Reconstruction of Under-sampled Dynamic Images by Modeling the Motion of Object Elements

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INTRODUCTION. The applicability of dynamic MRI imaging is restricted by its typically long acquisition time. Different techniques [1-3] have been developed that under-sample the *k-t* space and recover the lost information taking advantage of the space-time correlation of dynamic images. Usually, these techniques make assumptions about the pixel intensity changes (in the image or *k*-space). In contrast, we propose a technique to reconstruct under-sampled dynamic images recovering the lost data from the motion estimation of each object element (*obel*, think of a piece of tissue) in a continuous space. The proposed technique uses the fact that the displacement of an obel is smoother than the intensity fluctuation of the voxels caused by this movement (Fig.1 and 3), and thus can be described with fewer parameters. This can be used to have a more accurate model of the motion or to increase the undersampling factor and therefore the temporal resolution.

It was shown previously [4] that this method works effectively in computer simulated phantoms. This abstract presents the technique and the results of applying it to in vivo images. The results show that the method can effectively reconstruct cardiac images with an undersampling factor of 4. The application of higher factors has been limited by computational costs. In addition to recovering the full dynamic sequence, the method estimates the motion vectors of each obel which could be used to quantify dynamic information (cardiac volume evolution, for instance).

METHOD. Let the obels be the pixels of a reference frame ($\boldsymbol{m_0}$) in the dynamic sequence $\boldsymbol{m_t}$. Let the vector $\boldsymbol{e}$ be the parameter set that describes the movement of each obel in time and let $\boldsymbol{P_t(e)}$ be the motion transformation matrix that relates each obel in $\boldsymbol{m_0}$ with its new position in $\boldsymbol{m_t}$, under the assumption that obels do not change their intensity over time, $\boldsymbol{m_t = P_t(e)\cdot m_0}$. The undersampling transforms this equation in $\boldsymbol{b_t = W^{-1}S_tW\cdot P_t(e)\cdot m_0}$ where the unknowns are $\boldsymbol{e}$ and $\boldsymbol{m_0}$, $\boldsymbol{b_t}$ is the aliased data acquired in the image domain, $\boldsymbol{S_t}$ is the undersampling pattern and $\boldsymbol{W}$ is the Fourier Transform. As described in [4] this is solved by two nested optimization loops. The first one finds $\boldsymbol{m_0}$ as a function of $\boldsymbol{e}$ with LSQR (Conjugate Gradient method) and the second employs Trust Regions Methods to find $\boldsymbol{e}$ minimizing $\|\boldsymbol{b_t - W^{-1}S_tW\cdot P_t(e)\cdot m_0}\|$. The acquired data in *k*-space is used, instead of the computed values, where available to ensure consistency as in [3].

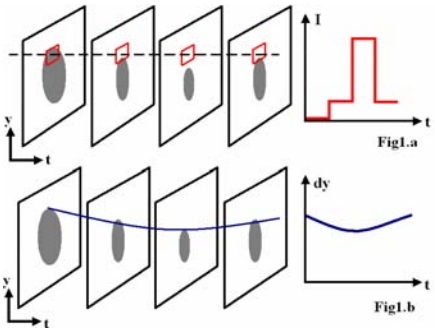

Fig1.a) Intensisity fluctuation of the one pixel in the time. b) Obel movement in the time.

The proposed algorithm was employed to reconstruct a sequence of 2D cardiac images, acquired in a Philips Intera 1.5T scanner (*B-FFE, 256x154x50, TR/TE=3/1.46ms*). Undersampling was performed, from a fully sampled image, taking one every four samples in a skewed pattern like k-t Blast. To lower the computational load we worked on *64x64x50* image.

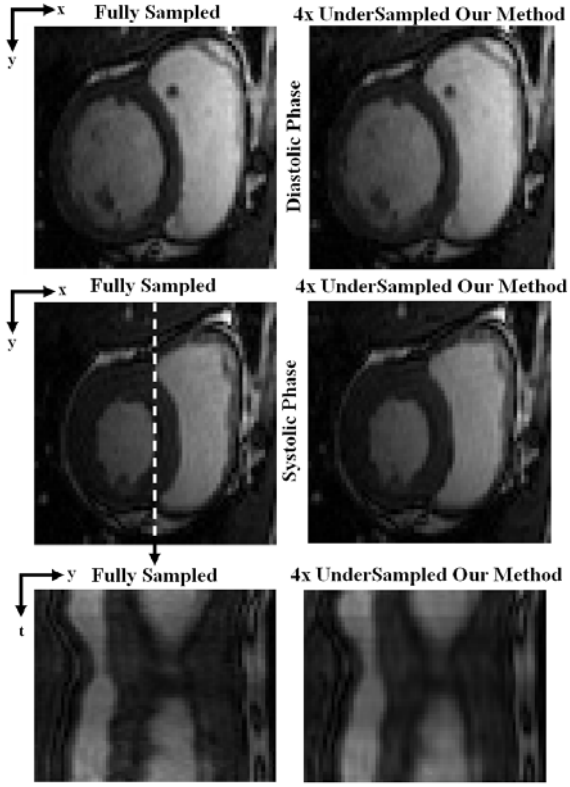

Fig2. Fully sampled (first column) and our reconstruction of 4x undersampled data (second column) for two cardiac phases and time evolution.

Each obel time evolution is estimated adjusting two 5th order Chebyshev series to describes its motion in both spatial directions, considering that their motion is independent of its neighbors.

RESULTS. The results of the reconstruction of two cardiac phases are shown in Fig.2. The reconstructed image is in good agreement with the fully sampled image with root mean square error of 1.96% of pixel intensity. The comparison between the displacement of an obel of the ventricular wall and the intensity of this pixel is shown in Fig.3. This reconstruction took 3 hours in a typical PC.

CONCLUSION. We have presented a method for reconstructing under sampled in vivo dynamic images estimating the parametric movement of each object element (obel). We tested the method with a sequence of 2D cardiac images and an undersampling factor of 4. The method obtains the vectors of movement of each obel and does not require the motion to be confined to a part of the field of view or to a portion of the temporal frequency. Furthermore it can be adapted to non-cartesian trajectories and non uniform undersampling patterns. A further benefit of the technique is that it automatically quantifies myocardial motion trajectories as well as the images.

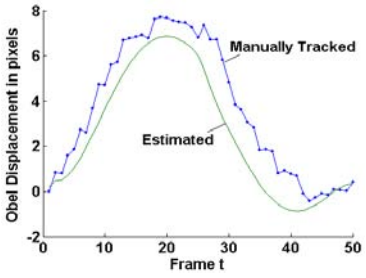

Fig3.a) Displacement of an object element (obel): Manually tracked and model estimation.

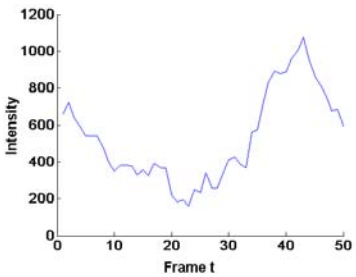

Fig3.b) Intensity values for a pixel in the same position.

References. [1]Madore et al. MRM 42,5 (1999); [2]Tsao et al. MRM 50,5 (2003); [3]Irarrazaval et al. MRM 54,5 (2005); [4]Prieto et al. In Proceedings 13th ISMRM