Towards Non-Invasive Automatic Detection of Cardiac Pathology by Strain and Rotation Analysis

H. C. van Assen[1], L. M. Florack[2], F. F. Simonis[1], J. J. Westenberg[3], G. J. Strijkers[1], and B. M. ter Haar Romeny[1]
[1]Biomedical Engineering, Eindhoven University of Technology, Eindhoven, Noord Brabant, Netherlands, [2]Mathematics and Computer Science, Eindhoven University of Technology, Eindhoven, Noord Brabant, Netherlands, [3]Radiology, Leiden University Medical Center, Leiden, Netherlands

Introduction – In the EU and the USA together, cardiovascular disease (CVD) accounts for approximately 2.8 million deaths, annually. CVD is estimated to cost the USA economy $475.3 billion a year. These increasing healthcare costs underline the need for cost-effective automated quantitative techniques for diagnosis, disease staging, and intervention timing. Currently, image-based computer aided diagnosis of cardiac diseases is mainly based on the geometry of the cardiac chambers and coronaries, and on function inferred from apparent surface and volume dynamics using cine MRI. Already in early stages, cardiac left ventricle (LV) diseases manifest themselves in altered contraction patterns (e.g. reduced twisting motion [1]), which can be diagnosed using techniques that are able to quantify local function and wall strain, such as velocity encoding and tagging MRI. Although tagging MRI is a well-established technique, there is still need for fast, automated, accurate and sensitive tag-tracking methods.

Aim – Here, we propose a new MR tagging image analysis based on a first order approximation of the multi-scale optical flow constraint equation [2] applied to the tag phase information, to assess left ventricle contraction patterns, and derive parameters such as strain and rotation. We have tested our method to both phantom and in vivo volunteer and patient data.

Materials and Methods – We use the classic optical flow constraint equation

$$\frac{\partial L}{\partial x}u + \frac{\partial L}{\partial y}v + \frac{\partial L}{\partial t} = 0 \qquad (1)$$

where L is the pixel intensity and (u, v) is the two-dimensional velocity vector of the point in the tissue. We take the first order Taylor expansion of Eq. (1), and set its derivatives with respect to x, y, and t equal to zero, which yields a set of four equations. Application to both a horizontally and a vertically tagged image run, and assuming equal motion (u, v) in both yield a set of eight equations

$$\mathbf{Av} = \mathbf{a} \qquad (2)$$

where $\mathbf{v} = (u,\ v,\ u_x,\ v_x,\ u_y,\ v_y,\ u_t,\ v_t)$, the unknowns to be solved for. This yields a contraction pattern (u,v) and its first order derivative structure required for the calculation of strain. This approach assumes conservation of pixel brightness, which does not hold for the tags, due to T_1 relaxation. Therefore, the phase of the tags is exploited obtained through Gabor filtering, which *does* remain constant.

We tested our method in vitro with a phantom built from two concentric cylinders – of which the innermost rotated in a controlled fashion – with a deformable gel in between. Short-axis MR tagging image data were acquired in vivo with a Philips Intera 1.5T scanner (Philips Healthcare, Best, Netherlands) from four healthy volunteers and one patient in a basal slice. The patient was diagnosed with several small myocardial infarctions, using delayed-enhancement MRI and had known wall motion abnormalities. A 2D multi-shot gradient-echo EPI with breath holding in end-expiration was used. Scan parameters were: TE 4.4 ms, TR 19 ms, flip angle 10°, EPI factor 9, FOV 300 mm, matrix 128, voxel size 2.34x2.68x8 mm^3 reconstructed into 1.17x1.17x8 mm^3. Tagline spacing was 8 mm.

