ECG-Gated High Frame Rate Echocardiography with Respiratory Motion Correction

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Introduction

The Verasonics Vantage™ is a state-of-the-art ultrasound system used in High Frame Rate (HFR) Contrast Enhanced (CE) echocardiography research[1] to visualise the myocardium. However, two major sources of variability perturb the accuracy of physiological observation: **non-rigid motion** due to heart pumping and **rigid motion** due to breathing.

Current clinical cardiac CE systems are ECG-triggered to remove non-rigid motions – a feature currently lacking in the Verasonics systems. Moreover, clinicians rely on patients to hold their breath to account for rigid breathing motion, however this can be problematic for those with compromised respiratory function.

Accordingly, this project aims to achieve:

•**Real-time ECG-gating** to Verasonics Vantage™ system

•Develop an **image processing** method to correct **breathing artefacts** in MATLAB.

Medical Background

Myocardial contrast echocardiography (MCE) is a non-invasive ultrasound imaging modality ubiquitous in diagnostic cardiology. The present generation of contrast agents are microbubbles, which are administered as a continuous intravenous infusion, such that signal intensity reflects myocardial blood volume. An ultrasonic pulse is triggered to destroy the microbubbles, and their subsequent replenishment in the myocardium reflects myocardial blood velocity. The product of myocardial blood volume and myocardial blood velocity quantifies myocardial blood flow. Hence MCE can be used to diagnose **coronary artery disease** (CAD).

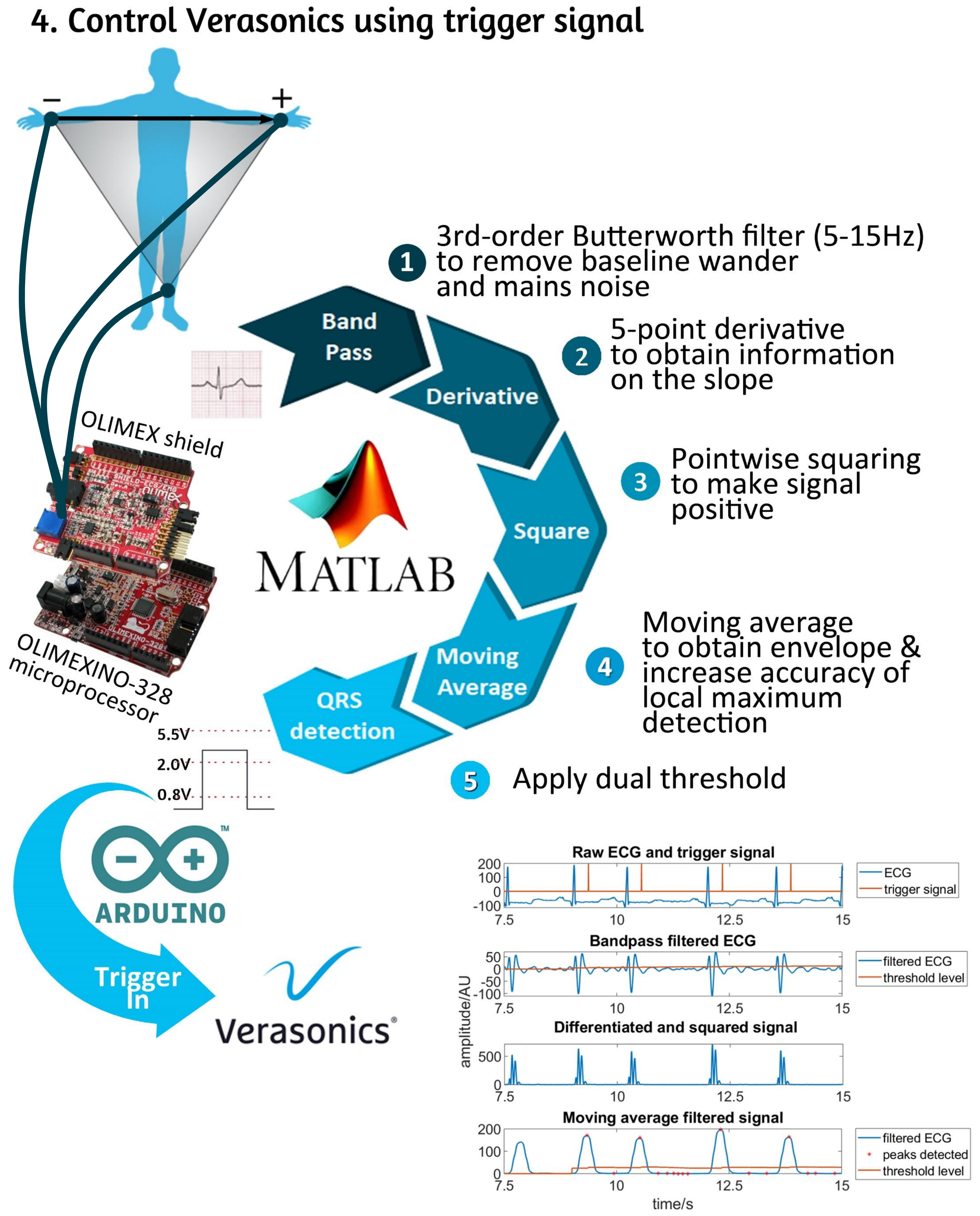
For the detection of CAD, end-systolic images of the heart obtained at rest and under stress are compared. The microbubbles replenish in 5 seconds at rest, and in 1 second if maximal hyperemia is achieved using a vasodilator. Thus, images acquired 5 seconds after microbubble destruction at rest should be the same as those acquired at 1 second after destruction when under stress. Lack of this finding could indicate the presence of CAD. For stress testing, vasodilators are usually preferred over dobutamine due to absence of tachycardia and tachypnea-induced cardiac motion, allowing easier image interpretation. Application of the ECG-gating with breathing motion correction should **remove motion artefacts** induced by dobutamine, enabling better image interpretation and comparison, giving clinicians more options.

