Harvard College Research Project Final Report

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Project: Classification of Mitral Valve Component Dimensions
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Introduction

Every time the heart beats, the two upper chambers of the heart known as atria contract, pushing blood down into two larger chambers below called ventricles. Deoxygenated blood is then pushed out of the right ventricle into the lung tissue to be oxygenated and freshly oxygenated blood is pushed out of the left ventricle around the body. In order to ensure that blood never flows in the wrong direction, the heart has four valves that open and close in pairs; however, these valves can malfunction and cause serious problems. One of the most common heart valve malfunctions is regurgitation in which a valve fails to close completely and allows blood to flow backwards, reducing the amount of blood that actually gets pumped out of the heart per beat. The mitral valve, which separates the left atrium from the left ventricle, is the site of most cases of valve regurgitation.

In a well-functioning heart, freshly oxygenated blood flows through the mitral valve from the left atrium into the left ventricle where it can then be pumped around the body. The mitral valve is composed of leaflets which open to allow flow into the left ventricle. Once the left atrium has been emptied, the leaflets seal shut, and the heart's papillary muscles pull on tendons called chordae that keep the leaflets taut. When valve regurgitation prevents this, patients can experience shortness of breath, chest pain, pulmonary hypertension, and even heart failure.

Depending on the severity of symptoms, surgery can be necessary to repair or replace the valves. Unfortunately, while a common surgery, the surgical methods of repairing mitral valves are difficult to execute. Therefore, determining how to provide cardiac surgeons with tools to plan these surgeries and execute them with optimal accuracy is an issue of interest to biomedical engineers and computer scientists.

The Harvard Biorobotics Lab at the John A. Paulson School of Engineering and Applied Sciences is currently engaged in such a project. To this end, Visiting Professor, Pierre-Frederic

Villard is using computer graphics and image analysis techniques to create and biomechanically accurate 3-D computational models of the heart and its valves. Since the surgical utility of these 3-D computational models is dependent on their accuracy, I joined the project this September with the aim of classifying each of the mitral valve components to determine its influence on overall valve function. Due to time constraints, my project ultimately focused on mitral valve chordae only rather than the chordae and leaflets.

Project Details

The mitral valve has roughly 50 chordae, each with different diameter and strategic position, so the goal of project was to implement a method for extracting chordae diameter from CT slides in order to find the minimum chordae diameter that would significantly influence simulation results. The process that Prof. Villard and I developed for extracting this feature was heavily influenced by the thesis of Dr. Ahmed Yureidini, *Robust blood vessel surface reconstruction for interactive simulations from patient data*.[1] Yureidini offers a 3-part model for computer-based anatomical reconstruction consisting of 1) RANSAC, 2) ray-casting, and 3) cylinder estimation. The majority of my algorithm focuses on the second step, ray-casting, which is a 3-D rendering technique in computer graphics that allowed us to obtain the boundary points of each chordae, and therefore, each diameter. The algorithm works as follows. First, the CT scan slide images are loaded and the set of consecutive slides with the best views of chordae are selected. From there, the user is prompted to select two points at either end of the chordae (Fig. 1). From these two points, a centerline is determined and eight vectors, or "rays", are cast out from 10 evenly spaced points along the centerline (Fig. 2). The gradient with reference to pixel intensity is then calculated along each of these, and by using a threshold value for black pixels, the points that form the chordae boundary are

[1] Robust blood vessel surface reconstruction for interactive simulations from patient data, Ahmed Yureidini, PhD Thesis, 2014 (https://tel.archives-ouvertes.fr/tel-01010973/file/Thesis_Ahmed_Yureidini.pdf), chapter 3

determined. Once obtained, these points can be plotted alone (Fig. 3) or superimposed onto the original image as a check (Fig. 4). This process is repeated for each step until a large cloud of points is obtained which would be the basis for an approximate cylinder model of the chordae. This model will be further optimized during the RANSAC step – an iterative, statistical method that removes outliers in order to estimate the true parameters of a model – in this case, the chordae.[2]

Conclusion and Takeaways

I was enthusiastic to begin this project, and that enthusiasm lasted the entirety of the project. I felt my confidence and knowledge of MATLAB, computer vision and graphics, and programming best practices grow exponentially during this semester with Dr. Villard. Many aspects of the project proved to be more difficult than anticipated, and as a result, my implementation was not as ambitious as originally proposed; however, I hope that what I was able to accomplish will prove useful to Dr. Villard in his future simulation work. Looking forward, this project has helped solidify my interest in a post-graduate career that combines medicine and computer science research. In the coming spring semester, I plan to supplement my schedule with SEAS electives that will strengthen skills I've encountered this semester.

Without the support from HCRP, I would have had to work throughout this semester and miss out on this experience. I'd like to thank Dr. Villard, Mr. Degirmenci, Mr. Loschak, Dr. Howe, SEAS, and HCRP for this opportunity to delve into an area of interest and gain hands-on experience solving a really meaningful problem. I am incredibly grateful.

[2] Derpanis, Konstantinos G. "Overview of the RANSAC Algorithm." (2010): n. pag. EECS York University Keele, 13 May 2010. Web. 15 Jan. 2016.

Figures

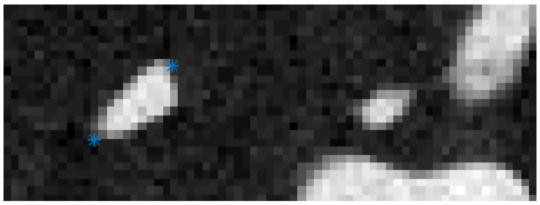

Fig. 1

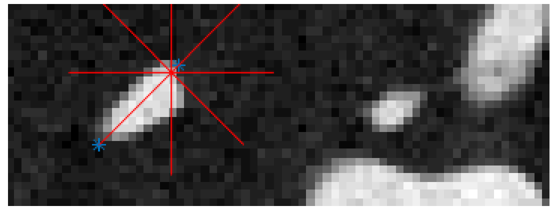

Fig. 2

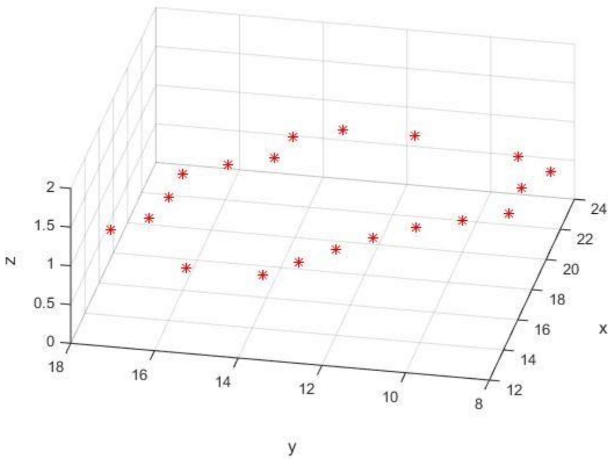

Fig. 3

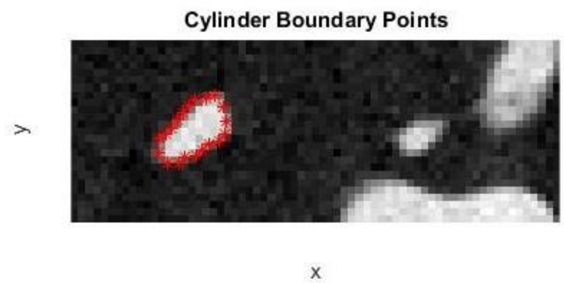

Fig. 4