Comparison of Algorithms for Prediction of Respiratory Motion

T. Nair[1], and H. M. Gach[1]
[1]Research Imaging, Nevada Cancer Institute, Las Vegas, NV, United States

Introduction: Physiological motion is a challenging problem in quantitative or functional MRI. Slight displacements between acquisitions can create large errors in subtraction-based methods like arterial spin labeling (ASL). Real-time prospective tracking and free-breathing navigators were developed to eliminate breath-holds and minimize deadtimes associated with gated acquisitions [1]. The utility of the navigator data can be extended through motion prediction [2]. Motion prediction can be used to adjust 2D slice acquisitions in real-time and freeze the motion of the region of interest, or interpolate the position of organs for 3D acquisition k-space phase corrections. Three motion prediction algorithms were compared using *in vivo* data: 1) the constant velocity (CV) model; 2) the interacting multiple model (IMM) which includes the CV model; and 3) a weighted fourier linear combiner (WFLC) [3, 4]. The CV and IMM models incorporate Kalman filters.

Theory: The CV model captures the respiratory motion dynamics when the motion is at a constant velocity. The state variables for the Kalman filter are displacement and velocity. By contrast, a constant acceleration model (CA) captures constant acceleration/deceleration. Displacement, velocity and acceleration are the state variables for the Kalman filter. The IMM model (2) combines the CV and CA models and switches modal states based on the normalized likelihood of the models. Alternatively, the WFLC algorithm represents a signal using a truncated Fourier series. The Fourier coefficients and the fundamental frequency are represented by adaptive weights based on the incoming respiratory motion signal. Statistical information of the respiratory motion signal is used to improve the prediction accuracy of the WFLC.

Methods: Sagittal echo planar images of real-time abdominal motion were acquired from two healthy volunteers using a Siemens 1.5T Avanto scanner (TR: 92 ms, TE: 29 ms, FOV: 275 mm, Matrix: 256x64, single slice, 4096 repetitions). The respiratory motion profile of the diaphragm was obtained along the superior-inferior (SI) direction using 1D registration. The respiratory motion profile was provided as the input to the CV, IMM, and WFLC prediction models. The software for the prediction models was developed in MATLAB (The MathWorks, Inc., MA) for simulation and C++ (http://gcc.gnu.org/) for eventual implementation on the MRI. MATLAB based codes were tested on an Intel Xeon processor (64 bit, 2.8 GHz, quad core), 8 GB RAM based workstation with Windows 7 (Microsoft Corporation, WA). C++ based codes were tested on an Intel Core i7 processor (64 bit, 2.13 GHz, quad core), 8 GB RAM based workstation with CentOS 5 (http://www.centos.org/).

Results & Discussion: The models were tested with the respiratory motion profiles at multiple time points. We were able to predict 1 s into the future with a mean root mean square error (RMSE) of >6.6 mm with the CV model, >5.3 mm with the IMM and >1.5 mm with the WFLC (Table 1). The CV and IMM algorithms are computationally more efficient (Table 2) and require less training time than WFLC (0 vs. 4 cycles) but are much less accurate (Fig. 1).

Table 1: Comparison of Predictor Accuracies

Prediction Model	RMSE range (mm)		
	Prediction horizon		
	0.1 s	0.5 s	1 s
CV	0.7 - 1.7	3.2 - 7.3	6.6 - 12.4
IMM	0.3 - 1.3	2.1 - 6.5	5.3 - 10.2
WFLC	0.2 - 1.1	0.6 - 5.1	1.5 - 8.6

Table 2: Comparison of Computational Performance

	Average computational time/prediction (μs)		
Software	CV	IMM	WFLC
MATLAB	106.2	342.5	4551.8
C++	1.1	7.2	211.3

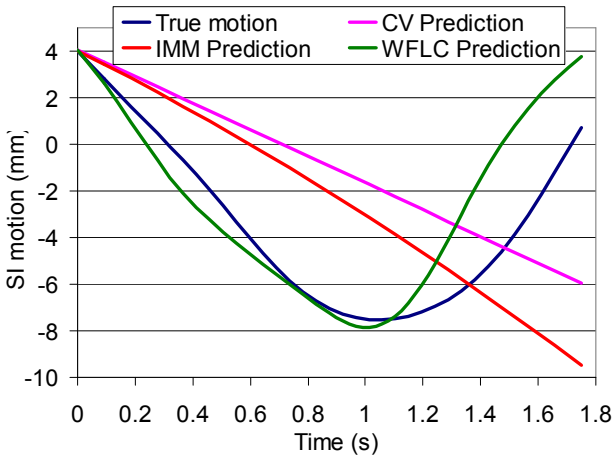

Figure 1: True and predicted respiratory motion versus time after navigator data input ends.

References: 1) H Pedersen et al., MRM 61:734-738 (2009). 2) NA Ablitt et al., IEEE Trans Med Imaging 23(10):1315-1324 (2004). 3). CN Putra et al., Phys. Med. Biol. 53:1651-1663 (2008). 4). CN Riviere et al., IEEE Trans. on Biomed. Eng. 45(7):839-846 (1998).