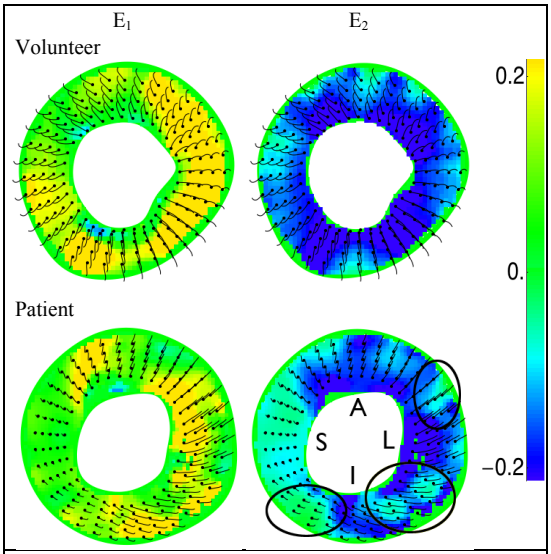

Figure 1 Maximal (E_1) and minimal (E_2) strains for a basal slice of a volunteer (top) and a patient (bottom). The black lines overlay shows motion trajectories throughout systole. Clear deviations in E_2 can be seen in the patient. These corresponded with enhanced areas in late-enhancement MRI. The septum of the patient was confirmed to be static by a cardiologist.

Results and Discussion –Tag fading resulting from T_1 relaxation is not an issue in this optical flow approach, due to Gabor filtering. Because the first-order derivative structure of the motion field is an intrinsic part of the solution vector **v** in each pixel, calculation of high-resolution strain is straightforward. The method is algorithmically very elegant in that it requires only off-the-shelf algorithms. Strain was calculated as a 2x2 tensor within the myocardium of the subjects. Maximal strain E_1 and minimal strain E_2 were extracted per pixel as the Eigen values of the strain tensors. These are plotted in figure 1 for both the basal slice of a volunteer and a patient. Clear deviations can be seen in E_2 for the patient, indicated by the ellipses. Rotation of the basal slice was calculated for all subjects, by calculation of the angle between the position vectors of each pixel within the tissue in consecutive frames. Curves of rotation during systole are plotted in figure 2. Also in this plot it is clear that the rotation pattern of the patient deviates from those of all the healthy volunteers. The lack of rotation during early systole is also visible in figure 1. The contraction trajectories for the patient are almost all straight lines, whereas those for the volunteers clearly show rotational motion as well.

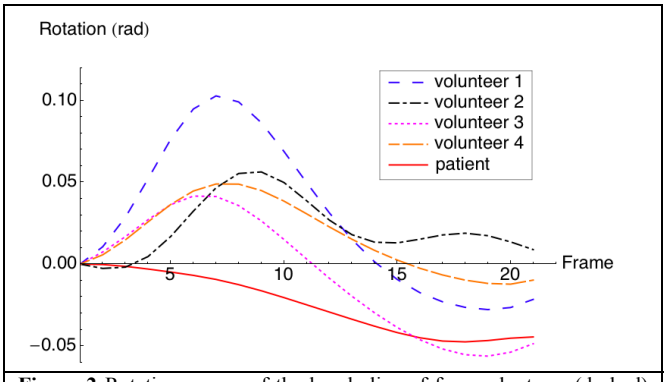

Figure 2 Rotation curves of the basal slice of four volunteers (dashed) and the patient (solid). Rotation was calculated during systole. Clearly all volunteers show a counter clockwise rotation, which has a peak in early systole. The patient shows almost no rotation during early systole.

Conclusion – The new optical flow based motion analysis method is able to detect differences in both minimal strain E_2 and amount of rotation in the basal slice between healthy volunteers and patients. The new method combines two perpendicularly encoded tagging series, and does not suffer from tag fading. Calculation of high-resolution strain and LV rotation from the first-order optical flow solution is straightforward. The method is algorithmically very elegant in that it requires only off-the-shelf algorithms.

Acknowledgements – The Netherlands Organisation for Scientific Research (NWO) is gratefully acknowledged for financial support.

References – [1] Delhaas et al., MRM 2004; [2] Florack et al., IJCV 1998