Motion Estimation from 3D Cardiac Images

Interim Report 2019-2020

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ABSTRACT

Coronary Heart (Artery) disease diagnosis and prognosis can be advanced with the help of applying AI(Deep Learning Models) in Cardiac Motion Estimation.

Motion Estimation from 3D Cardiac Images is the goal of this project. As the name suggests, the input to our final application will be cardiac images (2D and 3D). For this purpose, a sequence of images which display the motion of a heart with respect to time are considered. The output of our final application will be the estimated movement of heart during its motion in all the directions during its contraction and relaxation phases. The other advantage of this application is computation of blood (fluid) flow through arteries.

The purpose of fluid flow computation is to figure out the presence of cholesterol plaques(if any) as well as blood clots in arteries.

1 . Introduction

Coronary heart disease(CHD) also called as coronary artery disease(CAD), is an important type of Coronary Vascular Disease(CVD),causing more than 20% of deaths all around the world.

The coronary arteries run along the surface of the heart and provide oxygen-rich blood to the heart muscle[7].

Over the years, cholesterol plaques can narrow the arteries supplying blood to the heart. The narrowed arteries are at higher risk for complete blockage from a sudden blood clot (this blockage is called a heart attack)[7].

Deep learning (DL) is a branch of Artificial Intelligence(AI), showing increasing promise in medicine, to assist in Motion Estimation, Optical flow computation and complex decision making.

Deep learning is a form of ML typically implemented via multi-layered neural networks[8].

Coronary Heart (Artery) disease diagnosis and prognosis can be advanced with the help of applying AI(Deep Learning Models) in Cardiac Motion Estimation.

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2. Purpose of the Project

Can be used as a better tool in CHD prognosis and diagnosis.

3 . Cardiac Motion Estimation

Cardiac Motion Estimation involves consideration of two types of Heart Function (movement) called as “Cardiac Cycle”.

1. Contraction
2. Relaxation

Cardiac Cycle

The cardiac cycle refers to the alternating contraction and relaxation of the myocardium in the walls of the heart chambers, coordinated by the conduction system, during one heartbeat. Systole is the contraction phase of the cardiac cycle, and diastole is the relaxation phase. At a normal heart rate, one cardiac cycle lasts for 0.8 second[9].

Challenges:

The following challenges have to be considered for estimating cardiac motion.

1.Cardiac Cycle.
2.Structured Motion (Rigid body motion Ex: Tissues,Valves).
3.Un-structured Motion (Fluid Motion Ex: blood).

4. Objectives of the Project :

➔ To estimate the motion from cardiac images through Optical Flow:
  1.Structured movement: Optical Flow Constraints (implementing for 3D images)
  2.Fluid movement: Continuity Model based on fluid Dynamics

➔ To estimate the motion from cardiac images through learning paradigm:
  1.LiteFlowNet: for rigid body motion (reimplementation in PyTorch)
  2.Adapt the LiteFlowNet to cardiac images with the symplectic gradient descent constraint

➔ To perform basic Image Processing operations on 3D cardiac images

1.Working with DICOM format images.
2.Working with 3D slicer tool and ITK library.
3.Image segmentation and Reconstruction.

5. Optical Flow

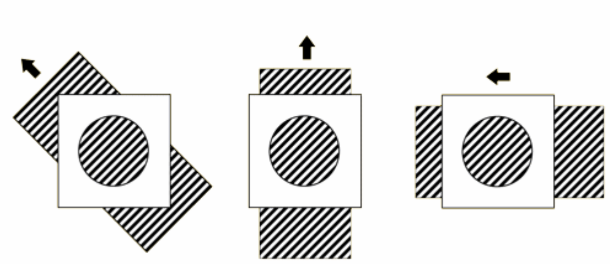
Optical flow is an approximation of the local image motion based upon local derivatives in a given sequence of images. That is, in 2D it specifies how much each image pixel moves between adjacent images while in 3D in specifies how much each volume voxel moves between adjacent volumes.

The 2D image sequences used here are formed under perspective projection via the relative motion of a camera and scene objects[11]

The 3D volume sequences used here were formed under orthographic projection for a stationary sensor and a moving/deforming object[11].

5.1 Aperture problem

Whether the rectangular structure is moved diagonally, horizontally, or vertically, the image will be identical when viewed through the aperture in all three instances. This produces ambiguity as to the actual direction, orientation, and speed of the object.



