Segmentation of anatomical structures of the heart based on echocardiography

V V Danilov[1], **I P Skirnevskiy**[1], **O M Gerget**[1]

[1] Tomsk Polytechnic University, 30, Lenina Ave., Tomsk, 634050, Russia

E-mail: viacheslav.v.danilov@gmail.com

Abstract. Nowadays, many practical applications in the field of medical image processing require valid and reliable segmentation of images in the capacity of input data. Some of the commonly used imaging techniques are ultrasound, CT, and MRI. However, the main difference between the other medical imaging equipment and EchoCG is that it is safer, low cost, non-invasive and non-traumatic. Three-dimensional EchoCG is a non-invasive imaging modality that is complementary and supplementary to two-dimensional imaging and can be used to examine the cardiovascular function and anatomy in different medical settings. The challenging problems, presented by EchoCG image processing, such as speckle phenomena, noise, temporary non-stationarity of processes, unsharp boundaries, attenuation, etc. forced us to consider and compare existing methods and then to develop an innovative approach that can tackle the problems connected with clinical applications. Actual studies are related to the analysis and development of a cardiac parameters automatic detection system by EchoCG that will provide new data on the dynamics of changes in cardiac parameters and improve the accuracy and reliability of the diagnosis. Research study in image segmentation has highlighted the capabilities of image-based methods for medical applications. The focus of the research is both theoretical and practical aspects of the application of the methods. Some of the segmentation approaches can be interesting for the imaging and medical community. Performance evaluation is carried out by comparing the borders, obtained from the considered methods to those manually prescribed by a medical specialist. Promising results demonstrate the possibilities and the limitations of each technique for image segmentation problems. The developed approach allows: to eliminate errors in calculating the geometric parameters of the heart; perform the necessary conditions, such as speed, accuracy, reliability; build a master model that will be an indispensable assistant for operations on a beating heart.

1. Introduction

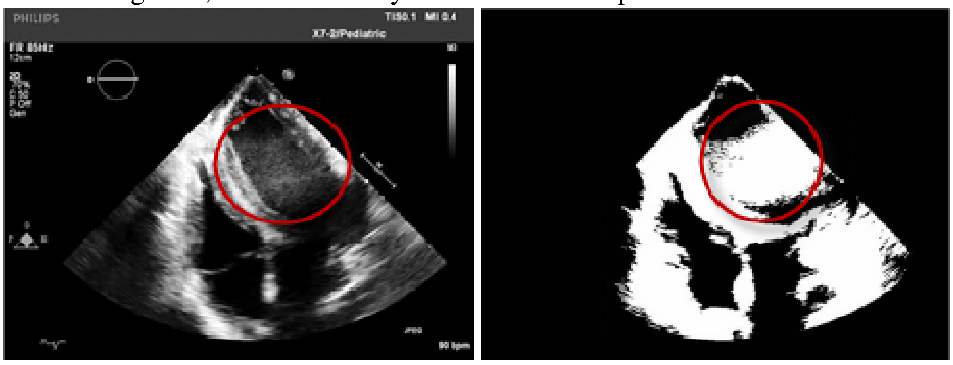
Currently, there are many different kinds of medical research studies and medical imaging modalities, closely related to image processing problems, such as angiography, echocardiography (EchoCG), cell magnetic resonance therapy and computed tomographic scanning. Today, these types of imaging modalities have been actively developing and they are the main diagnostic tools in their fields. The main disadvantage of the above-described methods of diagnosis is a limited software bundle of existing facilities. Thus, the effectiveness and validation of automated diagnostic methods directly depend on the level of proficiency of a researcher. In addition, image processing methods used in medical diagnostic belong to the static methods, i.e. working with each individual image and not taking into account the dynamics. Analysis shows that in the diagnostic studies, for example in angiographic and echocardiographic diagnosis, an application of dynamic segmentation methods of image sequences is the most efficient.

It should be noted that image segmentation is a preliminary stage of image processing and analysis of any system. The quality of image segmentation has a significant impact on the quality of the final stage of image processing. For example, one of the key features is the accuracy in the task of searching for the boundaries of anatomical structures of the heart by echocardiography. Thus, the main aim of our research is to develop algorithms for automated dynamic imaging and segmentation of two-dimensional and three-dimensional echocardiographic diagnosis in medical challenges. The main hypothesis, considered in the study, is that the medical images of anatomical structures of the heart can be classified according to their geometrical properties and the properties of their environment; a segmentation algorithm can be defined for each class of objects, which allows getting a result that satisfies the subsequent usage in the scientific work.

