Title: Live video-guided volumetric tracking of respiratory motion

Introduction: To detect or irradiate mobile lesions in thorax and abdomen, dynamic volumetric medical imaging (4DMI) and in-room real-time imaging are desired. However, up to now, no 4DMI exists that can do live tracking of the dynamic volume changes in respiration. This research introduces a real-time tracking of target motion by using live 4D video imaging (4DVI) that contains dynamic volumetric information being closely synchronized with 4DMI.

Methods: The proposed technique consists of a 4DVI camera attached onto a CT couch and to a linear accelerator tabletop during treatment. The 4DVI system will capture sequential surface images of patients during 4DCT or 4DCBCT scans and during the dose delivery. The paradox of image matching without similarity or common data between 4DVI and 4DMI is overcome by a novel concept that the integral of the balanced forces over the moving surfaces is directly proportional to the lung volume changes. The respiratory motions, representing the lung volume variations, were then measured with the dynamic volume under the moving surfaces of the thorax and abdomen. To validate the hypothesis and test the feasibility of the proposed technique, we have acquired sequential surface images on several patients and volunteers. Respiratory patterns were repeatedly measured on volunteers while taking a normal or a deep breath. The dynamic volume under the moving surface is calculated by subtraction of the sequential surfaces from the reference. The dynamic volume under the moving surfaces were then robustly fitted as a linear trend plus a trigonometric function that was compared with the fitted curves for internal target moving trajectories derived from about forty 4DCBCT scans.

Results: Figure 1 illustrates the thoracic and abdominal surface movements of a volunteer taking a deep breath. The surface on top, acquired 3 seconds after the first reference imaging, shows the large chest wall expansion by >20 mm, variable abdomen displacements, and total 2000 cubic centimeter (cc) volume changes. Figure 2 illustrates the measured dynamic volume data and modeled curves for the volunteer during deep and normal breaths. Normal breath had less chest wall movement and measured data agreed with the model. Missing top portion of the chest wall in available video imaging induced some errors in modeling the data in deep breath. We observed no large chest wall movement for our patients and dynamic volume rather than surface shifts or rotations as shown in Fig. 3 appeared to be more reliable for respiratory tracking. Importantly, 17 patients with early stage lung cancer underwent SBRT, their lung nodule movements were measured and well fitted with the same formula, showing the feasibility of the technique. The linear draft in the dynamic volume curves were much smaller after the patient stabilized on treatment table shown in Figure 4 with less displacement (< 1-mm and 0.1°) by matching the same phase abdominal surface (in red) with the reference.

Conclusions: A novel 4DVI guidance based on dynamic volume information under the moving surface is introduced for real-time volumetric imaged guided 4DMI scans and image-guided radiotherapy. Results of our initial tests are promising and encouraging.