In motion detection, each motion sensor or directional selectivity (DS) neuron in the visual system is sensitive or responsive only to events that take place within the small part of its own receptive field. Since each neuron can only respond to stimuli within such a small area of it receptive field, it is as if each neuron is looking through a small aperture. Because of this minimal window through which the neuron is able to “see,” motion direction of an object can often be ambiguous. Such ambiguity means that a DS neuron will often produce identical responses for a number of different forms having different orientations traveling at different speeds[10].

5.2 Brightness Constancy

The moving patterns cause temporal varieties of the image brightness. It is assumed that all temporal intensity changes are due to motion only. The below equation is called as Brightness Constancy Equation.

$$\nabla I \cdot \vec{V} = -I_t$$

5.3 2D Optical Flow Estimation

Assume I(x, y, t) is the center pixel in a n×n neighbourhood and moves by δx, δy in time δt to I(x+δx, y+δy, t+δt).

Since I(x, y, t) and I(x + δx, y + δy, t + δt) are the images of the same point (and therefore the same) we have:

$$I(x,y,t) = I(x+\delta x, y+\delta y, t+\delta t)$$

$$I_x V_x + I_y V_y + I_t = 0$$

One Equation 2 unknowns : Ill Posed Problem

5.4 3D Optical Flow Estimation

The 3D Motion Constraint Equation is a simple extension of the 2D motion constraint equation with an extra dimension variable z.

$$I(x,y,z,t) = I(x+\delta x, y+\delta y, z+\delta z, t+\delta t)$$

$$I_x V_x + I_y V_y + I_z V_z + I_t = 0$$

One Equation 3 unknowns : Ill Posed Problem

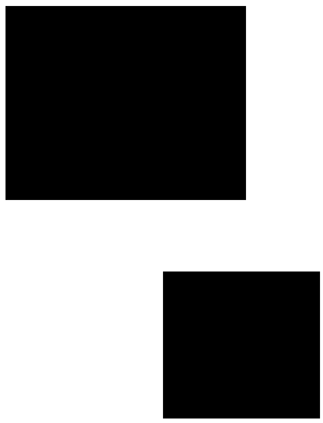
6. Implementation Modules of the Project

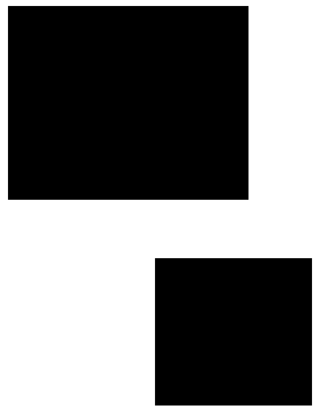
6.1 Computing Optical Flow using following Methods :

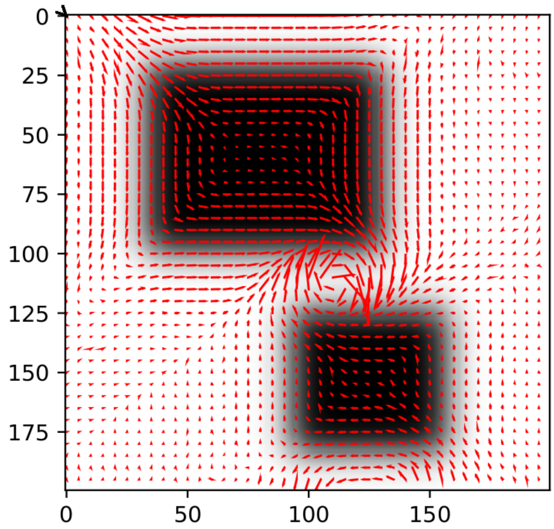
6.1.1 Horn-Schunk Optical Flow model for 2D images

$$E = \iint_{(x,y)} [\underbrace{(I_x v_x + I_y v_y + I_t)^2}_{\text{OF constraint}} + \underbrace{\lambda^2 (\|\nabla v_x\|^2 + \|\nabla v_y\|^2)}_{\text{Smoothness constraint}}]\, dx\, dy$$

The above energy functional solves the Ill Posed Problem of One Equation 2 unknowns.