2. Materials and methods

Methods of digital processing of signals and images, mathematical analysis and mathematical modeling are used as the theoretical methods of the research. For solving posed tasks we also used: the methods of computer vision, methods of conversion and analysis of images, neural networks, statistical analysis, expert evaluation and decision-making. As for epicardial 2D echocardiography, datasets were acquired on a porcine animal model using an X7-2 transducer on a Philips iE33 machine and a PMS5.1 Ultrasound software (Philips Healthcare, Andover MA). The experimental protocols were approved by the Boston Children's Hospital Institutional Animal Care and Use Committee (IACUC). All animals received humane care in accordance with the 1996 Guide for the Care and Use of Laboratory Animals recommended by the US National Institutes of Health. The datasets were then processed off-line on the machine equipped with Intel Core i7-4820K 3.7GHz CPU using MATLAB (MathWorks, Natick MA).

The preparatory stage of image analysis is connected with processing digital noise, reduction of the noise and interferences, and assessment of the resulted image. Digital image noise is an image artifact presented as random deviation of brightness or color from its original values. Noisy pixels may be erroneously classified as edge ones. An algorithmic mistake in segmentation by the threshold method is shown in Figure 1, where the noisy area of the blood pool was classified as an endocardium.



a b

Figure 1. Results of thresholding: a – reference image; b – the mistake of the thresholding method.

As for the segmentation stage, the Laplacian automated segmentation method was used. Using this approach allows one to recognize edges with high accuracy. However, Laplacian and Gaussian segmentation methods strongly depend on digital noise. In order to improve segmentation accuracy, the pre-processing stage using the median filter was implemented. The results are shown in the Figure 2.

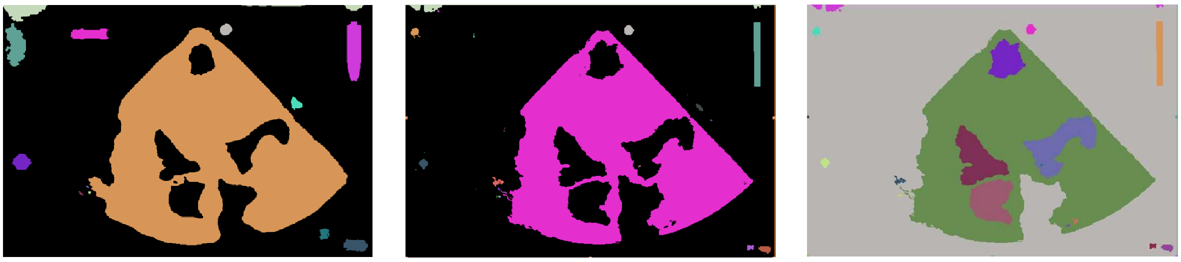


Figure 2. Automated segmentation: a – Gaussian method with median filtering; b – Laplacian method with median filtering; c – Final results of segmentation.

3. Results of pre-processing and segmentation of 2D EchoCG images

This section is dedicated to the study of algorithms of echocardiographic image processing. The main results received during the study are described below.

Procedure for conducting EchoCG:

1. During conducting EchoCG for a patient, it is possible to obtain up to 357 slices in four key views.
2. Under the existing manual processing technology of echocardiographic images, obtained by ultrasound, the average time of image analysis that the doctor manually does for one patient takes about 30 minutes. The doctor usually analyzes from 1 to 10 slices of the examination. It is not possible to trace the change dynamics of cardiac parameters from the entire set of frames, which does not allow concluding about a disorder of the cardiac activity of the heart.

Segmentation and processing of EchoCG images:

1. Existing algorithms for detecting the boundaries of the heart chambers, based on texture segmentation and morphological transformations, do not take into account the angle of inclination of the heart chambers and discontinuous contours. Algorithms, using active contours, require a template - the initial approximation of the chamber border that iteratively manually adjusted to the real border. But due to the characteristics of each slice, it is difficult to find contour parameters, such as flexibility, elasticity, step, that give the acceptable results. Furthermore, these methods are iterative. There are no EchoCG image processing algorithms on the long axis.
2. Many filters have been used to suppress speckle phenomena and noise, for instance median filters, Kuan filter [1], [2], sigma filter [3], Ramponi filter [4] et al. The values of the standard parameters, such as root mean square deviation (RMSD) [5] and a peak signal to a noise ratio (PSNR), were assessed [6]. The studies were conducted based on the real images in various positions (276 images were processed). Results are shown in Table 1. According to the considered filters, it is more efficient to use the Ramponi filter to remove speckle noise, as it provides a minimum value of RMSD and a maximum value of PSNR.

