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COMPUTED TOMOGRAPHY IMAGE PROCESSING FOR DIAGNOSTIC AND TRAINING APPLICATIONS IN MEDICINE

The paper deals with processing of imaging data obtained in the course of different medical examination procedures, for use in applications focused on improving both the diagnostic process of a patient as well as extending the training possibilities for medical personnel. Computed tomography (CT) data serves as the main source of structural and volumetric information. Fusion with left ventricular systolic function map, provides a vital information on the state of heart muscle. In parallel, the same set of computed tomography data is reused for simulation of trans-esophageal echocardiography (TEE). The presented simulation setup is used in the course of medical personnel training.

1. INTRODUCTION

Cardiovascular diseases have been the major cause of mortality during the last 50 years. Almost 50% of all mortality cases in Poland are directly or indirectly related to different cardiovascular diseases (CVD). According to WHO statistics, in 2009, nearly 1.9 mln deaths in European Union (over 4,3 mln deaths in European region of WHO) were attributed to conditions related to cardiovascular dysfunction [1]. In Poland, in 2009, the number of deaths due to cardiovascular disorders was 177 965, with 83 613 males and 94 352 females. Among deaths caused by cardiovascular complications, most were a result of prior occurrence of myocardial infarction or stroke, while atherosclerosis, hypertension were identified as the most common risk factors.

According to data collected by European Society of Cardiology, the estimated cost of CVD for European economy in 2008, was calculated as 192 billion Euro annually, with more than half of the sum attributed to direct health care [3]. Cardiovascular diseases are typically chronic in nature [2]. Given the importance of providing patients with the access to medical care that can minimize the life threatening effect of CVD and enable them to function normally, an increase in the overall costs is expected in subsequent years.

Contemporary cardiology makes use of a number of medical tests that allow for diagnosis and evaluation of the disease advancement stage. The tests can be divided into invasive and noninvasive, with invasive techniques usually providing a clearer view on the state of the heart and circulatory system. Invasive examination, being more detailed, is typically required when choosing an optimal treatment path for the patient. According to data collected by Polish Cardiac Society, in 2006, for 73 thousand examinations, 1577 resulted in complications, with 315 (0.45%) being fatal. Invasive methods not only carry a higher risk of possible complications, but also are more costly from economic point of view.

For these reasons, noninvasive examinations methods, including imaging techniques, are an attractive alternative. Lower cost, limited amount of pain or completely pain free, significantly reduced influence of patient's health; the noninvasive methods are preferred whenever possible. However, the extracorporeal nature of these methods, results in lower level of detail compared to invasive test results.

Medical imaging has gone through a significant development throughout the recent years, providing a significant insight into structure and inner working of human body. Use of ultrasonography allowed for registration and segmentation of moving structures while the examination is in progress, allowing a real-time assessment of organ state. Most advanced medical examination techniques such as Computed tomography (CT) or Magnetic Resonance Imaging (MRI) combined with computer aided post-processing allows for observation of a patient’s body in three dimensions.

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Cardiology utilizes of a number of imaging methods in the diagnostic process of heart diseases, with USG and CT being in common use.

Assessment of resting and stress perfusion of myocardial function in chronic ischemic heart diseases is commonly done using stress echocardiography and perfusion scintigraphy (SPECT - Single-photoemission computed tomography). Fusion of morphological data obtained in CT and functional information from SPECT (perfusion at rest and stress) allows for comprehensive evaluation of location and severity of ischemia, thereby increasing the diagnostic and prognostic value of noninvasive imaging techniques[4, 5]. Unfortunately, both examinations result in increased radiation dose the patient is exposed to. It has been proposed to replace functional data from SPECT used in the fusion process, with stress echocardiography as an alternative considered safer for the patient. To the best of our knowledge, no studies of such fusion were published.

Detailed view on heart structures such as atria, valves, aorta or pulmonary artery can be obtained using TEE USG. The examination process is invasive, with the USG probe being inserted into patient’s esophagus at certain depth. The discomfort brought to the patient and risk of complications results in a specialized simulator being the preferred training method. Unfortunately the commercially available solutions allow only limited choice of the simulated devices and cannot be easily extended as needed.