Horn and Schunck optical flow output

6.1.2 William Harvey code Implementation

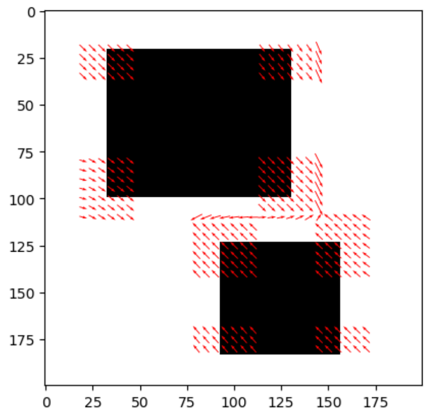
$$\iiint_{(x,y,z)} [(I_x v_x + I_y v_y + I_z v_z + I_t)^2 + \beta(\|\nabla v_x\|^2 + \|\nabla v_y\|^2 + \|\nabla v_z\|^2) + \alpha(\underbrace{\ldots\ldots\ldots\ldots\ldots}_{geometric\ constraint})^2]\, dx\, dy\, dz$$

OF constraint Smoothness constraint

Constraints: (motion based constraint) +(smoothness constraint)+ (geometric constraint)

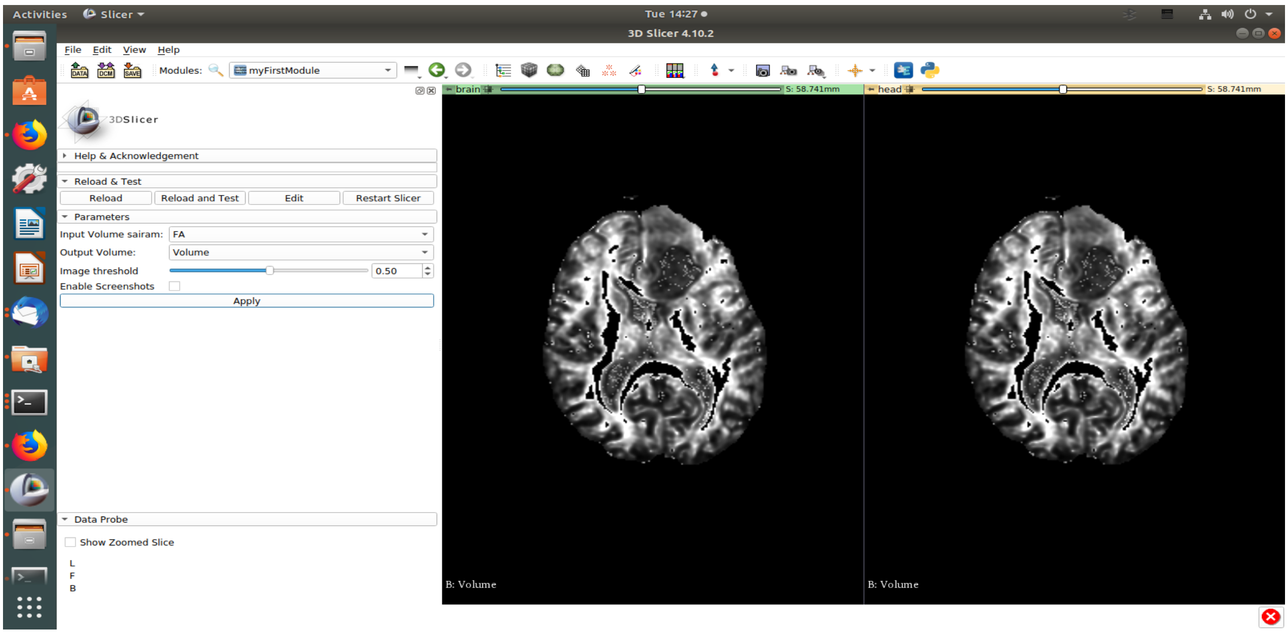
The above energy functional solves the Ill Posed Problem of One Equation 3 unknowns.

Output :



6.2 3D Image Processing using 3D Slicer software:

Adding a Module into 3D slicer



EXTENSION NAME : MyFirstExtension

Above extension contains the newly created module having name : MyFirstModule.py , MyFirstModule.pyc. New modules can also be added into the above extension.The above module creation is done using python scripting. Image : screenshot of the module output on brain image.

The function which I perform on the image with the help of this new module is to THRESHOLD the image and to capture the SCREENSHOTS(only if the checkbox is pressed.)

