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Short Paper

A Web-Based Tool for Cardiac Dyssynchrony Assessment on Ultrasound Data

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Abstract

Cardiac resynchronization therapy (CRT) is a broadly used therapy in patients that suffers from heart failure (HF). The positive outcome of CRT depends strongly on the parameters criteria used to select patients and a lot of research has been done to introduce new and more reliable parameters. In this paper we propose an interactive tool to perform visual assessment and measurements on cardiac ultrasound images of patient with cardiac dyssynchrony. The tool is developed as a web application, allowing doctors to remotely access images and measurements.

CCS Concepts

•***Human-centered computing*** → *Visualization systems and tools;* •***Applied computing*** → *Health care information systems;*

1. Introduction

The recent improvement of web technologies, together with the increasing popularity of cloud-based systems and connected devices, has produced a shift in the information workflow of medicine and healthcare. Web-based systems can, in fact, foster communication between individuals, easing team decision making and knowledge sharing [KBK*16]. Physicians, who are dealing with decision making process where time and accessibility of data are critical, could greatly benefit from the adoption of such paradigms. Although medical data visualization on the web has been proposed [SAO14, HRA*14], existing solutions for medical image visualization and analysis are, in most cases, desktop-based applications that require the installation of software.

The necessity to move towards web-based solutions was emphasized already in the early 2000s [EEDS*03]. The growing necessity of accessing and extracting information from distributed *big data* and the constant performance improvement of technologies and standards such as HTML5 and JavaScript engines, made the web-based approach very appealing for many medical imaging tools [HPD16]. Web-based solutions are especially appealing as they do not require to install software on the client and can run cross-platform directly inside the browser.

In this paper we introduce a web-based solution for the selection, calibration and measurement of ultrasound images. In particular, we propose an integrated environment for clinicians to obtain relevant parameters to detect cardiac dyssynchrony in heart failure patients. Using the dedicated interactive tool, doctors are able to analyse and annotate ultrasound image in order to obtain a comprehensive vision of the patient's cardiac condition.

The remainder of the paper is organized as follows: in Section 2 we will introduce the clinical background of the tool, highlighting the necessity of the proposed analysis tool. In Section 3 we will present the architecture, the technology used, and the functionalities introduced by the dyssynchrony measurement tool. Finally, in Section 4, we will discuss future development of the tool and preliminary results.

2. Background

Heart failure (HF) is nowadays one of the most widespread health conditions worldwide, affecting more than 6 million patients in Europe only [ABC*16]. It is a critical disease of the heart in which the cardiac output is reduced due to structural or functional cardiac abnormality.

Since HF can be determined by different causes, different approaches for treatments and therapies are used in medicine. These approaches range from drugs based treatments, non-surgical devices or surgeries. Non-surgical device treatments are generally represented by two principal therapies: an implantable cardioverter-defibrillator and the cardiac resynchronization therapy (CRT). Although CRT is one of the most successful heart failure therapies, only between 60% and 80% of the patients respond favourably to it depending on the selection criteria used for the patients [DSA*12]. The classic selection criteria for CRT are currently based on the clinical guidelines of the major cardiology societies, taking into account only few parameters such as left ventricle ejection fraction (LVEF), QRS duration from the electrocardiogram or the class of the New York Heart Association (NYHA) they belong to (e.g. classification of symptoms). However, this set of parameters and thresholds raises several criticism: guidelines generally use the

