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Non-Invasive Assessment of Cardiac Aortic Mechanics

Introduction

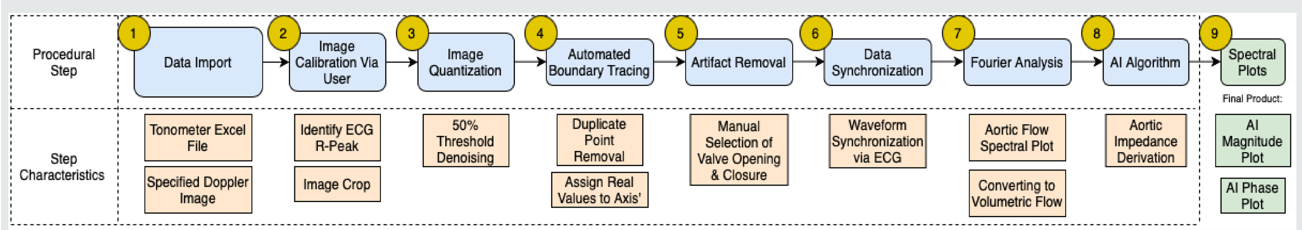
The CTC conducts medical care and assessments for various patients who have genetically triggered Aortopathy. Patients with genetic disorders (abnormal protein structure) are prone to aortic aneurysms that can result in the rupture of aorta, leading to large internal bleeding that could prove fatal. The current method of non-invasively assessing a patient's risk of aortic rupture is by monitoring the size of the aorta, using medical equipment. However, this method does not consider various health, genetic and lifestyle factors that could be affecting the patient. The team was tasked with developing a means of non-invasively assessing aortic mechanics in these patients to monitor their risk for aortic rupture, using various sets of data acquired by medical equipment.

The project will involve Pulse Wave Doppler Echocardiography, Carotid Arterial Tonometry and Speckle Tracking Echocardiography as the three main acquisition systems. These systems will provide the team with the various datasets, including aortic flow, arterial blood pressure and aortic strain, respectively. In addition, each of these acquisition systems will provide separate Echocardiographic (ECG) data, that will be utilized to synchronize the various datasets.

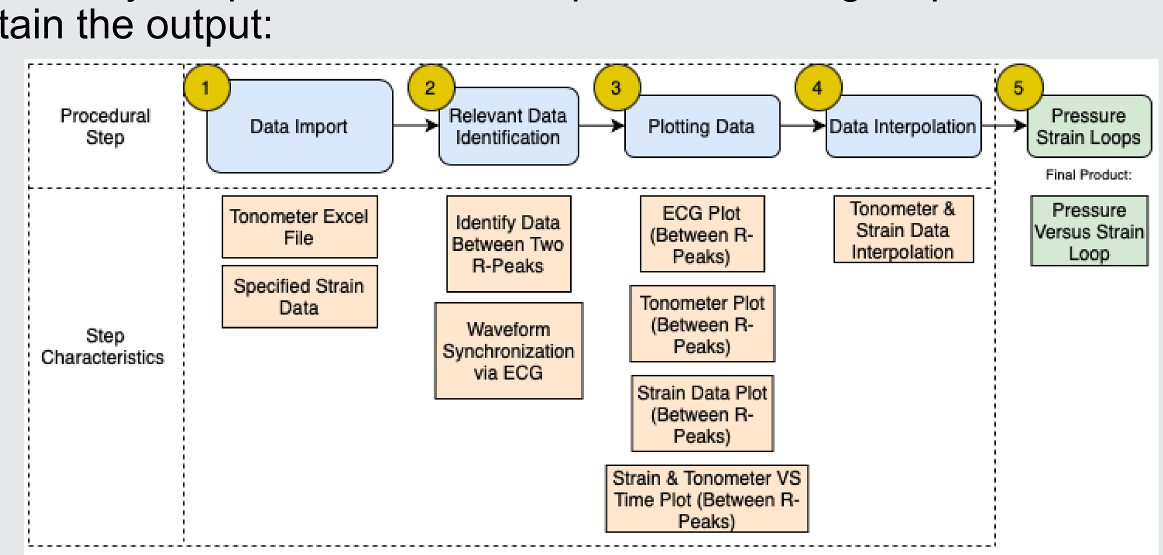
The team utilized MATLAB to design a custom image processing algorithm to analyze the Doppler Wave images as well as integrate the Tonometer data with the purpose of deriving Aortic Impedance. In addition, the team developed an algorithm that utilizes the Tonometer and Strain data in order to construct Pressure Strain loops. These are the two main deliverables given to the team by the CTC. These deliverables will provide the cardiologists with useful information on the mechanics of the aorta, which will be used to assess the patient's need for surgery.