The article is divided into two main sections, first of which deals with image fusion and describes an approach to fusion of CT and ECHO images, while the next describes a training setup for USG image simulation based on CT data. All CT data was collected using Toshiba Aquillion device at Clinic of Cardiology, W. Biegański Hospital in Łódź.

2. HYBRID IMAGING AS A FUSION OF CT AND ECHO

This section presents an image fusion on a 3D heart model captured in CT examination and a left ventricular (LV) wall movement function analysis obtained from ECHO examination (echocardiogram [8]) and explains the details of the implementation. The main goal of presented image fusion algorithms is to provide a way of creating easy to use and intuitive model depicting heart morphology and function. Proposed software solution is based on an idea of merging simple, independently prepared, analysis results into one, three dimensional image based on a surface heart model from CT examination.

Raw CT examination data set is prepared in DICOM file format [12] as a sequence of heart slices images, each 0.5mm apart, with detailed positional information. DICOM files sequence is treated as an input for segmentation algorithms to perform extraction of sections containing only the object of interest. Using intelligent thresholding processes [11] it is possible to extract the object of interest as a collection of voxels representing its structure. Next step of proposed solution algorithm is surface extraction. Using obtained collection of voxels it is possible to create an Triangulated Surface Mesh without model orientation and information on structure’s characteristic points placement.

One of the most important aspects of images fusion is to prepare proper solution for both (CT and ECHO) images mapping. Relative positioning of both images can be achieved by use of orientation points. A number of these points must be given manually in order to calculate object orientation, both in three dimensional (3D) model space and plain (2D) ECHO as bull’s-eye representation [8]. Proper quality of mapping process can only be assured if the reference points are placed carefully. For this reason, the choosing and marking of orientation points is performed by experienced medical personnel. To achieve a balance between usability and accuracy of mapping, the number of points required for object orientation can be adjusted, with at least 3 points being the required minimum. Final algorithm, which is last of sequence presented in Fig. 1, is texturing. Custom texturing is prepared to merge those two different domain (3D and 2D) images into one interactive view. By using prepared reference points it is possible to map all points of volumetric 2D image from ECHO into 3D LV model structure (see Fig. 2).

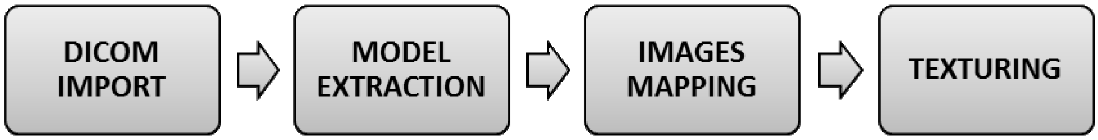

Fig. 1. Image fusion algorithm flow.