Methodology

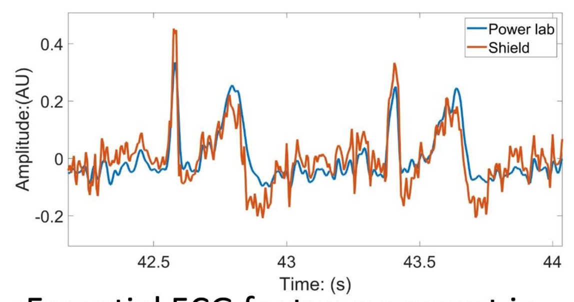
ECG-Gating

To achieve ECG gating:

1. Acquire ECG signal using ECG shield & microprocessor
2. ECG signal is processed using Pan Tompkins Algorithm [2] to locate QRS peaks in real time
3. Output is used by same microprocessor to generate trigger
4. Control Verasonics using trigger signal



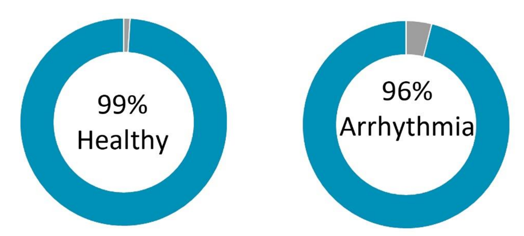
Evaluation of ECG Shield



•Essential ECG features present in both signals from ECG front end & PowerLab (a high performance data acquisition hardware)

•994 QRS peaks obtained with ECG shield & 1374 peaks with PowerLab used in evaluation

