Postprint of: Bobkowska K., Kaczyńska A., Kosiński A., Przyborski M., Digital Photogrammetry in the Analysis of the Ventricles' Shape and Size, *2017 Baltic Geodetic Congress (BGC Geomatics)*, Gdansk (2017), pp. 169-173, DOI: 10.1109/BGC.Geomatics.2017.60

Digital Photogrammetry in the Analysis of the Ventricles' Shape and Size

Katarzyna Bobkowska, Marek Przyborski
Faculty of Civil and Environmental Engineering,
Gdansk University of Technology
Gdansk, Poland
katarzyna.bobkowska@wilis.pg.gda.pl,
marek.przyborski@wilis.pg.gda.pl

Agata Kaczyńska, Adam Kosiński
Department of Clinical Anatomy,
Medical University of Gdansk
Gdansk, Poland
agata.kaczynska@gumed.edu.pl,
akoi@interia.pl

***Abstract*— This article presents spatial analyzes conducted to assess the potential of ReMake software to be used for medical purposes, with emphasis on the analysis of the shape and dimensions of the ventricles. To achieve this goal, the length of the sections measured with the ReMake and Image Master programs have been compared. RMS error was on the level of 1.2 mm. In addition to indicating the appropriateness of using this software, there are several examples of measurements that can be made on the basis of the obtained data in the digital 3D model. Measurements were prepared by using CloudComapre.**

Keywords*— *cardiology, image processing, 3D model

I. Introduction

With the increased demand for imaging of complex anatomical structures it was noticed that there is a necessity to introduce new technologies into medical sciences in order to visualize three-dimensional structures such as computer 3D models. It has also been found that with such virtual models, it is possible to reproduce anatomical structures using 3D printing technology. The 3D model has a wide range of applications, both clinical and educational [1].

Nowadays, the greatest development of 3D technology, both modeling and printing, is undoubtedly associated with the central organ of the cardiovascular system - the heart. This organ is extremely demanding in terms of 3D imaging because it has an irregular shape and its internal structure is greatly complex. What is more, the heart is a dynamic organ which has different dimensions depending on the cardiac cycle [2]. Modeling of the heart and its interior poses a major challenge, particularly in the exploration of very complex right ventricular structure which is of great clinical importance, for instance, in cardiac electrostimulation [3].

There are several imaging technologies that make it possible to visualize the heart as a virtual 3D model. The most commonly used imaging techniques, both cardiac and post mortem, are CT (computed tomography), MRI (magnetic resonance imaging) and echocardiography [4], [5]. Thanks to these techniques a 3D image of the heart is obtained, which after appropriate virtual processing, can be used in 3D printing technology. Such 3D cardiac models can be used to perform computer simulations used in surgery, improve skills in surgical techniques, during cardiac surgery planning (the choice of technique and equipment), visualization of the hearts of patients with congenital malformations in order to match the best therapeutic treatment through the personalized patient`s heart model [1], [6].

Unfortunately, still too little attention is paid to the development of imaging technology of the inner cardiac structure, such as the internal surface of the heart cavities and their architecture. This publication presents the digital photogrammetry method, which was designed to visualize the 3D model of the interior of the heart chambers and their structure. For this purpose, a method of silicone molding of the heart of adult people fixed in formalin was developed, which reflects the internal architecture, size and structure of the walls of the ventricles [7], [8].

Such silicone models, which will be subjected to virtual visualization, will be used to examine the complexity of the right ventricle, to isolate ventricular components based on the location of important anatomical structures in the interior and to examine the position of right ventricle to the other parts of the heart.

This article describes the use of images made with a non-metric camera for the purpose of developing the hearts' ventricular model. Modern methods of close-range photogrammetry are used for the modeling of small objects. Experience indicates the fact that these methods are often an interdisciplinary application. One of the areas that uses more and more photogrammetric techniques is archeology. An interesting example may be zooarcheology [9] or under water excavation [10]. In the case of construction, and more specifically the control of building materials, these methods are also applicable [11]. It can not be forgotten that medicine use commonly digital 3D models, for example in the manufacture of dental [12] or other type of prostheses [13], [14]. For the safety of building use, the inventory of rooms can also be made using imaging and modeling systems [15]. It has become very popular to take pictures from different platforms, unmanned in general. The top use of UAV photogrammetry is topographical application- terrain and its cover analysis [16], [17], [18]. These few examples of the possibilities of the interdisciplinary links of photogrammetry show that it is widely used [19].

