E, the reconstruction is similar to the 100 burst model but more complete and better defined. Finally, Figure 6F presents a good quality model but with more protuberances in the calf zone. Same as the models of the arm, the best model was generated by the video-to-frames method.

The results are shown in Table 2. The model with the fewest triangles and the best reconstruction time was from video-to-frames. The number of triangles has a direct impact on the reconstruction time. As this is minimal, less computational resources are required, which allows the use of this technique and technology for educational purposes.

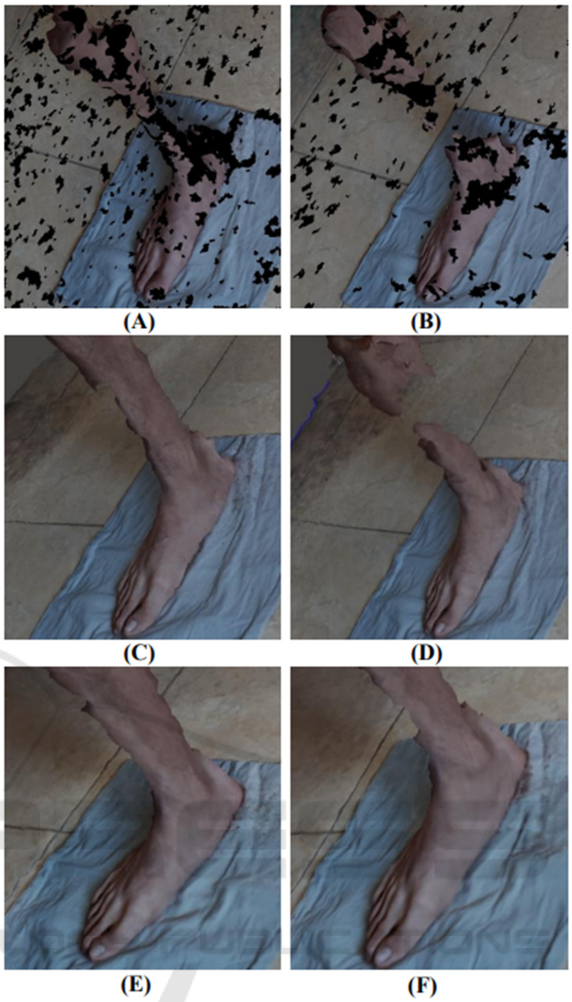

Figure 6: Foot reconstruction with (A) 100 and (B) 50 photos, (C) 100 and (D) 50 burst photos, (E) 100 and (F) 50 frames.

Table 2: Vertices, triangles, and reconstruction time for each foot model.

Model	Vertices	Triangles	Time
100 photos	477171	949084	94m 16s
100 bursts	461408	918505	76m 6s
100 frames	190621	379804	38m 36s
50 photos	406215	808415	51m 56s
50 bursts	417762	816884	58m 58s
50 frames	138283	275557	15m 43s

Best models will be selected for arm and foot on purpose to be optimized with Meshmixer® and printed with Ultimaker Cura®. Both are the models obtained with 50 frames due to being better reconstruction, with minor time and weight file.

Meshroom® delivers unsmoothed models with some surface defects, for this is necessary to use CAD software to eliminate this problem. Meshmixer® is an open-source software useful to optimize OBJ/STL files and will be used to visualize and fix our models.

To optimize arm and foot, both were cropped and just stayed with body part of interest (Figure 7). Auto-repair Meshmixer® tools were used to solve mesh problems if they exist. After, the models are exported as STL files.

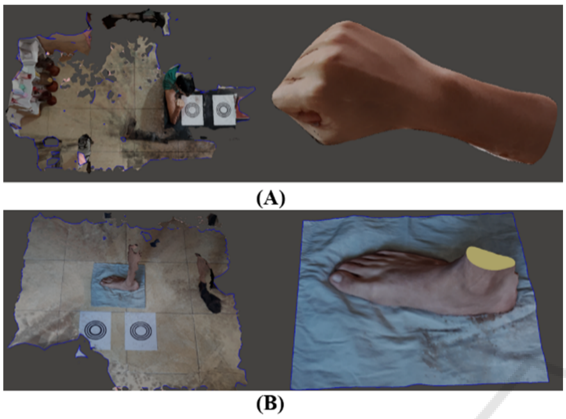

Figure 7: Cropping and optimization with Meshmixer® for the (A) arm and (B) foot models.

To obtain the physical model, the 3D printing technique used was Fused Material Deposition (FDM). Between the steps of this process was included the lamination in several layers of the STL models using the Ultimaker Cura® slicer. The G Code was exported from Ultimaker® to manufacture the 3D models employing Ender 3 Pro® printer.

The parameters used for the impression were the following: PLA Flibox Silver, infill 10% and infill pattern line, wall line count 3, bottom and top layers 4, speed 50 mm/s, retraction activate, fan speed 100%. Supports were used for the foot model.