Success Rate of Pan-Tompkins



112298 QRS peaks from MIT-BIH arrhythmia database & 1215 QRS peaks from ECG ID database is used in evaluation

Respiratory Motion Correction

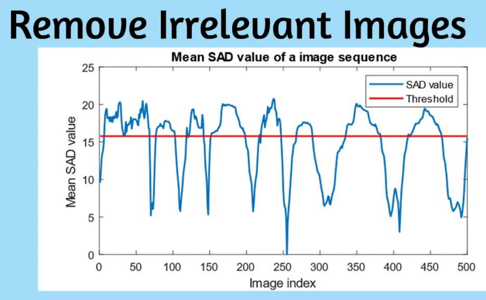
Pre-Processing

Input Image Sequence

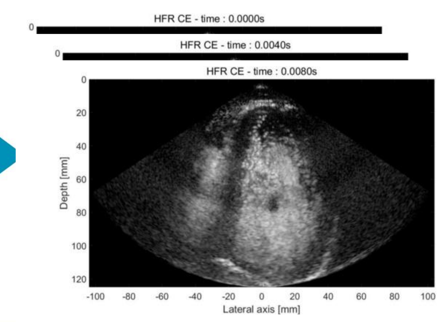
3x3 Gaussian Filter

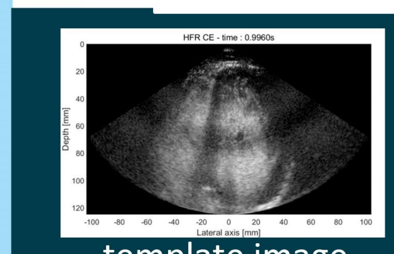
Select Template Image

Remove Irrelevant Images



Based on SAD (Sum Absolute Difference) & setting a threshold [3]





template image based on image index 250

Rigid Motion Correction

Centroid Realignment

Based on the largest convolution result of images and a binary mask to correct translational motions

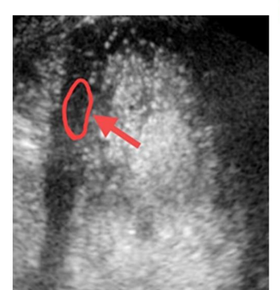
Determine Search Space

Image Registration

Output Image Sequence

Crop image to only include the heart

MI [4] (a similarity criteria) based image registration corrects both translational & rotational motions



Evaluation

ROI (region of interest):

Manually select a region on myocardial wall

TIC (time-intensity curve):

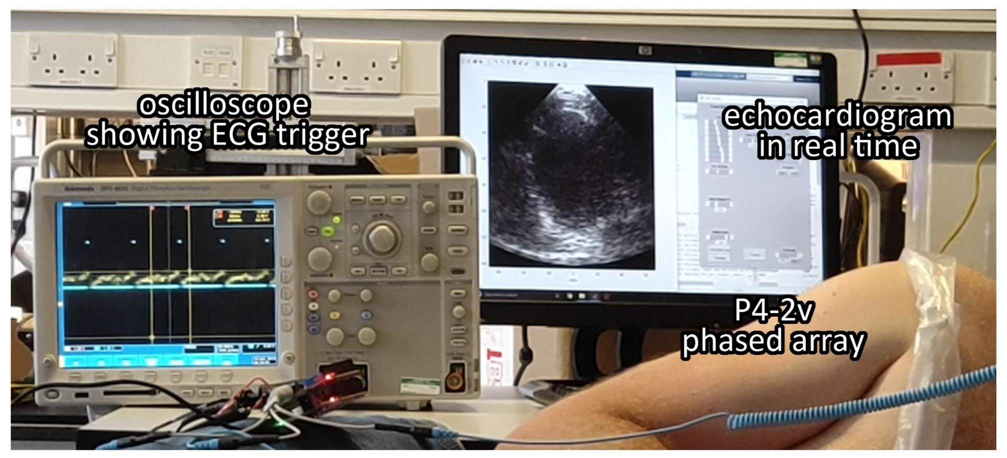
represent intensity change in ROI over time, & suppression of fluctuation on it qualitatively indicates the effectiveness of methods above