II. Method and Analysis

The purpose of this paper is to assess the potential for using photogrammetric techniques for the visualization, measurement and analysis of ventricles. Within this work two photogrammetric studies have been established:

A. *Measurement of Reference Values for Analyzes*

The first studies were carried out to measure the lengths of reference values and the model was made using Image Master (IM). These values were used to evaluation of accuracy of the model, which was made another photogrammetric method. For the purpose of this part of the work, a test box with 9 intended photo points was developed. Figure 1 shows one of the images (left image from stereo pair) taken for analysis in the software. An non-metric camera Canon EOS 5D with Canon Lens EF 50 mm f/1.4 was used in all works by the authors. As part of working with Image Master software, the camera has been calibrated. The most important step in this study was to determine the coordinates in three-dimensional system (units - meter) based on the stereo pair. The accuracy of the measurement was: 0.3 mm in the image plane, 1.0 mm - in the depths. After measuring the coordinates of the characteristic points, the length of 21 randomly selected sections (1 for scaling purposes, 20 for accuracy purposes) between the measured points were calculated.

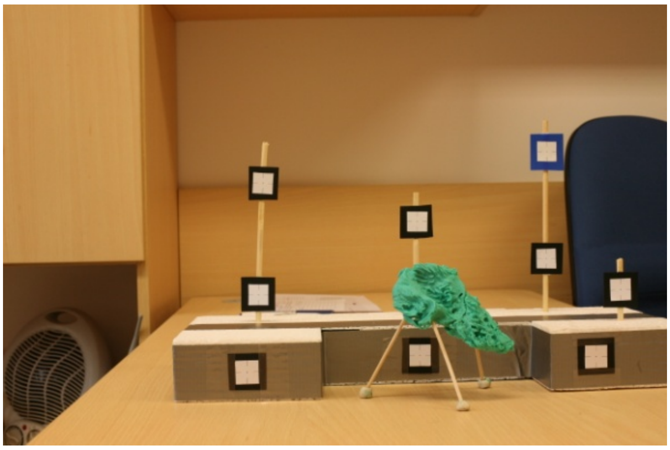

Fig. 1. Left image from stereo pair

B. *Development of the target model*

At this stage a model was made using ReMake software. The program does not require prior calibration of the camera. The whole process of development was automatic. The captured images were processed in the cloud (external IT infrastructures). An example effect is shown in Fig. 2. Model was exported as *.obj* file. The next step was the scaling the model to "real" dimensions. For this purpose, one of the sections, which was measured on the basis of the work in the IM software, was used. On a scaled model, the length of 20 sections - the same ones that were determined by IM - was measured. The results are presented in the table I. The table also includes the values measured with IM. Fig. 3 shows a graph of ordered lengths and differences between measurements in two programs (Image Master and ReMake). The orange color indicates the trend line, evidently indicating that the value of the difference increases with the length of the segment. What points to the fact that the error is closely related to the initial error of the model scaling.

Fig. 2. An example heart part model developed in ReMake

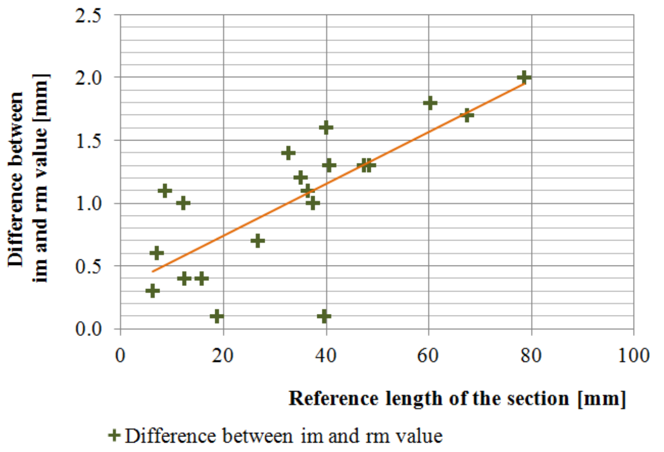

Fig. 3. Lengths and differences between measurements in Image Master and ReMake software

C. *Accuracy analysis*

Based on the collected data (Table I), mean error (1), standard deviation (2) and RMS error (3) were determined. The results are summarized in Table II.