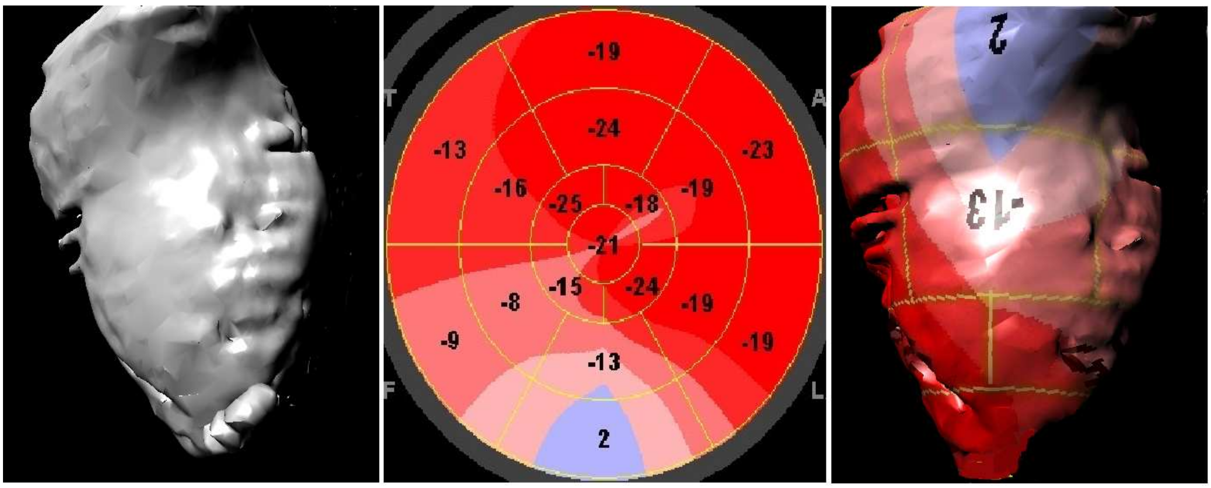

Fig. 2. Images set of CT and ECHO fusion, from left: 3D LV model, bull's-eye ECHO diagram, image fusion result.

3. TEE SIMULATOR

The following section describes an appliance for simulation of USG heart imaging, which is developed as a part of an interdisciplinary project between Technical University of Łódź and Medical University of Łódź. The research focuses on simulation of transesophageal echocardiogram (TEE), a USG procedure in which a probe is inserted into patient's esophagus, so that a clear image of a heart can be obtained. The procedure needs to be carried out by trained personnel, where a supervised training process involves performing on patients. A simulator package is a welcome enhancement to the training process [6, 7], and although a number of commercially available simulators are available, an independently developed one has a unique advantage of being easily extensible to support multiple scenarios and equipment configurations, while not being closely tied to a solution from a single vendor.

The described TEE simulation package is composed of two elements: a software application running on a host PC, and a hardware probe emulator.

3.1. ULTRASOUND IMAGE SIMULATION

USG image simulation is performed using a desktop application. Input data is provided in form of DICOM format files containing a sequence of slices from CT examination, all 0.5mm apart. The spatial information provided in input files allows for positioning of slices with respect to each other and reconstruction of a complete scan sequence.

Visualization toolkit (VTK) library [13], a popular medical data visualization package, is used for both presentation and manipulation of the imaging data.

Fig. 3. Side by side comparison of CT and simulated USG image.

An example of simulated USG image is shown in Fig. 3. It was concluded that a simple histogram adaptation (pixel brightness transformation with use of a predefined transformation function) is a sufficient initial step, as the CT imaging data shares many of the characteristics of a USG image (blood/tissue interfaces, organ visibility), yet at a different brightness levels (blood in CT is bright, in contrast to dark pixel values in USG). Similar approach was used in [14], where it was also found to be sufficient. The implementation can be easily improved by use of GPU accelerated LUT based color space transformation.

A sample of simulated USG images was positively assessed by the medical personnel as sufficient for use in the training process. No quantitative assessment was carried out yet.

The resulting images lack some features typically found in USG imaging, with artifacts and noise being the most visible ones. An acoustic wave generated by the probe, traveling through human body is a subject to reflection and scattering. A number of models for simulation of these effects have been proposed, both purely synthetic and empirical ones. A synthetic model [16], although accurate proves to be computationally unfeasible for interactive applications. On other hand, access to cheap computing power on GPUs resulted in interactive applications, providing accurate simulation quality with acceptable computational cost [8].

For the purpose of this research, we have decided to use a naïve, ray based simulation model where reflections and scattering are both in linear relation to the gradient of pixel brightness. More sophisticated solution that will provide a better level of realism is under development.

Having access to CT slice data, and the necessary spatial information, both a reslicing of the image stack at an arbitrary location and a reconstruction of a 3D structure of the scanned region is possible. As a training application, presentation of both the projection plane and a 3D data is helpful for improving the trainee's orientation.

An example of such view is shown in Fig. 4.

