3D Motion Analysis of MR Imaging Using Optical Flow Method

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Purpose

Optical flow is the velocity distribution of each pixel in an image. In this paper, we extend 2D optical flow method to 3D optical flow analysis and also improve its performance around boundary. Dynamic Analysis of heart and knee is under investigation.

Introduction

The optical flow constraint equation defines the relation between the variation of the gray level gradient and the velocity of each pixel in the whole image[1].

$$E_x u+E_y v+E_t=0$$

In 1993, Amartur and Vesselle use the second order derivative method to calculate optical flow[2]. It assumes the velocity field to be continuous in the small region and derive the method using second order derivative. Its algorithm is simpler and therefore needs less time in computation. But it uses a larger neighborhood (5x5) to calculate the second order derivative which ends up with bigger area with error, especially around the boundary of a certain tissue. To solve this problem, we use only 3x3 neighborhood and fit its gray scale with a polynomial and obtain the first, second order derivative from this polynomial. This method improves a lot in the calculated optical flow at boundary region and, moreover, get more accurate gradient values in general.

To extend 2D optical flow algorithm to 3D, we derive the 3D constraint equation as follows,

$$\begin{bmatrix} E_x & E_y & E_z \\ E_{xx} & E_{xy} & E_{xz} \\ E_{xy} & E_{yy} & E_{yz} \\ E_{xz} & E_{yz} & E_{zz} \end{bmatrix} \times \begin{bmatrix} u \\ v \\ w \end{bmatrix} = - \begin{bmatrix} E_t \\ E_{xt} \\ E_{yt} \\ E_{zt} \end{bmatrix}$$

Here, subscript means partial derivative, u,v,w denotes the velocity in the x,y,z direction respectively.

Material & Methods

We use Sun sparc workstation and MATLAB to implement the algorithm.

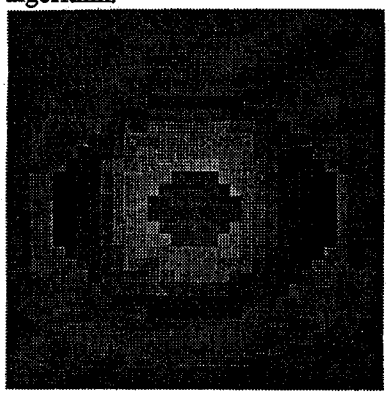

Fig.1 The myocardium phantom

Phantom Study A donut shape phantom is simulated as the left ventricle myocardium(Fig.1). The phantom's resolution is 32x32 and the gray level distribution of this phantom is set to be,

$$E(x,y,z)=32+4(1+\cos(\frac{\pi x}{16})\cdot\cos(\frac{\pi y}{16})\cdot\cos(\frac{\pi z}{16}))$$

, while the gray level distribution of the static background is:

$$E(x,y,z)=32+4(1+\cos(\frac{\pi x}{32})\cdot\cos(\frac{\pi y}{32})\cdot\cos(\frac{\pi z}{32}))$$

The motion we simulate includes, 2D and 3D translation, rotation and contraction.

Result Display To display the calculated 2D velocity distribution, we overlay the velocity field on the phantom with vectors represent the related velocity magnitude and direction of each pixel.

Cine Study Short axis view of left ventricle is imaged using gated Cine sequence with GE 1.5 Signa MR imager. The ROI is 64x64. In the spatial domain, we use diffusion filter[3] to get smooth gray level distribution while keep the edge at the same time. In the time series direction, gaussian filter is applied to avoid errors. Finally, in the velocity field, a 3x3 median filter is used to keep the field continuous. .

Trajectory Display In dynamic imaging Cine mode display, it is more convenient to observe the trajectory of certain chosen ROI to trace its movement.

Results

2D Contraction We compare the performance between previous method(Fig.2a) and our method(Fig.2b) to calculate the gradient. This is a 2D contracting heart simulation, where we can see our results has much advantage over boundary regions.

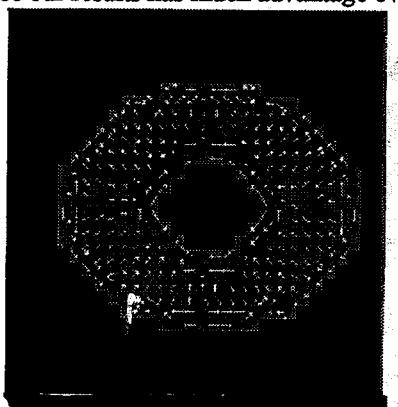

Fig.2(a)

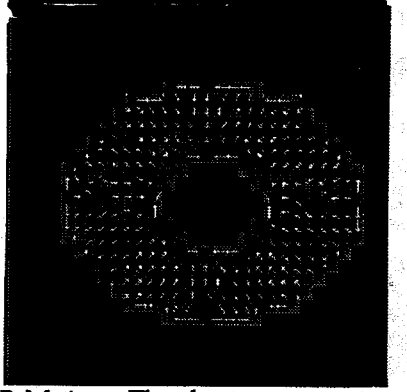

Fig.2(b)

3D Motion The phantom contracts a pixel toward the center in the xy plane and translates a pixel in the z axis at the same time. Fig.3a shows the velocity in the xy plane and Fig.3b shows the velocity in the z axis direction .The results matches well with the true motion field.