QOF (quality-of-fit)

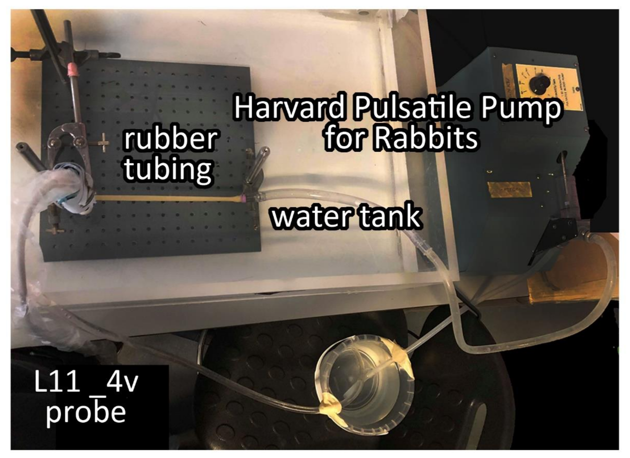
quantitatively show how much methods above remove the respiratory artefacts in TICs.

Evaluation Approaches

Set-up of human experiment



Set-up of phantom

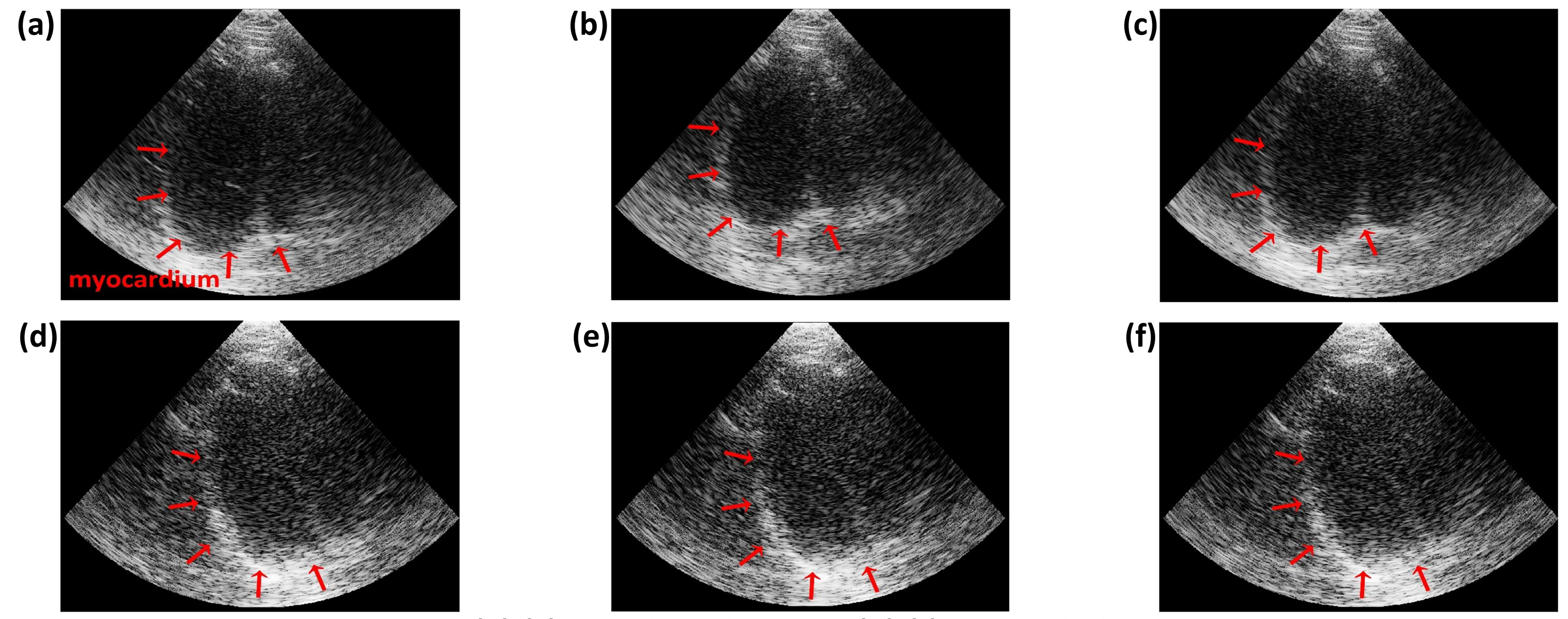


• pulsatile pumping of water through rubber tubing at 60 bpm to simulate non-rigid deformation

