

Subject specific respiratory motion correction accounting for hysteresis

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Introduction

Respiratory motion of the heart poses a problem for high resolution cardiac MR imaging. Prospective slice following uses the navigator position immediately prior to the imaging segment to correct the slice positions throughout the segment [1]. The navigator is typically placed over the right hemi-diaphragm and a fixed correction factor is used to adjust for the difference to the displacement of the heart. The relationship between the motion of the heart and the superior-inferior motion of the diaphragm is approximately linear although highly subject specific, with an element of hysteresis [2]. We investigated a more complex model to incorporate non rigid transformation of the heart as well as hysteresis.

Methodology

In this study we investigated the possibility of modelling the respiratory motion of the heart affinely including the hysteretic effect. Nine healthy subjects received MR scanning according to protocols that had been approved by the IRB's of Imperial College London and University of Cape Town. A single-shot 2D image of the heart, preceded by a navigator, was acquired during each cardiac cycle during free breathing for ninety cardiac cycles. Coronal and sagittal images were acquired with in-plane resolution 1.61x1.88 mm after interpolation. Acquisitions were repeated twice; the first data set was used to define the model, the second to validate it.

Images were cropped, segmented and registered affinely to the first image in the series. Anterior-posterior and left-right motion were ignored. The first navigator value was used as the reference. In order to account for the hysteresis, superior-inferior respiratory motion was modelled using an ellipse superimposed on a straight line. A cost function set to minimize the RMS-error of the model was used to calibrate each component of the affine matrix model. The model was tested by comparing transformation matrices for specific points on the heart from the second scan computed using the navigator outputs for each cardiac cycle and our subject-specific respiratory model to transformation matrices obtained using co-registration.

In order to determine how many cardiac cycles need to be imaged in a pre-scan to build a subject-specific model with sufficient accuracy for prospective correction of motion, we investigated the effect of reducing the number of datasets used to construct the model. We repeated the process of creating the model with datasets from the first acquisition, ranging from five to 90 in increments of five. The RMS (root mean square) error of the model was again determined by investigating the prediction accuracy of the model constructed from these different numbers of datasets for all 90 measurements of the second acquisition. Each component of each transformation matrix predicted using the model was compared to each component of the corresponding transformation matrix obtained using co-registration of the images.

Results

Figure 1 shows one of the components plotted against the navigator values for one of the subjects and the curve fitted. Figure 2 shows the mean error \pm standard deviation of the components of the transformation matrix for straight line and elliptical models in the coronal plane. In figure 3 the RMS error when using different number of datasets to construct the model is illustrated.

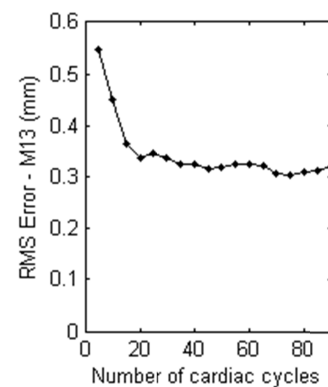
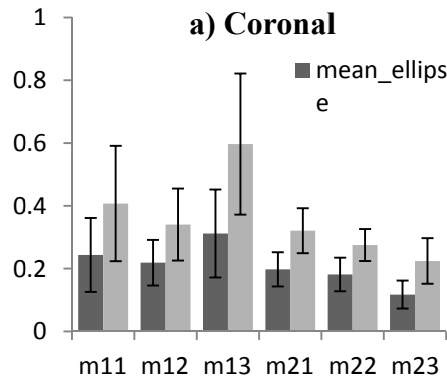
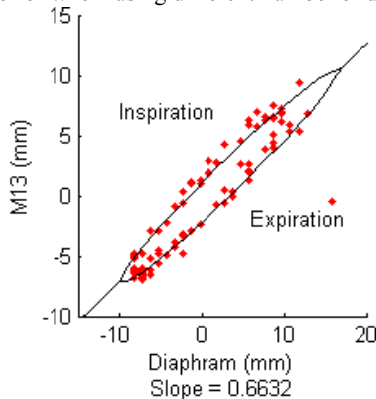


Figure 1: One of the components of the affine transformation matrix plotted against the navigator values for one of the subjects (Coronal)

Figure 2: The mean error \pm standard deviation of the components of the matrix for straight line and elliptical models in the coronal plane

Figure 3: The RMS error of the prediction for each component of the transformation matrix compared for models constructed with different numbers of datasets, ranging from five to 90 in increments of five.

Discussion and conclusion: The process was completely automated in order to be replicable online to allow rapid construction of a subject-specific model from a short pre-scan. The results show that the elliptical model performs better than the linear affine model. Further, we have demonstrated that a pre-scan of about 25 seconds (~25 cardiac cycles) is sufficient to construct the model.

References: [1]. I Burger, Prospective diaphragm position prediction for Cardiac MR using multiple navigators, ISMRM Motion correction workshop 2010, [2] A Scott, Motion in Cardiovascular MR Imaging. Radiology 2008

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