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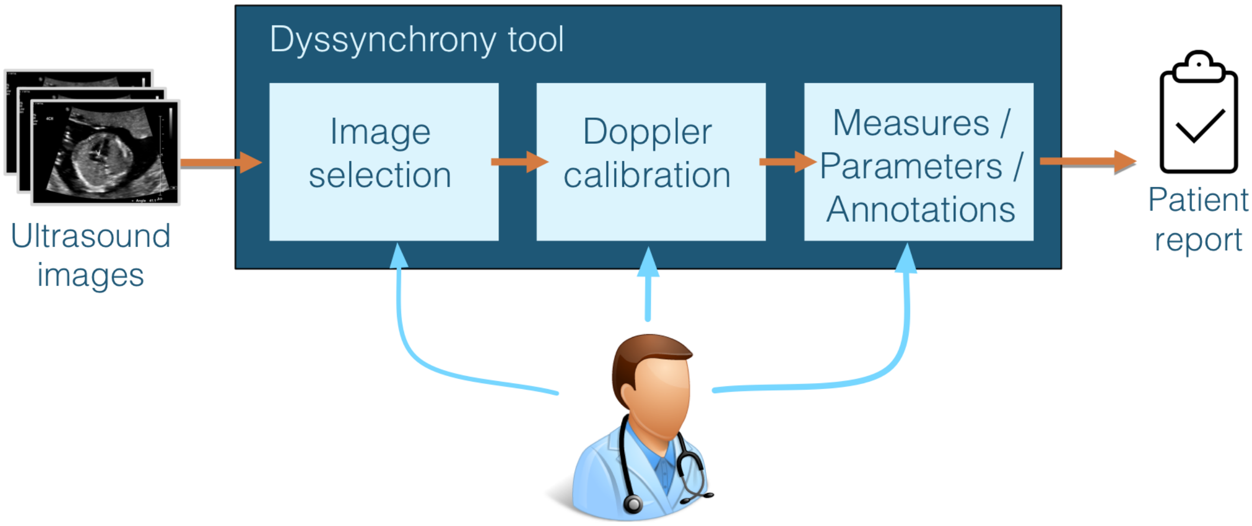

Figure 1: *Dyssynchrony tool typical workflow*

same hard thresholds for all the patients and individual parameters are sensitive to measurement noise and errors. Furthermore, since cardiac performance is a complex phenomenon, a simplification including only a few parameters is generally not representative of the patient condition.

For these reasons, a lot of research [CLT*08, PBS*08, DBT*14] has been made to propose a more precise and reliable set of parameters. These studies propose that a better prediction of the response to CRT therapy can be obtained by observing the presence of septal flash, an exaggerated left-right interaction in presence of a dysfunctional septum. To extract such information about the patient, an analysis is usually performed by visual inspection of ultrasound images including M-mode, 2D Doppler velocities, and 2D+t images. Using a dedicated image processing software tool to visualize and analyze this information, clinicians would be able to identify the type of dyssynchrony and have a better understanding of the overall cardiac condition in order to decide the best treatment for the patient.

Although many commercial ultrasound images visualization and annotations exists (i.e QLAB Ultrasound Cardiac Analysis by Phillips, EchoInsight, Ecofile), these softwares are generally meant for a general purpose usage. In this particular application, these softwares do not have an interface where to visualize jointly all the relevant ultrasound images, making it hard for doctors to assess the type of cardiac dyssynchrony and extract parameters useful to predict CRT response. In this paper we propose an integrated tool to perform dyssynchrony assessment from 2D and 2D+t ultrasound images. Using the proposed tools, doctors are able to extract relevant parameters and obtain a thorough understating of cardiac condition in HF patients.

3. Dyssynchrony tool

The dyssynchrony tool proposed in this paper allow doctors to identify the different parameters that indicate the type of dyssynchrony of the patient and therefore have a better prediction on how the patient will respond to CRT treatment. The tool takes as input a set of cardiac ultrasound images containing different types of of information (such as 2D Doppler blood flow velocities, 2D+t images) and provide the doctor with an easy to use interface to obtain a set of time calibrated cardiac ultrasound images, annotations of cardiac cycle temporal events and report of measurements of cardiac event parameters.

The tool is designed starting from a typical clinical use case of HF patient assessment. In the first stage the doctor can select relevant ultrasound images from the set of images collected during an echocardiography session. Before being able to extract relevant measures, Doppler velocity images need to be manually synchronized in terms of cardiac cycle. Finally, the doctor can perform an in-depth analysis and extract important parameters by visualizing all the relevant images and using the measurement and annotation interface implemented. The pipeline implemented by dyssynchrony tool is further described in the following subsection and summarized in Figure 1.