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \quad (1)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(d_i - \bar{d})^2}{n-1}} \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} {d_i}^2}{n}} \quad (3)$$

where:

n - number of sections

TABLE I. LENGTH OF SECTIONS MEASURED IN IMAGE MASTER AND REMAKE SOFTWARE

Section Number (i)	**Image Master (im_i)**	**ReMake (rm_i)**	**Difference ($d_i = rm_i - im_i$) [mm]**
	Section Length [mm]		
1	40,5	41,8	1,3
2	12,1	13,1	1,0
3	78,6	80,6	2,0
4	39,9	41,5	1,6
5	12,4	12,8	0,4
6	67,5	69,2	1,7
7	32,7	34,1	1,4
8	15,8	16,2	0,4
9	6,2	6,5	0,3
10	47,4	48,7	1,3
11	8,6	9,7	1,1
12	35,0	36,2	1,2
13	18,8	18,9	0,1
14	36,5	37,6	1,1
15	26,6	27,3	0,7
16	60,3	62,1	1,8
17	6,9	7,5	0,6
18	48,4	49,7	1,3
19	37,4	38,4	1,0
20	39,6	39,7	0,1

TABLE II. ACCURACY ANALYSIS VALUES

Standard deviation σ	0.6 mm
Mean $\bar{d}$	1.0 mm
RMSE	1.2 mm

The results show that developing a heart internal model with ReMake software is justified. The measurement error of the section does not exceed the admissible values - 1.5 mm. However, particular attention should be paid to the size of the sections analyzed in relation to the size of the section used for the rescaling. The program is a tool that makes it easy and intuitive to get a model. Thanks to this, it can find interest among professionals not only in the field of photogrammetry, but even among medical specialists.

III. EXAMPLES OF MODEL ANALYSIS FOR MEDICINE NEEDS

Three-dimensional models of parts of the human body are used in biometrics for various purposes [20], [21]. The need to develop methods of obtaining this type of data is growing. Model analysis was done using CloudCompare software. For measurements, pre-processing of the model was necessary - change from mesh to point clouds (.las file). As examples may be presented:

A. *Distance Measurement*

Measuring distances between individual structures was one of the reasons why the authors chose to develop a digital three-dimensional model of the interior of the heart that allows measurements in 3D space. As an example of use, the measurement of the length of the segment, that connects tricuspid valve (TV) and – right ventricular apex (RVA), was shown (Fig. 4).

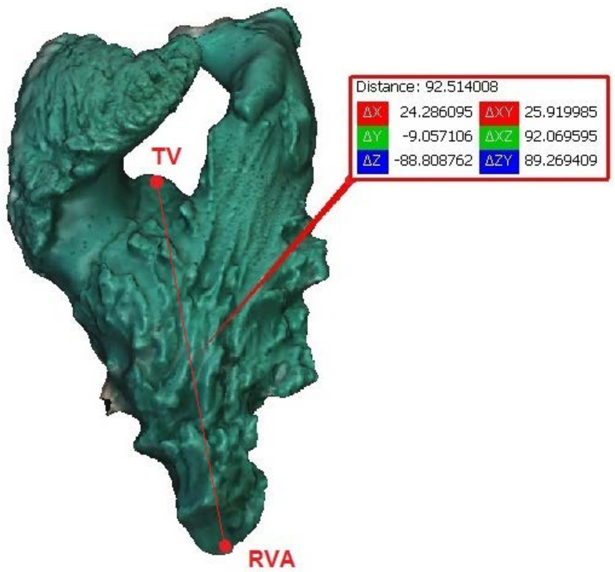

Fig. 4. Example of distance measurement – units mm

B. *Cross-section Analysis*

Fig. 5 shows cross-section at the level of the right atrioventricular fibrous ring to which the tricuspid valve is attached. This valve prevents blood from regurgitation from the right ventricle into the right atrium during the cardiac cycle. The right part of the figure is the view of the cross-section, superimposed on the entire model. While the left part of the figure is a cross-section, along with the sample length. This makes it easy to visualize the spatial arrangement of clinically relevant cardiac structures and their measurement.

