PhD INRIA 2016

Title:
Image-based Biomechanical Simulation of Mitral Valve Closure

- **Location:** INRIA Nancy research center - France

- **Research theme:** (Among the five themes Applied Mathematics, Computation and Simulation , Algorithmics, Programming, Software and Architecture, Networks, Systems and Services, Distributed Computing, Perception, Cognition, Interaction, Computational Sciences for Biology, Medicine and the Environment)

Perception, Cognition, Interaction
- **Project-team:**
MAGRIT

- **Scientific Context:**

The MAGRIT project-team research aims at proposing robust solutions to issues faced in augmented reality. We are particularly involved in medical applications, where 3D models are extracted from patient-based images.

We are interested in modeling Heart valves. They ensure the one-way flow of oxygenated blood from the left atrium to the left ventricle. However, many pathologies damage the valve anatomy producing undesired backflow, or regurgitation, decreasing cardiac efficiency and potentially leading to heart failure if left untreated.

Such cases could be treated by surgical repair for the valve. However, it is technically difficult and outcomes are highly dependent upon the experience of the surgeon. One of the main difficulties of valve repair is that valve tissues must be surgically altered during open heart surgery such that the valve opens and closes effectively after the heart is closed and blood flow is restored. In order to do this successfully, the surgeon must essentially predict the displacement and deformation of anatomically and biomechanically complex valve leaflets and supporting structures.

One way to facilitate the repair is to simulate the mechanical behavior of the pathological valve with patient-specific data.

- Missions: (objectives, approach, etc.)

The aim of this project is to develop a technology for patient-specific heart valve model for surgical operation planning and scientific understanding. Such models have been already studied in the literature. However, these models were based on simplified geometries, dependent of many manual interactions and not fully validated [1, 2, 3 and 4]. The objective of this PhD is to realistically simulate the valve closure based on segmentation methods faithful enough to model real anatomical geometries and based on biomechanical model appropriate enough to model the accurate valve behaviour .

The PhD work involves two interconnected components: image processing (in order to segment every valve component geometries) and biomechanical modeling (in order to simulate the mechanical behavior of the valve closure). One of the leading ideas is using constrains to extract features corresponding to the valve anatomy such that the 3D model is mechanically valid.

The segmentation will more specifically consist in extracting thin flat structures and thin cylinders from 3D CT scans using model-based detector like in [5]. The valve topological separations between leaflets and the corresponding coaptation surface will also need to be estimated. The method will first be tested on the 10 cases of mitral valves that have already been scanned and check if it is generic enough to be applied on more dataset. A dataset include 3D CT scans of a close and of a open valve.

The biomechanical simulation will include the study of both the boundary conditions and the mechanical parameters. The valve anisotropy is defined by the collagen fiber directions that should also be studied similarly to [6] but by extracting the directions from the image. Validation criteria will need to be defined in order to check if the simulation is valid and accurate enough. For instance, a metric should indicate if their is no leak when the valve is close and pressurized. The idea is to use the latter information to monitor the segmentation such as the extracted features satisfy this condition.

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- **Bibliography:** *(if any)*

[1] Kunzelman K, Einstein D, Cochran R. Fluid–structure interaction models of the mitral valve: function in normal and pathological states. Philosophical Transactions of the Royal Society of London B: Biological Sciences 2007; 362(1484):1393–1406, doi:10.1098/rstb.2007.2123.

[2] Wang Q, Sun W. Finite element modeling of mitral valve dynamic deformation using patient-specific multi-slices computed tomography scans. Annals of Biomedical Engineering 2013; 41(1):142–153, doi:10.1007/s10439-012-0620-6. URL http://dx.doi.org/10.1007/s10439-012-0620-6.

[3] Prot V, Haaverstad R, Skallerud B. Finite element analysis of the mitral apparatus: annulus shape effect and chordal force distribution. Biomechanics and Modeling in Mechanobiology 2009; 8(1):43–55, doi:10.1007/s10237-007-0116-8. URL http://dx.doi.org/10.1007/s10237-007-0116-8.

[4] Hammer P, del Nido P, Howe R. Anisotropic mass-spring method accurately simulates mitral valve closure from image-based models. Functional Imaging and Modeling of the Heart, Lecture Notes in Computer Science, vol.6666, Metaxas D, Axel L (eds.). Springer Berlin Heidelberg, 2011; 233–240, doi:10.1007/978-3-642-21028-0 29. URL http://dx.doi.org/10.1007/978-3-642-21028-0_29.

[5] 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

[6] Sacks, M.S., Smith, D.B.: Effects of accelerated testing on porcine bioprosthetic heart valve fiber architecture. Biomaterials 19(11) (1998) 1027–1036

- **Skills and profile:**

Required qualification: Master *computer science*

Skills :

image processing

biomechanical simulation

- **Additional information:**

This project is included in a collaboration environment with the Harvard Biorobotics Lab and the Boston Children's'hospital.

Supervision and contact:
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Additional links:

Duration: 3 years
Starting date: between Sept. 1st 2016 and Jan. 1st 2017
Salary: 1 957 euros gross monthly (about 1 600 euros net) during the first and the second years. 2 058 euros the last year (about 1 680 euros net).

The required documents for applying are the following:
- CV;
- a motivation letter;
- your degree certificates and transcripts for Bachelor and Master (or the last 5 years if not applicable).
- Master thesis (or equivalent) if it is already completed, or a description of the work in progress, otherwise;
- all your publications, if any (it is not expected that you have any).
- At least one recommendation letter from the person who supervises(d) your Master thesis (or research project or internship); you can also send at most two other recommendation letters.

The recommendation letter(s) should be sent directly by their author to the prospective PhD advisor (with cc to Sylvain.Lazard@inria.fr).

All the documents should be sent in at most 2 pdf files; one file should contain the publications, if any, the other file should contain all the other documents. These two files should be sent files to your prospective PhD advisor (in addition to the application on the web).