The proposed solution adopts a web-based architecture, enabling the doctor to import ultrasound images both from a PACS or from a local folder and to access the software through a browser, without installing any additional software.

3.1. Dyssynchrony analysis workflow

During an echocardiography session, several ultrasound images are collected. When analysing the patient condition with regards to cardiac dyssynchrony condition, only a subset of these images is necessary. On this set of images, the doctor needs to compare timing and size mesurements, so a visualization that integrate several

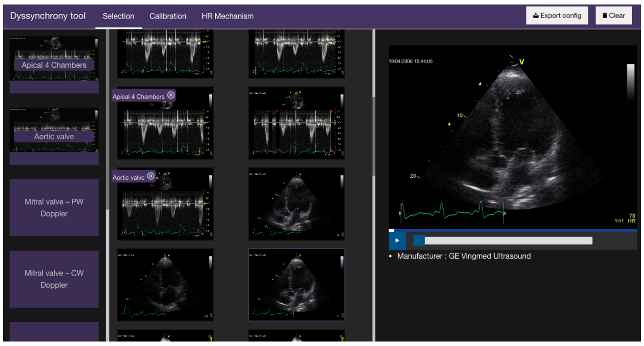

Figure 2: *Ultrasound images selection: the tool shows a preview all the images of the patient and allow the selection of the relevant ones.*

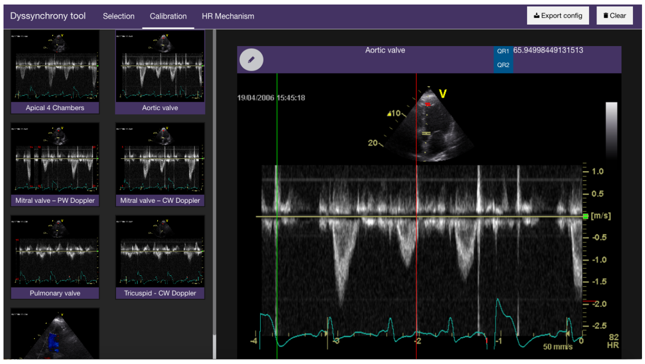

Figure 3: *Doppler calibration: the doctor annotate the beginning and the end of two cardiac cycles (green and red lines) for each image.*

views of the heart can greatly help the process. We propose a web interface that allows doctors to:

- Preview all the ultrasound images of a patient and select the relevant ones;
- Perform a calibration on the images that the same cardiac cycle can be compared;
- Visualize different differ images side by side and perform time measurements and annotation on the cardiac condition of the patient.

The first step of the the workflow implemented in the tool allows doctors to have a preview of all the collected ultrasound images and to select only those that are relevant for the assessment. Ultrasound images (generally stored in standard DICOM format), can be loaded in the tool both from a remote PACS server and from a local folder. As shown in Figure 2, the doctor can have a preview of all images and access to high resolution version by clicking on the preview of the image. The tool allows the doctor to select the relevant images using drag and drop interaction. In the proposed use case, the set of relevant images is composed by two 2D+t images (apical 4 chambers view and short axis view) and six Doppler velocity ultrasound images. The Doppler velocity images show the blood flow over time in the aortic valve, the mitral valve in continuous wave and pulsed wave modalities, the pulmonary valve and the tricuspid valve in continuous and pulsed wave modalities.

Once the images are selected, the tool proposes a calibration interface. In order to have a synchronized visualization of the different Doppler velocity images, a manual calibration needs to be performed. The doctor normally annotates one or two cardiac cycles that show important information from the patient. The tool will segment the images based on doctor's annotation in order to show only the chosen section. The interface for the calibration guides the doctor in the selection of the cardiac cycles by providing a simple annotation tool (see Figure 3).

The last step of the workflow is represented by the visual evaluation and measurement of the ultrasound images. To this end, the tool proposes an integrated visualization that shows all the relevant images and provides the user with measurements and annotation tools. A screenshot of the interface is shown in Figure 4.

