Diagnosing Cardiac Deformations using 3d Optical Flow

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Abstract

This paper explores the viability of applying 3D optical flow techniques on 3D heart sequences to diagnose cardiac abnormalities and disease. Tagged magnetic resonance imaging (TMRI) is a non-invasive method to visualize *in vivo* myocardium motion during a cardiac cycle. By tracking the 3D trajectories of tagged material points it is possible to construct a volumetric model of the heart. Specifically, we use generated meshless deformable models (MDM) which describe an object as a point cloud inside the object boundary. We extend the 2D least squares and regularization approaches of Lucas and Kanade to 3D in order capture the flow, specifically the contraction and expansion of various parts of the heart motion. Features are extracted from this flow and a rudimentary SVM is used to classify unhealthy hearts.

Introduction

In 2010, cardiovascular disease (CVD) contributed to approximately one third of global deaths [1] [2]. An elimination of CVD would increase the average life expectancy by 10 years. In contrast, elimination of cancer would only result in an increase of 3 years [3]. The earlier a coronary artery disease (CAD), CVD or related heart diseases are screened and detected, the more effective treatment can be. In light of this, medical imaging techniques are a suitable approach for early diagnostics. Currently, three dimensional imaging of the heart using modalities such as ultrasound, magnetic resonance imaging (MRI), computed tomography (CT) is a rapidly developing area of research. Compared to CT and Ultrasound data, MRI is non-invasive (no radiation dose required) and is high resolution with good blood/tissue contrast.

However, it remains challenging to capture the 3D motions the heart is undergoing. These motions are typically strong indicators of heart disease such as abnormalities in the left ventricle. Cardiologists are greatly interested in the motions of the left chamber as it pumps oxygenated blood to the body [3]. In this paper, we explore the viability of diagnosing unhealthy hearts by applying 3D Lucas and Kanade Optical flow to the MDM's. A motion descriptor is calculated from the optical flow and used in an SVM to classify healthy vs. unhealthy hearts.

Methodology

Xiaoxu Wang et Al. from the Shenzhen Institute of Advance Technology. Their data uses tagged magnetic resonance imaging (TMRI) to construct 3D meshless deformable models of the heart as shown below [4]:

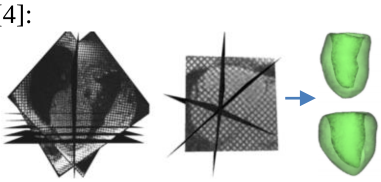

Figure 1 Illustration of Wang's TMRI to MDM's of Heart

The dataset features 10 healthy and 10 unhealthy hearts. Our methodology is composed of 3 main components:

1. Apply 3D Lucas Kanade to extract Optical Flow
2. Extract motion descriptors from Optical Flow
3. Train an Radial Basis Function Support Vector Machine

3D Lucas Kanade

Using the 3D motion constraint equation $I_x\mathrm{U} + I_y\mathrm{V} + I_z\mathrm{W} = I_t$. we assume a constant 3D velocity, $\mathrm{V} = (\mathrm{U}, \mathrm{V}, \mathrm{W})$, in a local *n* x *n* x *n* 3D neighbourhood and solve:

$$\mathrm{V} = [A^tW^2A]^{-1}A^TWB \quad (1)$$

Where W is a weighting matrix and A, B are the gradients of I.

Motion Descriptor

We use the sparse optical flow provided by the 3D Lucas Kanade and characterize it by a per-frame orientation histogram, weighted by the norm, with orientations quantized to 3d principal directions. Finally a set of global characteristics is calculated from the temporal series obtained from each histogram bin forming a descriptor vector. We calculate the quantized orientation based on the HOG descriptor:

$$H_t(\omega) = \frac{\sum_{\{x;\ \phi(v_t(x))=\omega\}} \|v_t(x)\|}{\sum_{\{x;\ \|v_t(x)\|>0\}} \|v_t(x)\|} \quad (2)$$

The description vector is a set of temporal statistics computed from the time series and includes: 1. Maximum, 2. Mean, 3. Standard Deviation, 4. Mean Begin, 5. Mean Middle, 6. Mean End.

Support Vector Machines

SVM's are well suited to the task of binary classification. In this specific instance, we used a radial basis function SVM. The SVM was trained and tested with 70/30 split. In this case 14 patients were used for training and 6 were used for testing.

Results

Due to the limited data set, the results should be looked at in terms of evaluating the potential of using 3D heart data instead of as a true measure of the accuracy of using optical flow features to classify the health of a heart.

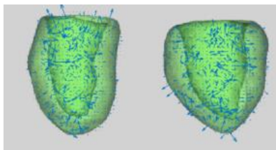

Figure 2 Left: Healthy Heart, Right: Unhealthy heart

Table 1 SVM Results

Category	*Accuracy*	*Sensitivity*	*Specificity*
Heart	83%	66%	100%

Conclusions

The results in this paper are a preliminary investigation into leveraging temporal and 3D spatial heart data for cardiac diagnostics. The initial results of the SVM using motion features indicate that using 4D heart data can provide accurate diagnosis. We close with the comment that there is a need to establish a 4D heart data set and significant improvements can be achieved by mitigating the discontinuous nature of MRI data.

References

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[3]W. J. N. Alejandro F. Frangi and M. a. Viergever, "Three-Dimensional Modeling for Functional Analysis of Cardiac Images: A review," *IEEE Transanctions On Medical Imaging*, vol. 20, no. 1, 2001.

[4] X. Wang, T. Chen, S. Zhang, J. Schaerer, Z. Qian, S. Huh, D. Metaxas and L. Axel, "Meshlessd eformable models for 3D cardiac motion and strain analysis from tagged MRI," *Magnetic Resonance Imaging*, vol. 33, pp. 146-160, 2015.