Real-time target displacement prediction using Dynamic MRI for radiotherapy

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INTRODUCTION: Advanced radiation therapy delivery techniques have the potential to deliver the required doses to the tumor while minimizing the dose to healthy normal tissue. However, these advancements require highly conformal dose delivery and without effective motion management techniques such therapies can be sub-optimal [1]. Currently, motion management is carried out by using either gating or breath-hold techniques. While these techniques are effective in reducing organ motion, they prolong the treatment duration, which may result in significant patient discomfort resulting in gross motion of the patient thereby reducing the biological effectiveness of the otherwise effective treatment.

Irrespective of the tumor motion management solution, a fundamental pre-requisite for tumor motion correction systems is the knowledge of the real-time tumor position. The purpose of this work is to explore the feasibility of using cine-MRI images acquired in conjunction with the real-time external surrogates to assist in the development of a robust model for real-time tumor displacement prediction.

METHODS: Healthy volunteers were recruited for the study. Four skin marks using indelible ink were placed on the volunteers to identify the appropriate location for optical reflectors that were used for monitoring free breathing. Optical reflectors were placed on each of these locations (Figure 1) and the 3D coordinates of these reflectors were tracked at all times by an infrared camera (DynaTracTM) placed at the edge of the MR table. Data from these reflectors were simultaneously obtained along with free-breathing cine MRI data. Volunteers were scanned in the supine position and feet first using the body coil of the scanner.

Turbo FLASH (fast-low-angle-shot) cine-images were obtained both in the sagittal and axial planes at a TE/TR/Flip/Matrix size of 1.5ms/3ms/12/80x256 at a spatial resolution of 1.56 mm. Phase conjugate symmetry was used for better temporal resolution. A total of 513 images were acquired with temporal resolution of 185 ms and the total scan time per volunteer was approximately 95 s. Three distinct vessels were identified and contoured using the Pinnacle[3] (PROS, Philips Healthcare, Fitchburg, WI) treatment planning system. The coordinate of these vessels were measured in the A-P and S-I direction on each image frame and correlated with the 3D reflector coordinates determined using the infrared camera system. Partial-least-squares (PLS) regression [2] was then used to investigate the feasibility of predicting internal anatomical motion using the coordinates of skin surrogates. The training set for the model was created from the initial n=20 or n=50 data points. The PLS regression model built with each training data set, was then used to predict the vessel (V1/V2/V3) position in the remaining data set. The performance of the model was benchmarked with standard multiple linear regression (MLR). The error between the measured and the predicted blood vessel positions was quantified using the mean of the absolute error and the standard deviation of the error.

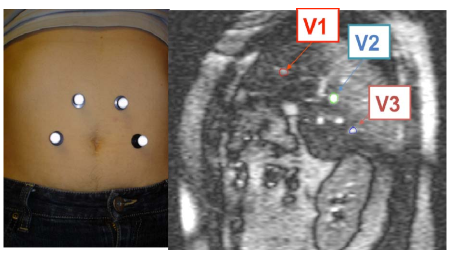

Figure 1: (left panel) Photograph of the location of the optical reflectors on volunteers abdomen. **(right panel)** Sagittal cine MR slice of a volunteer using the TurboFlash pulse sequence with a spatial resolution of 1.56 mm in the A-P and S-I directions and temporal resolution of 174 ms.

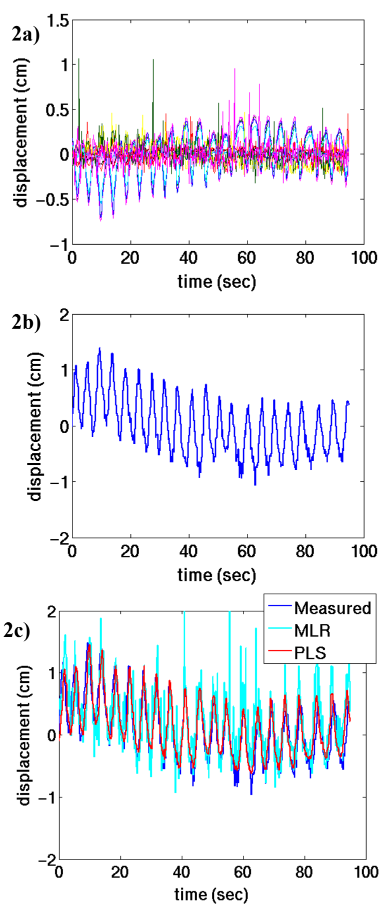

Figure 2: a) 3D displacement of 4 optical reflector coordinates using skin surrogate position acquisition with optical camera system, **b)** 3D displacement of liver vessel (V1) position during simultaneous cine MR, and **c)** prediction of vessel position using MLR and PLS techniques using 20 samples for training set.

	AP	SI
	mean + σ (mm)	mean ± σ (mm)
MLR	1.6 ± 2.2	3.9 ± 5.2
PLS	1.0 ± 1.4	2.9 ± 3.6

Table 1): Mean and standard deviation of absolute error in predicting liver vessel position using 20 samples in the training set with MLR and PLS techniques.

RESULTS AND DISCUSSION: Figure 1 shows a sample sagittal image from a volunteer with the Turbo FLASH pulse sequence. The three vessels marked (V1/V2/V3) were tracked. Figure 2a) shows the time-varying displacement of the 4 optical reflectors placed on the patient's skin. Figure 2b) shows the 3D displacement of a single liver blood vessel (V1) as extracted from the cine-MRI image. Figure 2c) shows the internal predicted 3D position for the blood vessel (V1) generated using the MLR and PLS techniques with n=20 training points.
As shown in Table 1) the mean prediction error for the 3 subjects ranged from 1.5 - 4 mm for the MLR technique and 1 - 3 mm for the PLS technique with 20 training points. A further reduction of the error to 1-2.3 mm was obtained when increasing the training subset to 50 points by both the MLR and PLS techniques (results not shown).

CONCLUSION: Cine MRI can be used to image the internal anatomy (for example: liver blood vessels) in real-time with adequate temporal resolution (< 200 ms) to measure internal organ motion and to obtain adequate correlation with external surrogates. This preliminary work in motion tracking shows that it is possible to predict tumor position accurately during real-time provided a relationship is established between external surrogates and internal organ motion (for example: tumor).

REFERENCES: [1] Shimizu S, *et al*, Int J Radiat Oncol Biol Phys 2001;51:304-310. [2] de Jong, Chem and Intel Lab Sys. 1993;18(3):251-63.
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