Design Process

1) Aortic Impedance – This is the first of the two main deliverables. The main output is the ***'Aortic Impedance Magnitude Vs Harmonic Number'***. This plot includes the first 10 harmonics, requested by the supervisors. The following steps were used to obtain the output:



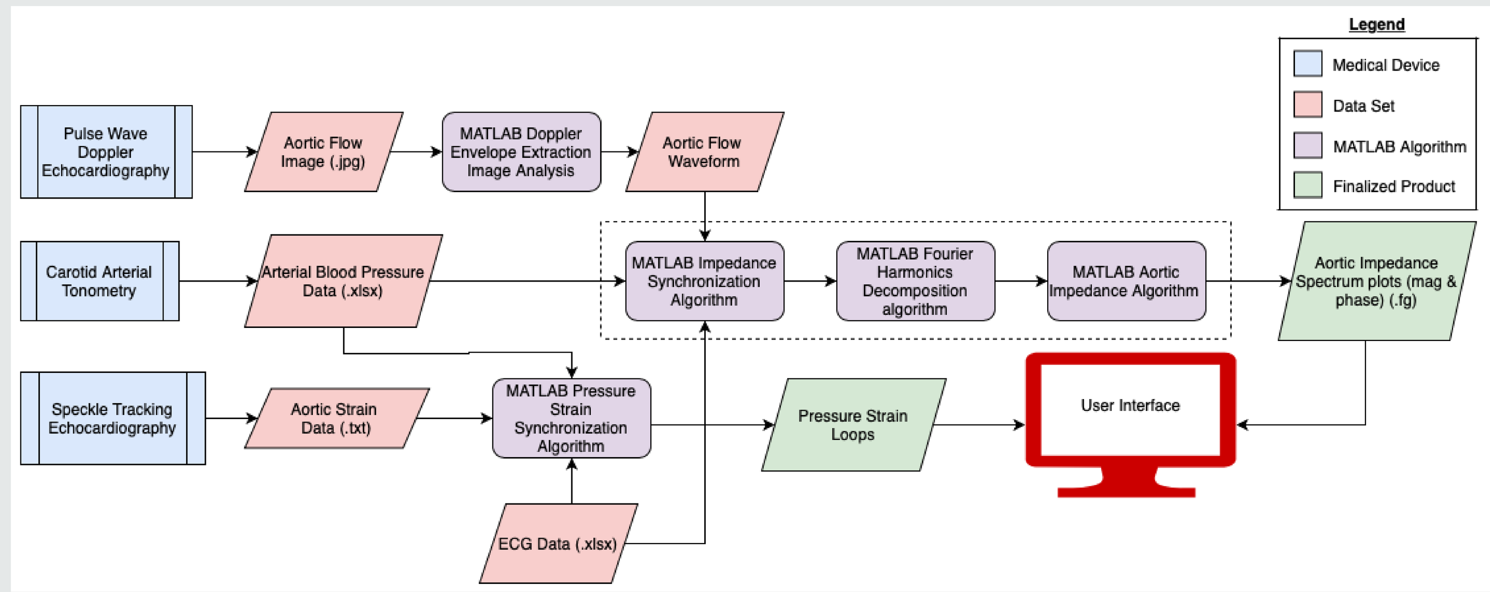
2) Pressure Strain Loops – This is the second main deliverable. The main output required is the ***'Pressure Vs Strain'*** plot which is essentially the pressure strain loop. The following steps were used to obtain the output:



All procedures are completed autonomously with a friendly 'User-Interface' present throughout the steps of the processing program.

Detail of Design

The following *System Architecture* was utilized in order to complete and provide the ***Connective Tissue Clinic*** with the proper tools to assess the mechanics of the aorta.