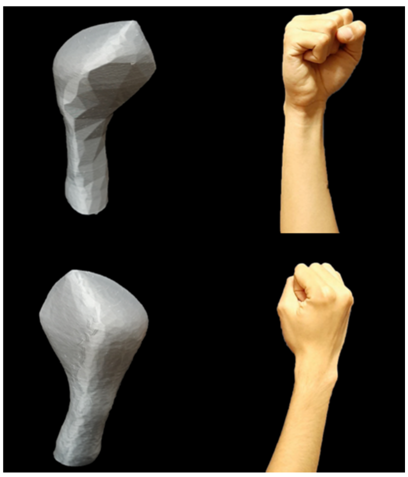

Figure 8: Comparison between the printed and real arm.

Figure 9: Comparison between the printed and real foot.

Figures 8 and 9 show two views of the 3D printed model compared with the scanned body for arm and foot respectively. Printed models are similar to real animated objects in shape and scale, the printed arm has the geometry of the forearm, and the fingers are unified due to Meshroom recognizing them as one body. For printed foot, the geometry matches with the real foot. Both models have good quality and if this methodology continues to be refined, it can be used to obtain the base bodies for the design of 3D printing orthoses (Górski et al., 2020), orthopaedic insoles (Cendrero et al., 2021; Shalamberidze et al., 2021) and facial protection masks (Morita et al., 2007).

Other authors (Peyer et al., 2015) constructed a system with 18 cameras to perform 3D reconstruction from taking simultaneous photos, minimizing the interaction time with the body. Their surface mesh presents high-resolution, but it is not easy for students from developing countries to obtain these systems.

The images used for these experiments had a quality of 25 MP and the results were good, if the number of pixels was increased, the results would have more detail and a better surface finish.

4 CONCLUSIONS

Printed models of OBJ/STL files generated with the proposed methodology have high quality for educational purposes and transmit the essence of the main piece coinciding with reality. This opens a world of possibilities for the reconstruction of animated objects from images as the design of biodevices or remote education through laboratories in study centres for the reconstruction of 3D models without an expensive camera.

The video-to-frames technique proved more reliable than only photos and burst mode. Their models show the essence of the shapes in both prints, also minimize the time for the reconstruction but still have a few protuberances due to the change of illumination concerning the angle of the shot and the limited number of pixels of the images. The method still could be better if images are taken in other prepared places where the lighting remains constant facilitating the reconstruction process and if a professional camera will be employed to record the video. Between the data used, exists blurry images which could be eliminated manually, but exist algorithms that can do this automatically like Fast Fourier Transform or Variance of Laplacian which can help to improve the proposed technique in the future.

Among main limitations of the study, it is important to mention that a simple camera has been used, which may affect precision, although at the same time its use puts forward the possibility of using very low-cost hardware and software for promoting MRE. Regarding future studies, our proposal is to progress in processes for automated generation of 3D models, to enhance precision and to employ these and similar reconstructions, as input for the design of personalized medical devices, such as splints, insoles, braces and multiple orthoses.

ACKNOWLEDGEMENTS

The authors would like to thank the support of the Biomechanics Group of the Universidad de Piura and to the Product Development Laboratory of the Universidad Politécnica de Madrid. Also, we acknowledge the support of reviewers and their relevant recommendations, which help to do a more consistent and detailed paper.

REFERENCES

Ahluwalia, A., De Maria, C., & Díaz Lantada, A. (Eds.). (2022). Engineering Open-Source Medical Devices (1st ed.). Springer International Publishing. https://link.springer.com/book/9783030793623

Alqahtani, M. S., Al-Tamimi, A. A., Hassan, M. H., Liu, F., & Bartolo, P. (2021). Optimization of a Patient-Specific External Fixation Device for Lower Limb Injuries. Polymers, 13(16), 2661. https://doi.org/10.3390/polym13162661

Bhatti, A., Syed, N. A., & John, P. (2018). Chapter 5—Reverse Engineering and Its Applications. In D. Barh & V. Azevedo (Eds.), Omics Technologies and Bio-Engineering (pp. 95–110). Academic Press. https://doi.org/10.1016/B978-0-12-804659-3.00005-1

CCTag/markersToPrint at develop · alicevision/CCTag. (2021). GitHub. https://github.com/alicevision/CCTag

Cendrero, A. M., Fortunato, G. M., Munoz-Guijosa, J. M., De Maria, C., & Díaz Lantada, A. (2021). Benefits of Non-Planar Printing Strategies Towards Eco-Efficient 3D Printing. Sustainability, 13(4), 1599. https://doi.org/10.3390/su13041599