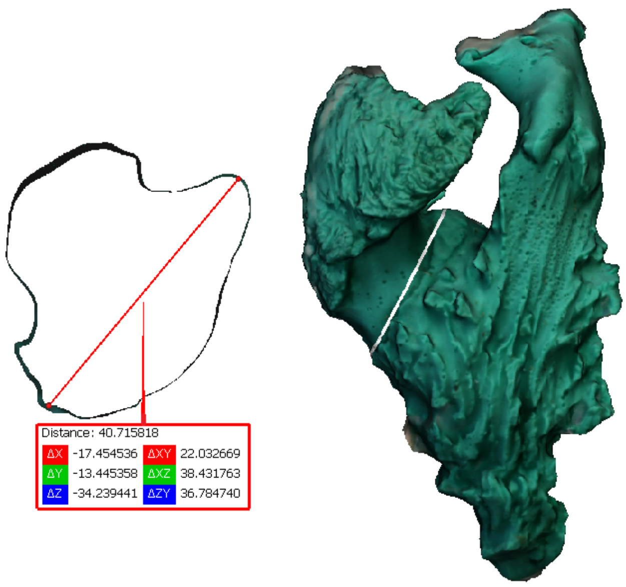

Fig. 5. Example of section analysis – units mm

These two examples were made for the purposes of this article, but in the future it is planned to analyze:

C. *Angle Measurement*

Measure the angles between the designated axes that will connect characteristic points inside the heart cavity. This approach will allow the spatial analysis of the internal structure of the right ventricle and its position relative to other surrounding anatomical elements.

D. *Volume Measurement*

Measuring the volume of heart cavities and their components will allow to study the differentiation of structures in the case of different hearts.

These are just examples of the possibilities of using the tool of analysis which is CloudCompare. On the other hand, they show how interdisciplinarity and cooperation of specialists in various fields are needed.

IV. Conclusions

The aim of the article was to indicate the possibility of using photogrammetric techniques for the analysis of silicone models of the interior of the heart. These analyzes indicate that the use of these techniques is very well-founded. ReMake software is an intuitive tool that can be used by people without much experience in photogrammetry. This is quite important for medical specialists. Because they themselves can acquire such models without seriously exploring the problem of developing a 3D model. The model, after scaling, is ideal for analyzing the shape or size of the medical structures of the heart.

The presented approach is an innovative way to obtain information about the inside of the heart. This innovation is not only due to the application of the photogrammetric methods presented but from the fact that the silicone model of the hearts' interior is imaged and processed to digital form.

References

[1] M. Vukicevic, B. Mosadegh, J. K. Min, and S. H. Little, "Cardiac 3D Printing and its Future Directions," JACC Cardiovasc. Imaging, vol. 10, no. 2, pp. 171–184, 2017. http://doi.org/10.1016/j.jcmg.2016.12.001

[2] P. Trunk, J. Mocnik, R. Trobec, and B. Gersak, "3D heart model for computer simulations in cardiac surgery," Comput. Biol. Med., vol. 37, no. 10, pp. 1398–1403, 2007. http://doi.org/10.1016/j.compbiomed.2006.11.003

[3] Y. hong Liang, L. Liu, D. li Chen, C. ying Lin, H. wen Fei, S. lin Chen, and S. lin Wu, "Right ventricular outflow tract septal pacing versus apical pacing: A prospective, randomized, single-blind 5-years follow-up study of ventricular lead performance and safety," J. Huazhong Univ. Sci. Technol. - Med. Sci., vol. 35, no. 6, pp. 858–861, 2015.

[4] C. Lorenz and J. Von Berg, "A comprehensive shape model of the heart," Med. Image Anal., vol. 10, no. 4, pp. 657–670, 2006. http://doi.org/10.1016/j.media.2006.03.004

[5] A. M. Taylor, O. J. Arthurs, and N. J. Sebire, "Postmortem cardiac imaging in fetuses and children," Pediatr. Radiol., vol. 45, pp. 549–555, 2015. http://doi.org/10.1007/s00247-014-3164-0

[6] M. Cantinotti, I. Valverde, and S. Kutty, "Three-dimensional printed models in congenital heart disease," Int. J. Cardiovasc. Imaging, vol. 33, no. 1, pp. 1–8, 2016. http://doi.org/10.1007/s10554-016-0981-2

[7] R. Kamiński, A. Kosiński, M. Brala, G. Piwko, E. Lewicka, A. Dąbrowska-Kugacka, G. Raczak, D. Kozłowski, and M. Grzybiak, "Variability of the left atrial appendage in human hearts," PLoS One, vol. 10, no. 11, pp. 1–9, 2015. http://doi.org/10.1371/journal.pone.0141901

[8] A. Kaczyńska, A. Kosiński, M. Zajączkowski, and M. Grzybiak, "Study of the morphology of right ventricular outflow tract with the use of

silicone heart models," in *Skeletons, Stories and Social Bodies Conference*, 2017, University of Southampton, United Kingdom.