Secure

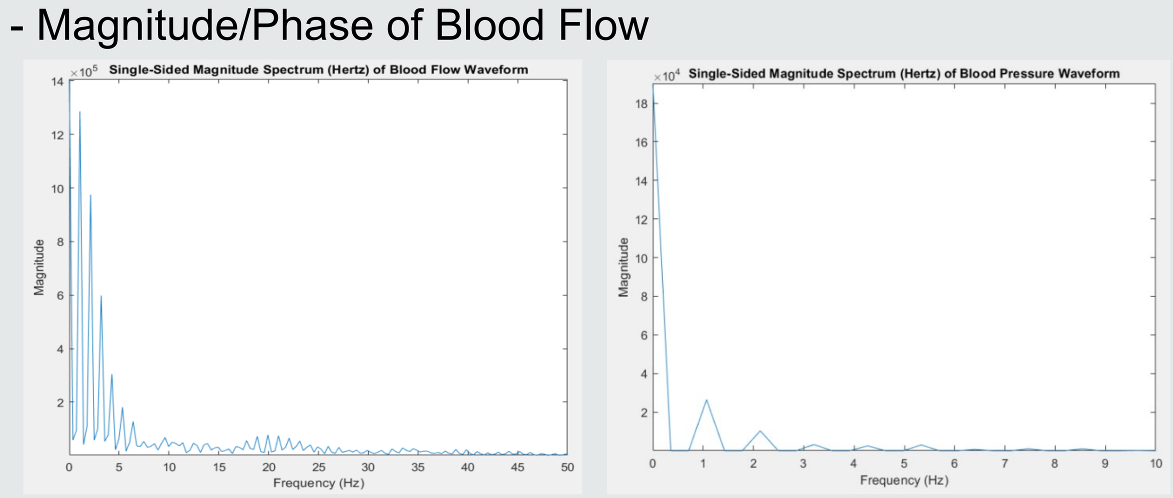
Easy to Trouble Shoot

Key Info

1) Aortic Impedance Spectra

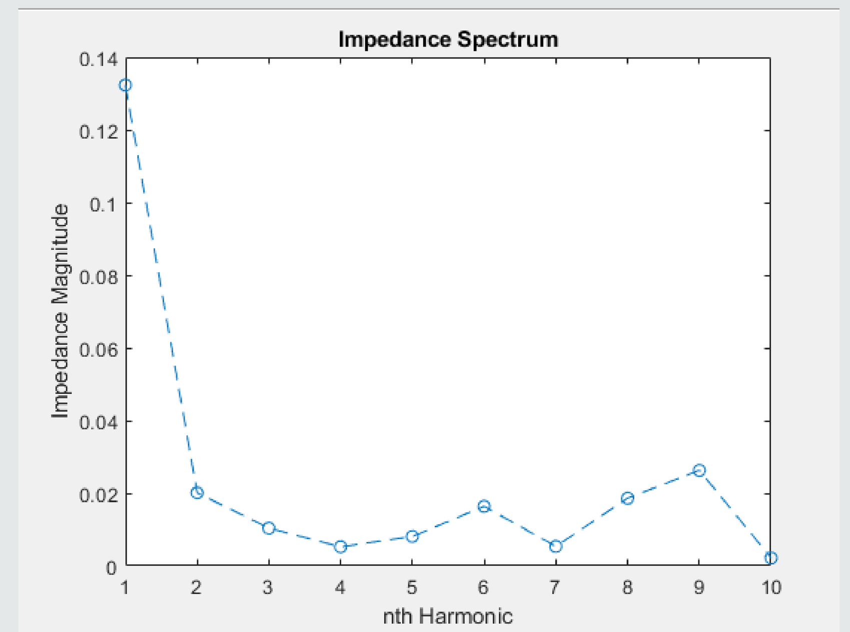
From the two data sets, the following plots are created:

- Aortic Impedance Magnitude Vs Harmonic Number
- Magnitude/Phase of Blood Pressure
- Magnitude/Phase of Blood Flow



In order to calculate the impedance, the following equation is utilized:

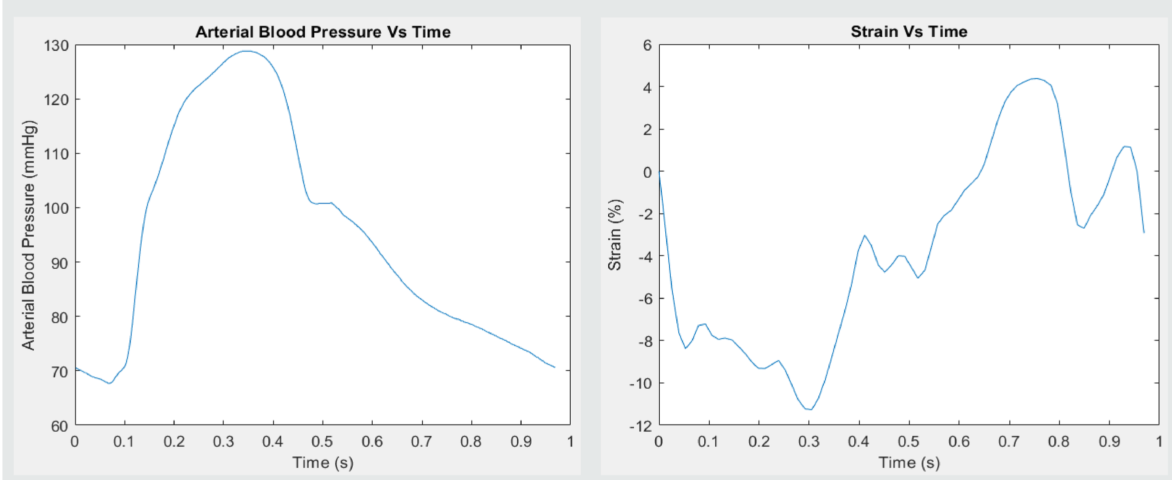
$$Z_n = \frac{P_n}{Q_n} = \frac{Aortic\ Pressure}{Aortic\ Flow}$$



2) Pressure Strain Loops

The finalized *'Pressure Strain Loop'* is produced from the two following plots:

- *Arterial Blood Pressure Versus Time*
- *Strain Versus Time*



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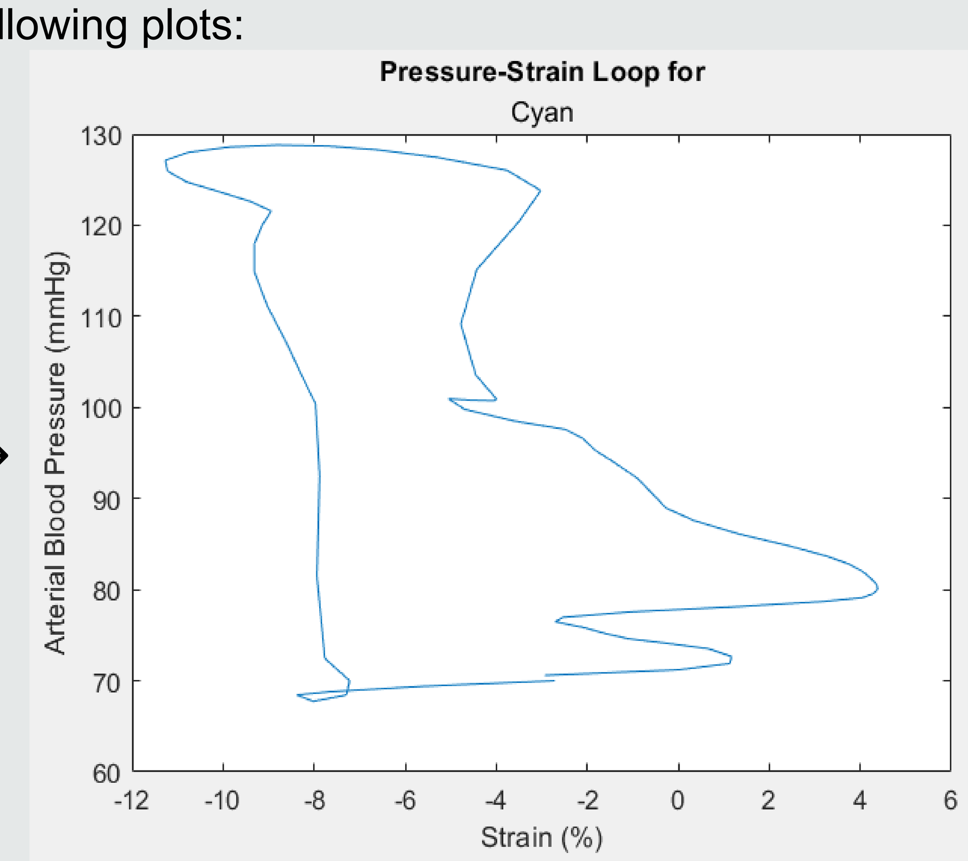
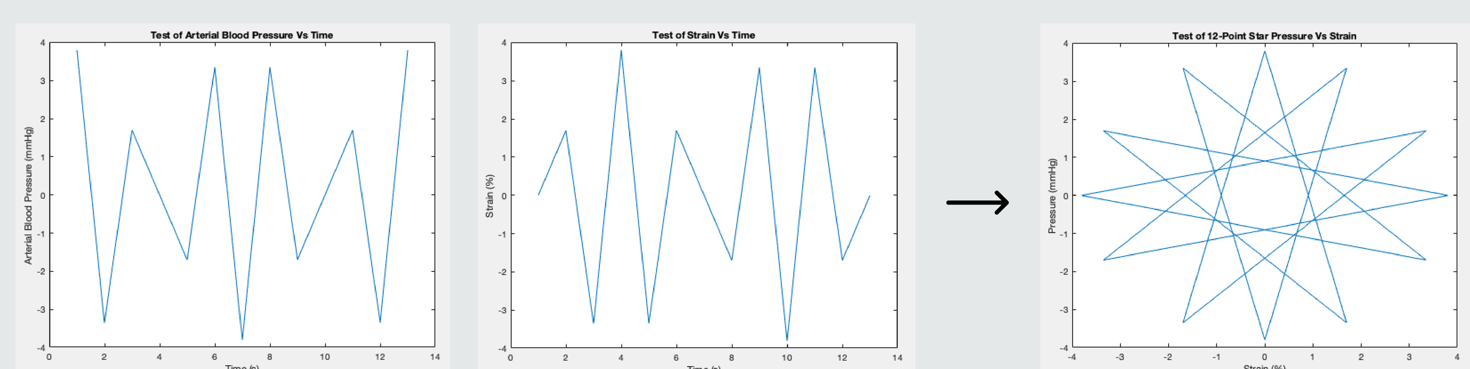


