Abstract

Nonlinear dynamics based 4D dose guided radiotherapy

for moving tumors

by

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Radiation, the mainstay of local nonsurgical treatment for regionally advanced non-resectable non-small cell lung cancer, is associated with poor outcomes due to local failure. Intra-fractional tumor motion mainly due to respiratory motion necessitates enlarged treatment margins to provide full tumor coverage, thus limiting the dose that can be escalated for tumor control. Tumor motion and breathing irregularity are two major hurdles which stop us from achieving this apparently simple goal of dose escalation while sparing normal tissues. Effective compensation to account for this depends on: Firstly, the robustness of the monitoring system for tracking real-time tumor motion and secondly the efficiency of the delivery system in adapting to the observed tumor motion.

Delivery of radiation therapy using synchronization methodologies requires knowledge of real-time tumor position. No matter how robust the methodologies are, they all suffer from the problem of system latency. System latency can be understood as a delay from the instant the tumor moves before the treatment system can make its corrective response. Predicting respiratory motion in real-time is challenging, due to the inherent chaotic nature of breathing patterns, i.e. sensitive dependence on initial conditions. In our previous work we analyzed the breathing pattern of 16 patients using time-delay based state space techniques and established

that respiratory system is 5-6 dimensional nonlinear, stationary and deterministic in nature albeit chaotic with sensitive dependence to initial conditions. In this thesis, we introduce nonlinear prediction algorithms based on state-space methodologies that have a larger prediction horizon than linear methods if an appropriate time delay and embedding dimension are chosen. In addition, a much larger prediction horizon can be achieved if patients can be coached to closely follow a regular breathing pattern. Patients revisit their breathing orbits arbitrarily closely and stay for a while before exponentially diverging from the orbit. These are called Unstable Periodic Orbits (UPOs) which can be used to intelligently coach the patients to maintain a comfortable breathing. This approach is called Chaos Control and its theoretical basis and preliminary results are elucidated in this thesis. However, many patients with high transients can be very challenging for both prediction and chaos control. We also introduce a novel method, Recurrence quantification analysis (RQA) that can be used as a quantitative decision making tool to classify patients breathing pattern. RQA is a promising and powerful tool to decide if a patient is a good candidate for Chaos control and prediction or just prediction bundled with 4D treatment. For highly chaotic breathing patterns, it might be best to adapt with the Maximum Projection Intensity (MIP) Image based Internal Target Volume (ITV) treatments.