6.3 Deep Learning based :

Immediate goal:

To implement **LiteFlowNet** in PyTorch

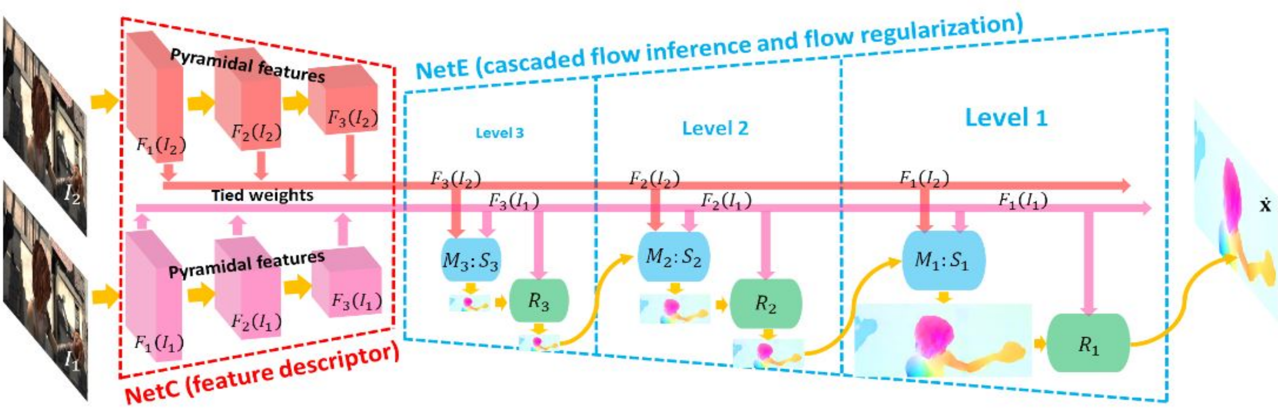
Steps to be taken during implementation of LiteFlowNet:

1. Reimplementing the network with kaggle dataset as input.
2. Checking the implementation on cardiac images
3. Symplectic gradient descent optimizer

Advantages of Using LiteFlowNet:

- State of the art model for computing optical flow.
- Can also take videos as input.
- DICOM format images are sequences of image frames(similar to videos) .
- Outputs color coded optical flow.
- Incorporates many advanced features to Compute optical Flow.
- Produces the accurate optical flow in high intensity colors(colour coded output).

LiteFlowNet Architecture :



7. Datasets:

- 4D CT scans (data provided by SSSIHMS)
- Kaggle Cardiac Dataset
- Middlebury Datasets (used in Horn and Schunck and WHC implementation)
- Sintel Dataset(pre-trained LiteFlowNet models)
- KITTI 2012 , 2015 Datasets(pre-trained LiteFlowNet models)

8. Timeline

April-May

- ML course (basics)
- Became clear with the objectives of the project

June

- Horn and Schunck(HS) optical flow C++ implementation
- DL Course
- Learning Python

July

- Horn and Schunck(HS) optical flow Python implementation
- Understanding William Harvey Code paper
- Implementing WHC optical flow

August

- Implementing WHC optical flow
- Exploring 3D slicer modules, tools, python interpreter

September

- Adding a module into 3d slicer, Volumetric Segmentation
- LiteFlowNet

9. References

[1] en.wikipedia.org

Generative adversarial network

Image segmentation

Optical flow

[2] Stack Overflow

[3] The William Harvey Code: Mathematical Analysis of Optical Flow Computation for Cardiac Motion Yusuke Kameda , Atsushi Imiya

[4] B.K.P. Horn and B.G. Schunck, "Determining optical flow." Artificial Intelligence, vol 17, pp 185–203, 1981. Manuscript available on MIT server.

[5] 3D Slicer Documentation

[6] LiteFlowNet Tak-Wai Hui, Xiaoou Tang, Chen Change Loy , CUHK-SenseTime Joint Lab, The Chinese University of Hong Kong

[7] webmd.com/heart-disease/guide/heart-disease-coronary-artery-disease#1

[8] ncbi.nlm.nih.gov/pubmed/30815669

[9] training.seer.cancer.gov/anatomy/cardiovascular/heart/physiology.html

[10] https://stoomey.wordpress.com/2008/04/18/20/

[11] *Computing 2D and 3D Optical Flow*,J.L.Barron and N.A.Thacker[2005].

10. Future Work

- Volumetric Segmentation (adding a module into 3D Slicer).
- William Harvey code for 3D cardiac images (extension)
- Adding a William Harvey Code optical flow implementation module into 3D slicer.

Signature :

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