De Maria, C., Di Pietro, L., Lantada, A. D., Ravizza, A., Mridha, M., Torop, J., Madete, J., Makobore, P., & Ahluwalia, A. (2020). The UBORA E-Infrastructure for Open Source Innovation in Medical Technology. In J. Henriques, N. Neves, & P. de Carvalho (Eds.), XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019 (pp. 878–882). Springer International Publishing. https://doi.org/10.1007/978-3-030-31635-8_106

Dong, C., Liang, W., & Xu, P. (2021). 3D refined reconstruction for brushes based on multiple images. 2021 3rd International Conference on Advances in Computer Technology, Information Science and Communication (CTISC), 309–314. https://doi.org/10.1109/CTISC52352.2021.00063

Górski, F., Wichniarek, R., Kuczko, W., Żukowska, M., Lulkiewicz, M., & Zawadzki, P. (2020). Experimental Studies on 3D Printing of Automatically Designed Customized Wrist-Hand Orthoses. Materials, 13(18), 4091. https://doi.org/10.3390/ma13184091

Grabherr, S., Baumann, P., Minoiu, C., Fahrni, S., & Mangin, P. (2016). Post-mortem imaging in forensic investigations: Current utility, limitations, and ongoing developments. Research and Reports in Forensic Medical Science, 6, 25–37. https://doi.org/10.2147/RRFMS.S93974

Griwodz, C., Gasparini, S., Calvet, L., Gurdjos, P., Castan, F., Maujean, B., De Lillo, G., & Lanthony, Y. (2021). AliceVision Meshroom: An open-source 3D reconstruction pipeline. Proceedings of the 12th ACM Multimedia Systems Conference, 241–247. https://doi.org/10.1145/3458305.3478443

Iwanaga, J., Terada, S., Kim, H.-J., Tabira, Y., Arakawa, T., Watanabe, K., Dumont, A. S., & Tubbs, R. S. (2021). Easy three-dimensional scanning technology for anatomy education using a free cellphone app. Clinical Anatomy, 34(6), 910–918. https://doi.org/10.1002/ca.23753

Le, C., Jos, V. S., Le, T. H., Lam, K., Soe, S., Zlatov, N., Le, T. P., & Pham, D. T. (2010). Medical reverse engineering applications and methods [Conference Proceedings]. University of Greenwich; INCDMTM. https://gala.gre.ac.uk/id/eprint/11735/

Linder, W. (2009). Introduction. In W. Linder (Ed.), Digital Photogrammetry: A Practical Course (pp. 1–17). Springer. https://doi.org/10.1007/978-3-540-92725-9_1

Matys, M., Krajcovic, M., & Gabajova, G. (2021). Creating 3D models of transportation vehicles using photogrammetry. Transportation Research Procedia, 55, 584–591. https://doi.org/10.1016/j.trpro.2021.07.025

Morita, R., Shimada, K., & Kawakami, S. (2007). Facial Protection Masks After Fracture Treatment of the Nasal Bone to Prevent Re-injury in Contact Sports. Journal of Craniofacial Surgery, 18(1), 143–145. https://doi.org/10.1097/01.scs.0000246729.23483.87

Munoz-Guijosa, J. M., Zapata Martínez, R., Martínez Cendrero, A., & Díaz Lantada, A. (2020). Rapid Prototyping of Personalized Articular Orthoses by Lamination of Composite Fibers upon 3D-Printed Molds. Materials, 13(4), 939. https://doi.org/10.3390/ma13040939

Peyer, K. E., Morris, M., & Sellers, W. I. (2015). Subject-specific body segment parameter estimation using 3D photogrammetry with multiple cameras. PeerJ, 3, e831. https://doi.org/10.7717/peerj.831

Pokhrel, S., & Chhetri, R. (2021). A Literature Review on Impact of COVID-19 Pandemic on Teaching and Learning. Higher Education for the Future, 8(1), 133–141. https://doi.org/10.1177/2347631120983481

Schonberger, J. L., & Frahm, J.-M. (2016). Structure-from-Motion Revisited. 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 4104–4113. https://doi.org/10.1109/CVPR.2016.445

Shah, F. M., Gaggero, T., Gaiotti, M., & Rizzo, C. M. (2021). Condition assessment of ship structure using robot assisted 3D-reconstruction. Ship Technology Research, 0(0), 1–18. https://doi.org/10.1080/09377255.2021.1872219

Shalamberidze, M., Sokhadze, Z., & Tatvidze, M. (2021). The Design of Individual Orthopedic Insoles for the Patients with Diabetic Foot Using Integral Curves to Describe the Plantar Over-Pressure Areas. Computational and Mathematical Methods in Medicine, 2021, e9061241. https://doi.org/10.1155/2021/9061241

Struck, R., Cordoni, S., Aliotta, S., Pérez-Pachón, L., & Gröning, F. (2019). Application of Photogrammetry in Biomedical Science. In P. M. Rea (Ed.), Biomedical Visualisation: Volume 1 (pp. 121–130). Springer International Publishing. https://doi.org/10.1007/978-3-030-06070-1_10