Figure 4: *Dyssynchrony assessment: the tool allow to visualize all the selected and calibrated images in order to perform measurements and annotations.*

One part of the interface presents the multi frame ultrasound images (2D+t) of the apical 4 chambers and the short axis. The doctor can visualize these images using a dedicated player, see the movement during a cardiac cycle and change the speed of visualization. It is also possible to navigate through the different frames to select a specific 2D slice. By comparing these multiframe images, the doctor can see the mechanical behaviour of the patient's heart over time and consequently identify the type of dyssynchrony of the patient.

The central part of the interface is designed for the measurement of ultrasound Doppler images of the aortic, pulmonary, mitral and tricuspid valves. Images are separated in left ventricle and right ventricle and aligned accordingly to the cycles annotations added by the doctor in the calibration step. In this visualization, doctors can add manual annotations that correspond to the events of the cardiac cycle related to each valve opening and closing. Annotations are color-coded based on the different events and displayed both as vertical lines on the ultrasound images and as numeric time value in the toolbar. From these onset lines and cardiac cycle events, the cardiologist is able to obtain the measured values of the time passed from the beginning of the cardiac cycle to the different events of the cycle as well as parameters that depend on the cardiac events (e.g.

left ventricle filling and ejection time, the isovolumetric contraction and relaxation time). Tricuspid mitral difference and the interventricular mechanical delay are also displayed in the toolbar based on doctor's annotation. The doctor can also annotate the pattern of mitral filling, adding description of possible peculiarity (e.g. if the pattern of mitral filling is with short AV, the doctor can choose if the patient has a truncated A wave). Finally, the doctor can add functional mechanism parameter values such as the pressure difference over time, the end-systolic volume, the end-diastolic volume and the ejection fraction for both ventricles, or the pulmonary artery pressure (PAP).

Once collected all the relevant measurements, the doctor is able to create a report including all the values of the different parameters and the different peculiarities or characteristics in order to have a complete overview of the HF patient condition.

3.2. System architecture

The tool is developed as a web application and relies on state-of-the-art frameworks. Clinicians can access the tool using a simple web browser, without the need to install any additional software. The tool allow to perform dyssynchrony analysis sessions using both images stored on a web server and using images on the local computer of the doctor. The set of relevant ultrasound images, the annotations and measurements taken by the doctor during the analysis can be stored a database in order to be accessed in a second time or shared with other doctors. The application uses a standard client-server approach. The server side is composed by three main components:

- File system containing ultrasounds images;
- A persistent database containing annotations and metadata obtained from dyssynchrony studies;
- A computation engines to execute image processing on ultrasound images (e.g. segmentation and resampling of Doppler flows).

The client-side component of the application is developed using recents HTML5 and Javascript frameworks (ReactJS, Bootstrap), so to ensure multi browser compatibility and high performance. Ultrasound images are stored in the commonly used DICOM format (Digital Imaging and Communication in Medicine). For the visualization of DICOM images on the web, we rely on the open source framework Cornerstone [†].

The client application communicates with the server using Web API to store and retrieve metadata about the patient's study and to specific computation algorithms on the ultrasound images (i.e. segmentation and resampling). DICOM images are transmitted to the end-user using the WADO protocol (Web Access to DICOM Object) [KL06].

4. Discussion and conclusion

In this paper we presented a web based interface for cardiac ultrasound image visualization and analysis. The tool allows clinicians to visualize 2D+t images and 2D Doppler velocity images to measure blood velocity through different valves in the different time instants of the cardiac cycle. With this tool, clinicians can obtain valuable measurements to detect the type of dyssynchrony of the patient, which will help them decide on the therapy that fits better the patient needs. The tool has been tested in 50 prospective cases of HF within an EU founded project, and encouraging feedback has been collected by clinicians. In particular, clinicians gave positive value to the web-based approach adopted by the tool. Future developments of the tools include the implementation of a visualization of M-Mode ultrasound images. These type of images could in fact give the clinician more information about the heart condition and also a better understanding of thse type of dyssynchrony. Furthermore, we plan to integrate the data obtained from the use of the dyssynchrony tool as an input for machine learning algorithms tools to produce predictions based on parameters and measurements obtained from the patient.

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