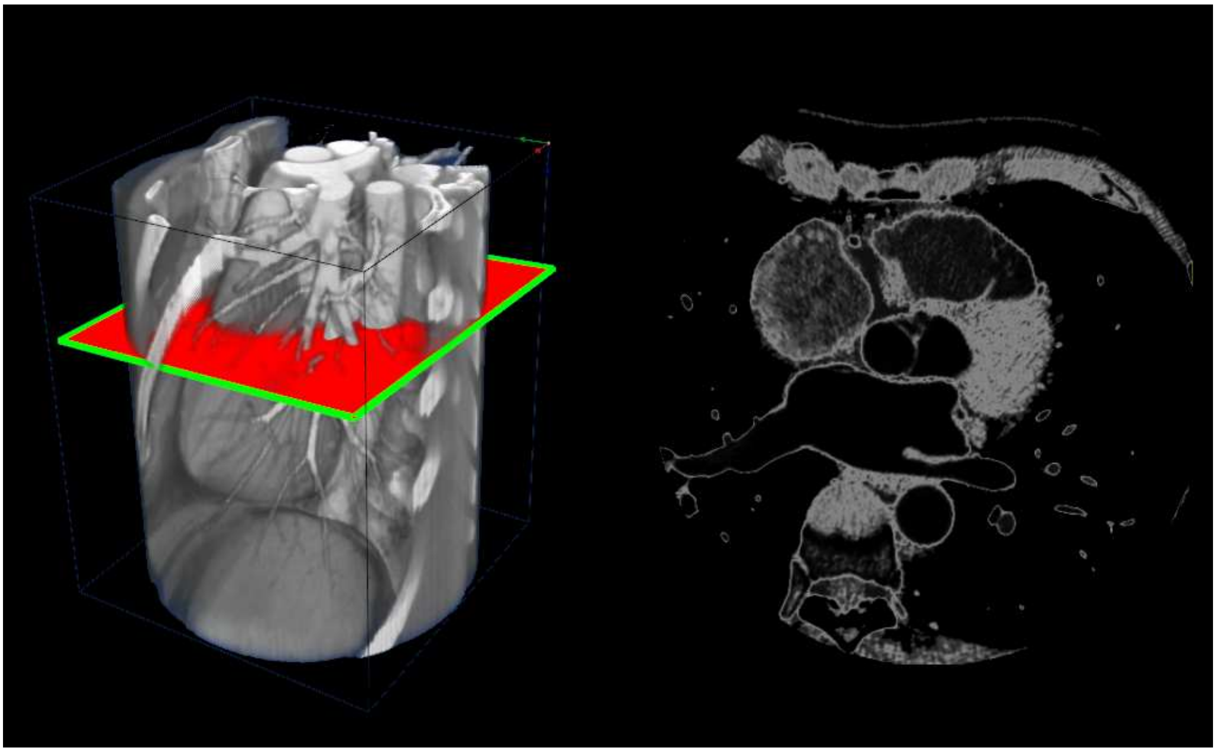

Fig. 4. Simulated USG image and 3D probe plane orientation volume.

A probe image registration plane is clearly marked in the scene (red face with green bevel), allowing the trainee to observe the probe's location, what stands in contrast to the conditions a real examination is performed in. Having the esophagus properly positioned in each of the CT slices, the virtual probe location can either follow a predefined path along the esophagus or can be arbitrarily position inside or outside of the body.

As a part of training device the application must provide the necessary level of interactivity. The visualization and simulation processes are performed in real-time. For this reason some adjustments to the level of detail of CT data had to be made. As observed in [15], the reconstruction of 3D data using marching cubes can be memory costly, thus rendering of probe orientation view on lower-end graphical units became prohibitively time consuming. This lead to initial pre-processing of CT images, where downscaling of source images was performed. Resulting volume reconstruction from size reduced image data took significantly less memory.

The application, written in Python, can be easily extended to accommodate new functionality. For the purpose of training, implementation of transthoracic echocardiogram (TTE), 1D USG or simulating a probe with another registration pattern can be done with low effort, proving to proposed solution to be an attractive training platform.

3.2. TEE SIMULATOR DEVICE PROBE

The main hardware component of a TEE simulation platform is a probe device, depicted in Fig. 5. TEE simulation requires the information on the 3D position of the probe. The distance of the probe's head with respect to the incisors is measured by use of ultrasound distance sensor. The rotational data, pitch, yaw and roll, is calculated by processing the readings obtained from accelerometer, gyroscope and magnetometer.