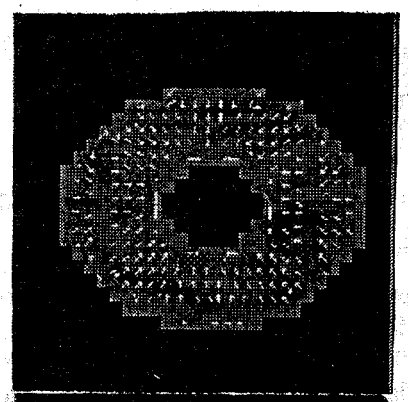

Fig.3(a)

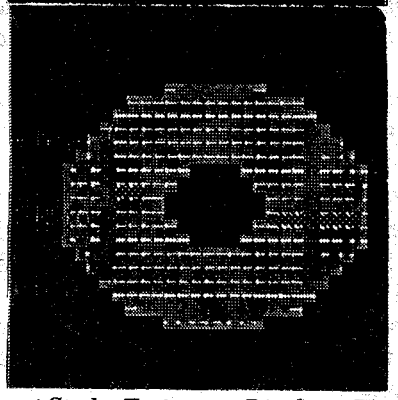

Fig.3(b)

Heart Study, Trajectory Display Fig.4 shows the results of left ventricle motion. ROIs of myocardium were selected to observe their time response. 27 images were acquired in a heart cycle, Figure 4 shows the ROI trajectories of four images. Different ROIs moves in different stage of heart cycle could be observed in this kind of cine display.

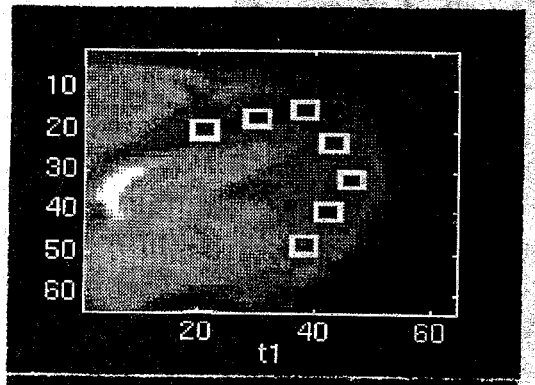

Fig.4 (a)

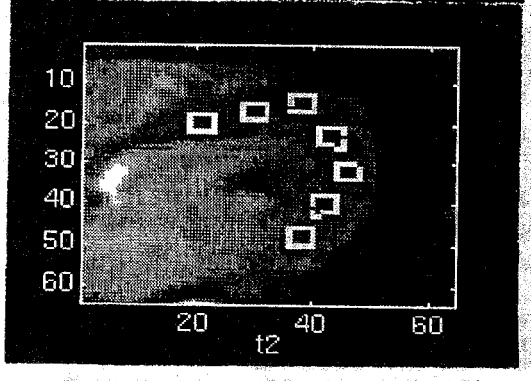

Fig.4 (b)

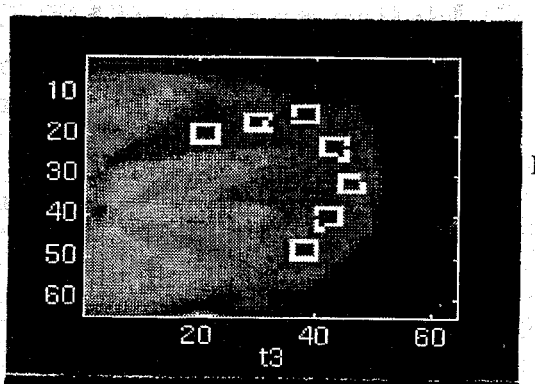

Fig.4 (c)

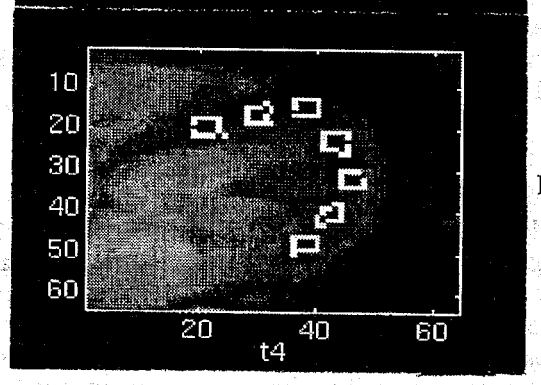

Fig.4 (d)

Discussion

Error Most velocity errors happen in which gradient is difficult to calculate accurately. This is observed at the boundary and at which the gray level has minimum or maximum values.

The assumption of optical flow is to assume a continuous velocity field. In order to reduce the error, one has to increase the spatial resolution. Reducing the time interval can also avoid the abrupt velocity field change. Using proper filters, either in spatial domain or time axis, can also get more accurate gradient and obtain better results.

Conclusion

In this study, we improve the optical flow methods to have better algorithm in gradient calculations and extend 2D velocity field to 3D motion study. Results shows better performance at boundary and general continuity of velocity field. To evaluate the clinical data results, we are comparing it with the MR tagging study.

Joint analysis is also under investigation at this moment.

Reference

1.Determining Optical Flow *Artificial Intelligence* 17 (1981) 185-203

2.A new approach to Study Cardiac Motion: The Optical Flow of Cine MR Images Sundar C. Amartur, Hubert J. Vesselle *MRI* 1993

3.Nonlinear Anisotropic Filtering of MRI Data *IEEE Trans. on Medical Imaging*, Vol. 11. NO. 2. June 1992