Table 1. The values of the root mean square deviation and a peak signal-to-noise ratio for different filters

Filter type	RMSD	PSNR, dB
Kuan filter	8.0	14.0
Median filter	12.0	13.0
Sigma filter	10.0	15.0
Ramponi filter	5.0	16.0

3. In this work, the possibility of using parallel processing methods to increase the speed of the pre-processing and segmentation algorithms was also explored. For example, one of the classic digital

nonlinear algorithms for noise removing is a median filter implemented using NVIDIA CUDA technology. The results are shown in Figure 3.

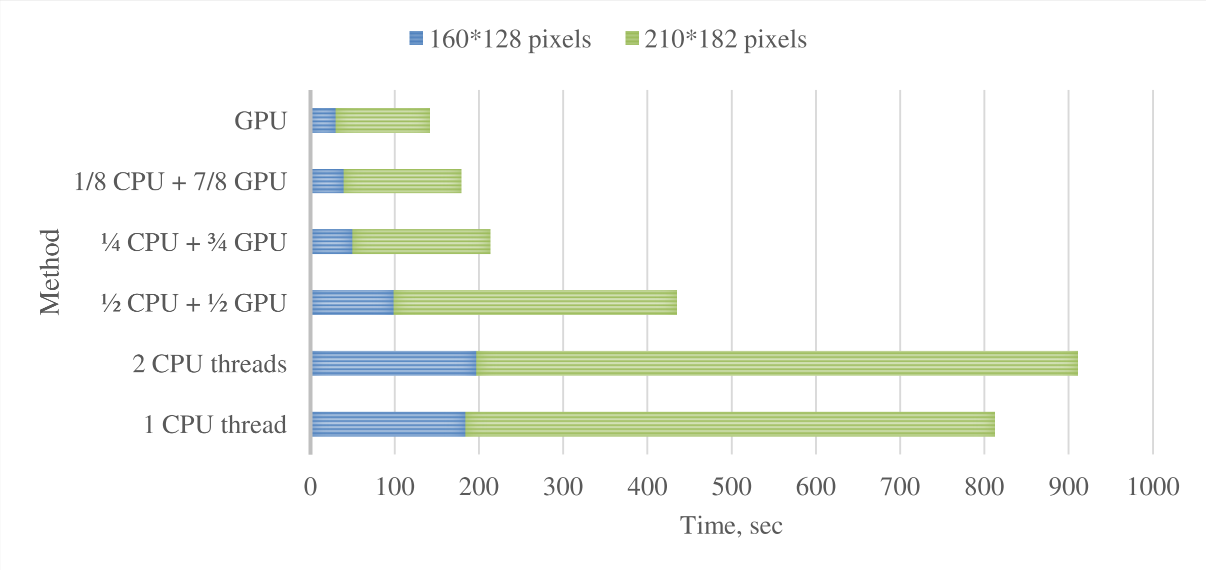


Figure 3. Results of the median filter, implemented on NVIDIA CUDA technology.

Basing on the represented data, we can conclude that the non-linear algorithms with high complexity can be implemented using parallel computing technology for increasing performance and reducing the operating time, which is one of the crucial characteristics of the implementation of the system with automatic pre-processing and segmentation of medical images.
4. Research of the developed algorithm, using different types of segmentation and an active contours method, was carried out on the basis of EchoCG test images of the heart in the apical view. The basic characteristics of the left ventricle, such as the area, length and volume, were calculated for each image. The fastest algorithm with high accuracy determination of the length, area and volume is an algorithm based on the sector segmentation.

4. Conclusion

As a result of the research study, the medical images of anatomical structures of the heart can be classified according to their geometrical properties and the properties of their environment; the segmentation algorithm can be defined for each class of objects, which allows getting the most accurate result. To increase the processing speed of complicated medical images, that is one of the crucial characteristics of the implementation of the automatic segmentation systems and medical image pre-processing, it is necessary to use parallel computing technologies.

5. Discussions

The existing manual EchoCG image processing technology does not allow one to complete full analysis of registered frames of each patient because of the complexity and the limited time of an appointment. Also, it is not possible for the doctor to estimate the change in the parameters of the dynamics from slice to slice in key positions that causes the loss of large amounts of information. In this regard, great attention is paid to the algorithm using different types of segmentation, as well as the method of active contours that were performed on the test EchoCG images.

6. Acknowledgments

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