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Frequency Based Strain Estimation and Clinical Research Tool Using Optic Flow for tMRI

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Introduction

For patients who require an aortic valve replacement, but have a high operative risk, the Transcatheter Aortic Valve Implantation technique has recently become available. Imaging, often including tagging magnetic resonance imaging (tMRI), is performed to assess the patient-specific situation and to verify the success of valve implantation. To assess functional success, we propose a method to estimate cardiac left ventricular deformation from tMRI based on local tag frequency estimation and which will be incorporated in a software tool being developed at TU/e.

Methodology

Frequency assessed deformation estimation (FADE)

Figure 1 illustrates the mapping of an infinitesimal vector $\boldsymbol{\xi}_1$ (represented by the arrow) in configuration V_{t_1} into $\boldsymbol{\xi}_2$ in configuration V_{t_2} by the deformation gradient tensor $\mathbf{F}$. The transformation of the frequency covectors $\boldsymbol{\omega}_1$ and $\boldsymbol{\omega}_2$ (dashed lines) is also induced by $\mathbf{F}$ (namely, $\mathbf{F}^{-1}$).

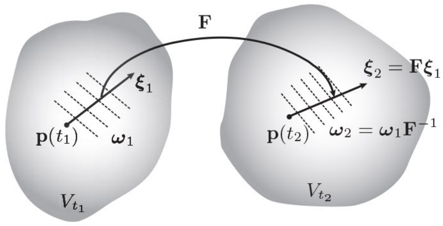
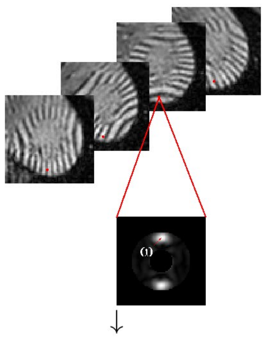


Figure 1: Transformation between configurations V_{t_1} and V_{t_2}.

The numerical implementation consists of the steps:



$$\boldsymbol{\Omega} = [\boldsymbol{\omega}^1, \cdots, \boldsymbol{\omega}^A]^\mathsf{T}$$

$$\downarrow$$

$$\mathbf{F} = \left(\boldsymbol{\Omega}_t^T \boldsymbol{\Omega}_t\right)^{-1} \boldsymbol{\Omega}_t^T \boldsymbol{\Omega}_{t_0}$$

$$\downarrow$$

$$\mathbf{E} = \frac{1}{2}(\mathbf{F}^T\mathbf{F} - \mathbf{I})$$

1. Calculate the Gabor transform for all tag directions, from 1 to A, using a Gaussian kernel.
2. Determine the local frequency $\boldsymbol{\omega}$ with highest intensity in the Gabor domain, excluding a priori unreachable areas limited by physical muscle deformation.
3. Compute the deformation tensor $\mathbf{F}$ relative to reference time t_0.
4. Calculate the strain tensor, and its components E_{cc}, E_{rr} and E_{cr}.

Software tool

To specify the requirements for the software tool, scientists and clinicians were interviewed, see Fig. 2 (left). The basic plug-in framework including an optical flow plug-in has been implemented in C++ using ITK, dTK, Qt and Eigen, and is up and running, see Fig. 2 (right).

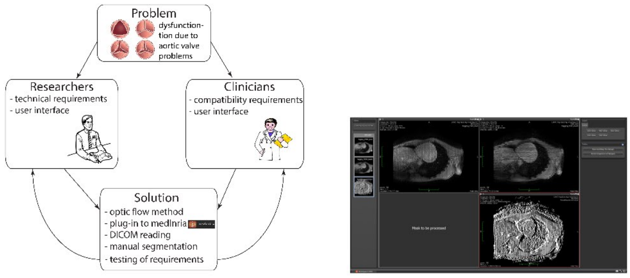


Figure 2: Problem and development overview (left) and screenshot of the tMRI workspace (right).

Results

Tracking errors obtained for phantom data are smaller for our method than for HARP, 0.32 ± 0.14 px versus 0.53 ± 0.07 px. For strain results on volunteer and patient data see Fig. 3.

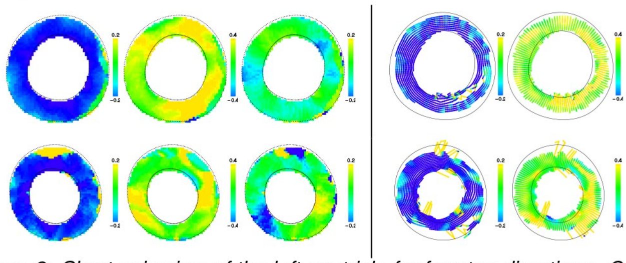


Figure 3: Short-axis view of the left ventricle for four tag directions. Components of the Lagrangian strain tensor, E_{cc}, E_{rr} and E_{cr}, in end systole obtained with local frequency extraction (left). Linearised strains E_{cc} and E_{rr} obtained with HARP [1] (right). Top: volunteer, bottom: patient data.

Discussion

FADE does not require knowledge of material motion or tag line extraction. It exploits frequency instead of amplitude information, and so is robust to tag fading. Moreover, it uses the full form of the strain tensor, instead of linearised strain. The method is shown to be applicable to grid and stripe tag patterns.

A stand-alone tMRI analysis software tool will provide the possibility to perform more clinically oriented research regarding cardiac function in the context of therapy selection, planning, and evaluation.

References

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[2] Bruurmijn, L.C.M., *et al.* FIMH (2013) DOI 10.1007/978-3-642-38899-6_34

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