Abstract

Detection of chaotic determinism in lung cancer patients' breathing patterns and tracking of moving lung tumors using dMLC

by

Dinesh Kumar Tewatia

Under the supervision of Professor Bhudatt R. Paliwal and Professor Wolfgang A. Tomé

Aggressiveness and precise tracking of tumors in real time with a nearly 100% duty cycle is likely to be the gating technique for the next generation of motion management strategies. A tumor tracking technique, meticulously designed with an integral quality assurance (QA) process, will enable us to achieve the most coveted aim of radiotherapy i.e., targeted dose conforming to tumor and sparing critical/normal tissue as much as possible. A step forward for making any of the tumor tracking techniques more robust, would be to get real time tumor coordinates and develop better breathing prediction methodologies.

Although tumor tracking techniques usually have a better duty cycle than gating techniques, these are more sensitive to associated uncertainties and demand a more rigorous QA procedure. Successful implementation of any tumor tracking technique directly depends on the radiation delivery hardware (dynamic MultiLeaf collimator (dMLC) or binary MLC) and the knowledge of real time tumor coordinates. Most common approaches involve direct tracking methodologies employing continuous observation of the implanted fiducials in the tumor or inferring the internal tumor position indirectly from surrogate anatomical motion that can be monitored externally. The uncertainties associated with any tracking technique could introduce large

dosimetric variations between the delivered dose distribution and the planned dose. Among the common types of uncertainties in treating moving tumors, intra-fractional organ motion is the most significant. The aim of the studies presented in this thesis was to investigate two techniques for tracking moving lung tumors, develop a model for numerical phantom based QA for moving tumors and analyze the breathing patterns (major cause of intrafractional motion) of lung cancer patients using nonlinear dynamics and chaos theory. The clinical implementation of these tumor tracking techniques requires an electronic interface to radiation delivery machines to trigger the beam ON and hold the beam OFF once the tumor goes out of the threshold window. It was not included in this work.

A breathing synchronized delivery (BSD) was developed using Eclipse™ treatment planning system (Varian Medical Systems, Palo Alto, CA). Delivered dose calculation on fifty percent (maximum exhalation) phase using shaper™ application (Varian Medical Systems, Palo Alto, CA) was performed to superimpose the instantaneous average tumor displacement on the dMLC position at the corresponding phase. An in-house developed free-form intensity based deformable registration toolbox was used. The BSD technique assumed a constant dose rate and the patient was guided to reproduce the breathing pattern that was acquired during the 4D computed tomography (4DCT) acquisition. As the BSD technique cannot be directly adapted to moving tumors in the case of volumetric modulated arc therapy (VMAT), we have developed a novel technique for arc-based treatments. In this work, we have demonstrated the implementation of this technique on the ADAC Pinnacle^{3TM} (Pinnacle, Philips Medical Systems, Fitchburg, Madison) treatment planning system. This technique does not require breath-hold or breath synchronization and has a nearly 100% duty cycle without any major hardware changes.

The variation in dose accumulation due to changes in breathing pattern as the treatment progresses was studied on a numerical phantom. Stereotactic body radiotherapy (SBRT) treatment was investigated to see the effect of changes in breathing patterns on five days of treatment. By varying the breathing patterns on every day of the five day treatment, we found that if the variation in breathing patterns is not substantial, then due to the physics of dose deposition, the total accumulated dose on that treatment day would not be significantly different from the planned dose distribution. On the other hand, if the breathing pattern on a given day changes beyond some threshold we may partially miss the target on that day of the treatment.

In a lung cancer patient tumor motion is mainly due to breathing. No matter how robust the tumor tracking methodology is, dose variations would result due to hardware limitations e.g., system latency. A novel motion management suite was proposed based on nonlinear dynamics and chaos theory. Respiratory waveforms were analyzed using tools from non-linear dynamics and it was deduced that chaotic determinism exists in the breathing patterns of all lung cancer patients. This finding may facilitate the implementation of complete automated motion management methodology and will be an asset once real time magnetic resonance imaging is available in clinics.