•translational motion simulated by manually moving the tube

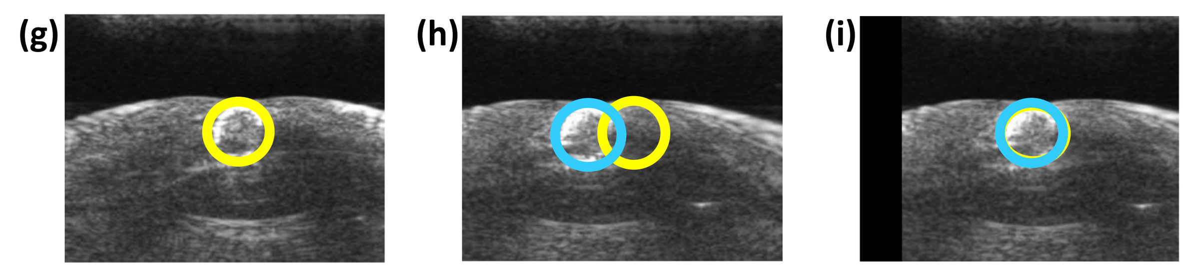
Results

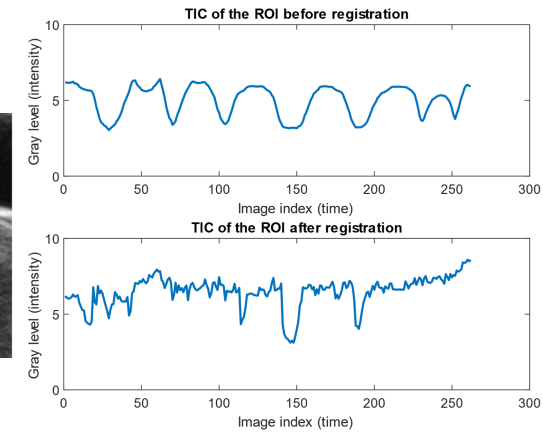
Test 1 – ECG-gated Echocardiography



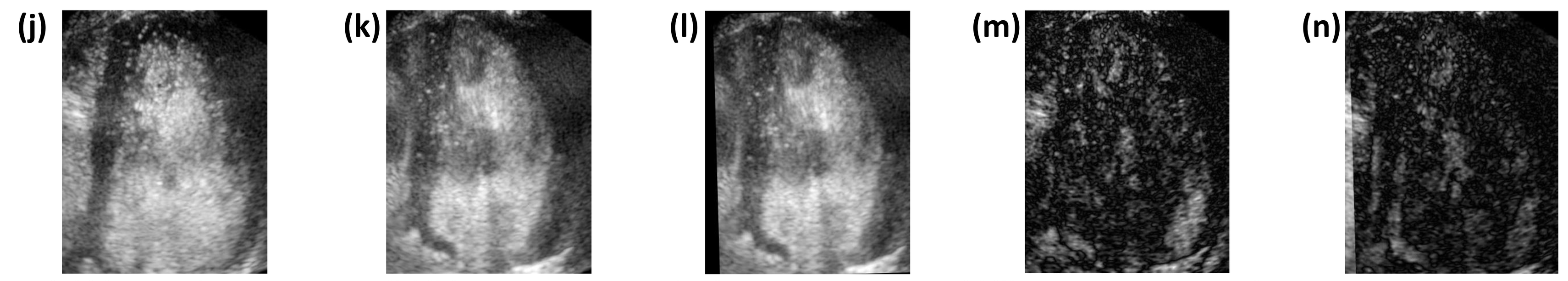
(a)-(c): Free-breathing (d)-(f): Breath-holding