The main board equipped with LPC1769 CPU (Cortex M-3 core) is shown in Fig. 6.

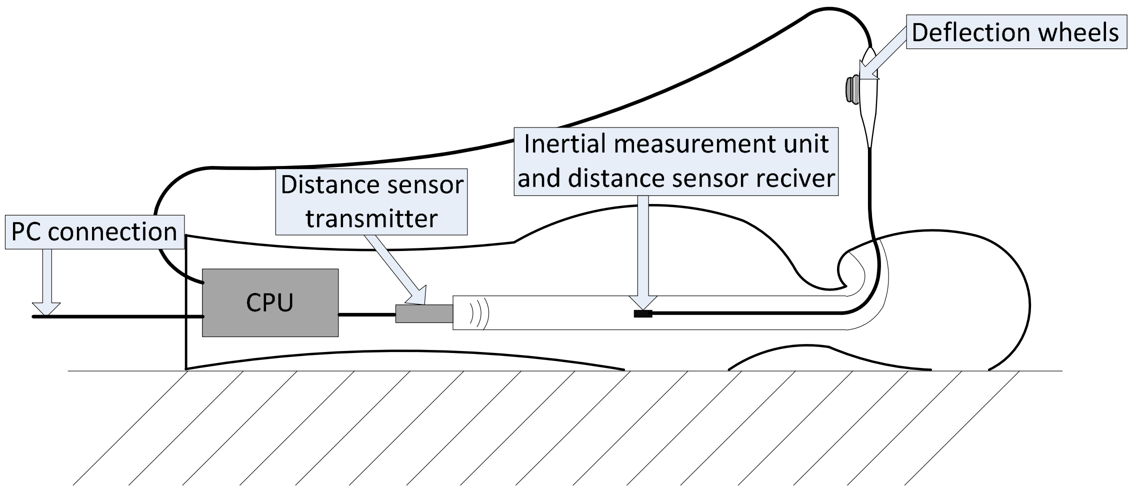

Fig. 5. Block diagram of TEE simulation device.

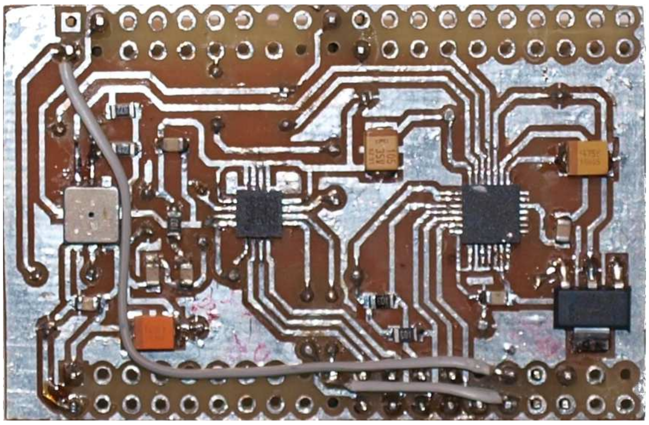

Fig. 6. Probe main circuit board.

4. CONCLUSIONS

The main goal of the both projects is to prepare technical solutions for medical applications. The proposed image fusion approach extends the diagnostic process of a patient. Merging images from CT and ECHO, both of different dimensionalities and methods of acquiring, enhances possibilities methods of non-invasive cardiac vessels inspection. Presented solution is innovative and to the best of our knowledge, has never been introduced to cardiology diagnosis techniques before. Overlaying of ECHO bull's-eye diagram on the 3D model of LV, allows for systolic function assessment to be carried out with greater precision. Presented system, with display of additional anatomical details such as vessels with luminal narrowing, is expected to increase the level of precision of heart attack predicted.

The proposed appliance for simulation of TEE is a welcome addition to the training process of medical staff and gives possibility of becoming familiar with expected USG view of the human heart before carrying out a real examination. Much care was taken for the software part of the system to be used as a platform for wider range of applications, other than TEE. Given applicable input, TTE or other image simulation techniques can be implemented as long as the CT based volumetric data contains enough information. Current work involves use of animated heart cycle sequences in the simulation process, to achieve greater realism.

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