[9] A. Evin, T. Souter, A. Hulme-Beaman, C. Ameen, R. Allen, P. Viacava, and K. Dobney, "The use of close-range photogrammetry in zooarchaeology: Creating accurate 3D models of wolf crania to study dog domestication," J. Archaeol. Sci. Reports, vol. 9, pp. 87–93, 2016.

[10] J. McCarthy and J. Benjamin, "Multi-image Photogrammetry for Underwater Archaeological Site Recording: An Accessible, Diver-Based Approach," J. Marit. Archaeol., vol. 9, no. 1, pp. 95–114, 2014.

[11] A. Janowski, K. Nagrodzka-Godycka, J. Szulwic, and P. Ziółkowski, "Remote sensing and photogrammetry techniques in diagnostics of concrete structures," Comput. Concr., vol. 18, no. 3, pp. 405–420, 2016. http://doi.org/10.12989/cac.2016.18.3.000

[12] M. Kanazawa, M. Inokoshi, S. Minakuchi, and N. Ohbayashi, "Trial of a CAD/CAM system for fabricating complete dentures," Dent. Mater. J., vol. 3, no. 1, pp. 93–96, 2011.

[13] O. Ciobanu, W. Xu, and G. Ciobanu, "The use of 3D scanning and rapid prototyping in medical engineering," Fiability Durab., 2013.

[14] J. V. Sabol, G. T. Grant, P. Liacouras, and S. Rouse, "Digital Image Capture and Rapid Prototyping of the Maxillofacial Defect," J. Prosthodont., vol. 20, no. 4, pp. 310–314, 2011. http://doi.org/10.1111/j.1532-849X.2011.00701.x

[15] H. Du, P. Henry, X. Ren, M. Cheng, D. B. Goldman, S. M. Seitz, D. Fox, I. L. Seattle, and A. Systems, "Interactive 3D Modeling of Indoor Environments with a Consumer Depth Camera," UbiComp'11, p. 10, 2011. http://doi.org/10.1145/2030112.2030123

[16] F. Remondino, L. Barazzetti, F. Nex, M. Scaioni, and D. Sarazzi, "UAV photogrammetry for mapping and 3d modeling–current status and future perspectives," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., vol. 38–1/C22, pp. 25–31, 2011. http://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-25-2011

[17] G. Stepien, J. Sanecki, A. Klewski, and E. Zalas, "Method of Parameter Reduction in the Transformation of Oblique Photographs and Proposal of Its Implementation in Unmanned Aerial Systems," in 2016 Baltic Geodetic Congress (BGC Geomatics), 2016, pp. 171–175. http://doi.org/10.1109/BGC.Geomatics.2016.38

[18] P. Burdziakowski, A. Janowski, M. Przyborski, and J. Szulwic, "A modern approach to an unmanned vehicle navigation," in 16th International Multidisciplinary Scientific GeoConference SGEM 2016, 2016.

[19] Z. Paszotta, M. Szumilo, and J. Szulwic, "Internet photogrammetry for inspection of seaports," Polish Marit. Res., vol. 24, no. 94, pp. 174–181, 2017. http://doi.org/10.1515/pomr-2017-0036

[20] K. Bobkowska, A. Janowski, M. Przyborski, and J. Szulwic, "Analysis of high resolution clouds of points as a source of biometric data," in Geodetic Congress (Geomatics), Baltic, 2016, pp. 15–21. http://doi.org/10.1109/BGC.Geomatics.2016.12

[21] K. Bobkowska, A. Janowski, M. Przyborski, and J. Szulwic, "A new method of persons identification based on comparative analysis of 3d face models," in SGEM2016 Conference Proceedings, Book2 Vol. 2, 2016, pp. 767–774. http://doi.org/10.5593/SGEM2016/B22/S10.098