Test 2 – Phantom Test

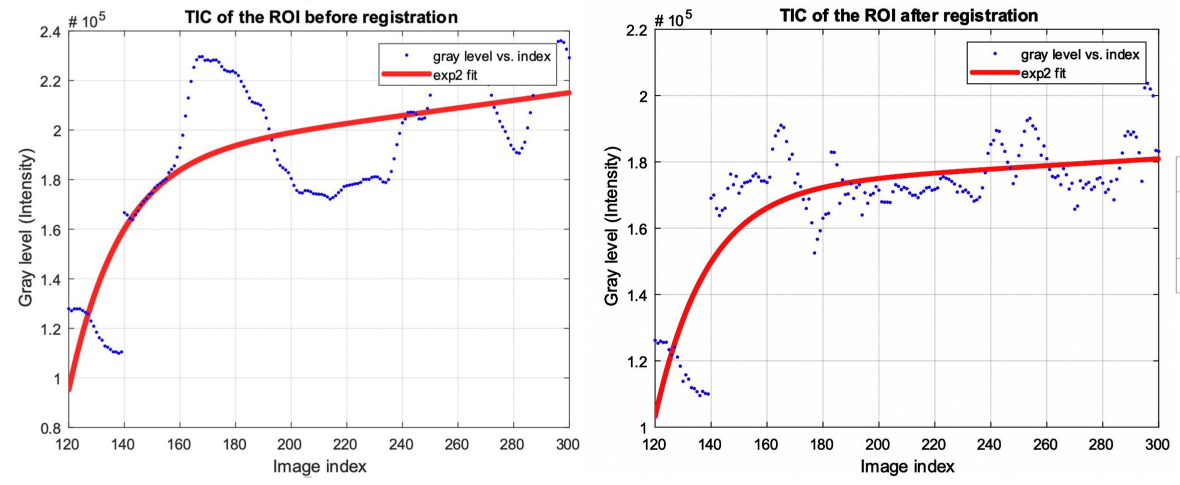




Test 3 – Cardiovascular Video



(g)(j) template image (h)(k) moving image before correction (i)(l) moving image after correction
(m) difference between (j) & (k) (n) difference between (j) & (l), has less white area than (m)



QOF		
Before correction	After correction	Improvement (%)
58.52	65.53	12.13

Conclusion

- ECG gated image acquisition on Verasonics is successfully achieved
- Removal of breathing motion is achieved using the proposed image processing method (indicated by decrease in variation of TIC curve & increase in QOF)
- **Future work:**
  1. Use **2-channel ECG** to detect multiple feature points
  2. Other pre-processing methods, e.g. discrete wavelet transform can be explored to **reduce trigger delay**
  3. Improve accuracy of **automated boundary drawings**
  4. Optimise **MI image registration speed**
  5. Imaging using higher voltage and multiple angles can also achieve **better image quality** for quantitative assessment.

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References

[1]Lepper, W. et al. (2004). Myocardial Contrast Echocardiography. *Circulation*, 109(25), pp.3132-3135.
[2]Pan, J. and Tompkins, W. (1985). A Real-Time QRS Detection Algorithm. *IEEE Transactions on Biomedical Engineering*, BME-32(3), pp.230-236.
[3] Zhang, J. et al. (2011). Respiratory motion correction in free-breathing ultrasound image sequence for quantification of hepatic perfusion. *Medical Physics*, 38(8), pp.4737-4748.
[4] Rognin, N.G. et al. (2014). A new approach for automatic motion compensation for improved estimation of perfusion quantification parameters in ultrasound imaging