User Friendly → Auto-nomous → Simple to the Point

Testing & Validation

In order to validate the pressure strain loop algorithm, the team developed an arbitrary data set from the image of a '12-Point Star'. The following were the results:



Conclusion & Recommendations

In recent studies conducted at the Connective Tissue Clinic, the importance of cardiac aortic assessment, especially regarding aneurysms, has grown drastically. The goal of the project was to promote accurate assessment, evaluating effective treatments, medications, or forms of help to patients based on the results of their specific assessment. During the research phase, the team reviewed the technical aspects of the project, creating various methods for deriving the final product. Initially, the team experimented with various methods for deriving the aortic impedance which included the utilization of ImageJ for denoising and removing artifacts, and LabVIEW for performing Fourier analysis, and calculating aortic impedance. It was concluded that using multiple software's requires a lot of manual work. The group focused on more autonomous methods to meet the supervisor's requirements. Upon further investigation with the provided data, the team agreed upon utilizing MATLAB as the only external software used for the development of the required algorithms.

The team has developed and finalized two MATLAB scripts. One is responsible for deriving the aortic impedance spectra and the other for constructing the aortic pressure strain loops. Using various functions within MATLAB, the programs can provide necessary user interaction, while autonomously processing the input datasets, performing the necessary calculations, finally exporting the desired plots.

For future work, the team will be conducting testing of the aortic impedance as well as fine tuning the MATLAB scripts. The team is wishes to closely monitor the effectiveness of the scripts and are open to providing future updates to further support the needs of the external supervisors.

Overall, the project turned out to be a huge success, with various principal concepts covered. The group successfully managed to meet all project requirements, satisfying the needs of the Connective Tissue Clinic.

References

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Kathpalia, A., Karabiyik, Y., Eik-Nes, S. H., Tegnander, E., Ekroll, I. K., Kiss, G., & Torp, H. (2016). Adaptive Spectral Envelope Estimation for Doppler Ultrasound. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control*, 63(11), 1825–1838. https://doi.org/10.1109/TUFFC.2016 .2587381

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