Adaptive imaging with motion tracking is a promising field of study in cardiovascular MR where respiratory induced motion represents a major challenge in capturing detailed anatomical structures. To this end, a reliable motion prediction method is required so that patient specific deformations can be established by using rapidly measurable 3D navigator traces. This work proposes a novel approach for predictive motion modelling based on partial least squares regression, with results validated by data acquired from 10 subjects during free breathing. The method has its potential application beyond cardiovascular MR where real-time deformation tracking is necessary during imaging.

### Introduction

With recent advances in MR hardware and computing architecture, adaptive imaging with motion tracking is becoming feasible for most commercial scanners. One fruitful area of the research is imaging the coronary arteries. Despite considerable advances in magnetic resonance imaging techniques over the last 10 years, MR imaging of the coronary arteries remains a technically challenging task primarily due to the small size and tortuous pathways of the arteries and to their movement with both the cardiac and respiratory cycles. The performance of imaging under normal physiological conditions of patients requires the monitoring of respiratory pattern and its induced cardiac deformation. The use of diaphragmatic navigators is now a popular choice for coronary imaging, but its application for real-time motion tracked coronary imaging can be problematic as deformation characteristics are patient specific and 1D navigators cannot truthfully represent what is inherently complex 3D deformation due to respiration. The adaptation of multiple navigator traces is ongoing research topic, and many centers are investigating the use of complementary MR compatible sensing methods to perform real-time measurements of surface distortions due to respiration. Since the signals measured reflect the same intrinsic biological model, many of them are therefore strongly correlated. For the deformation field introduced, the principal modes of variation are also limited, which renders major difficulty in using multiple linear regression to recover the inherent model that explains the causality between respiratory motion and surface distortions. The purpose of this work is to introduce a novel concept based on partial least squares regression (PLSR) for predictive motion modelling.

### Method

Segmented trueFISP sequence (TR=1.5ms, TR=3ms) running on a Siemens Sonata 1.5T MR scanner was used to generate 3D volumes of the left ventricle from 14 short-axis slices in early-mid diastolic (5mm x 1.6mm x 8.3mm, PE steps = 51, acquisition window=153ms). Twenty over-sampled consecutive acquisitions were performed whilst the subject breathes freely, with a diaphragmatic navigator echo being acquired immediately before each data set for retrospective reconstruction of reference 3D volumes at varying respiratory positions from end-inspiration to end-expiration as shown in Figure 2. A typical amount of deformation is illustrated in Figure 3, with two images acquired at different extremes of the respiratory cycle superimposed. Ten asymptomatic subjects were recruited for this study with informed consent.

3D free form image registration based on normalized mutual information was used [1] to align all image volumes with sub-pixel accuracy to the end-expiratory position. The derived deformation vector is a vector of the control points used as a reference to test the accuracy of the predicted motion based on 1D intensity patterns measured at the corresponding boundaries. They are selected to be parallel to the local 3D edge gradient. A total of 20 measurements are made for each subject.

The predicted deformation field was compared to the reference deformation vectors obtained from the free-form registration method to identify residual errors in the prediction method. The final result derived from PLSR motion prediction is shown in the last row of Figure 6 and the sum of the squared errors for all 10 subjects in Figure 7. The effectiveness of the prediction algorithm is evident by comparing the result to that derived from 3D image registration. The results suggest that the proposed method based on PLSR is an effective way of performing predictive motion modelling.

This provides an important computational modelling basis for using MR compatible surrogate methods such as chest straps, belts and tension arrays for accurate real-time prediction of 3D deformations during imaging.

### Results and discussion

The intrinsic pattern of deformation is then recovered from the navigator traces and the 3D deformation fields acquired from the above registration procedure by using PLSR. In PLSR, both the input and output are used for extracting the coefficient matrix, such that each is decomposed into their latent vectors. Our implementation was based on the NIPALS algorithm [2]. Once this learning process is completed, subject specific 3D deformation fields can be predicted directly from 1D surface measurement signals with the coefficient matrix derived above.

The method was validated with data acquired from the 10 subjects studied. Between 6 and 7 image volumes were reconstructed for each subject and the accuracy of the proposed patient-specific motion prediction method was assessed by the leave-one-out validation approach for each subject. For each volume, the subject was removed for validation while the remaining volumes were used to extract the regression matrix for the PLSR method.

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### References
