CS 766 Project Proposal:

Fiducial-Free tracking for Projection X-Ray Guided Radiation Therapy

Team Members:

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Project Website: https://github.com/twinfree/CS766-Final_Project

Background:

Intensity Modulated Radiation therapy systems deliver precise beams of ionizing radiation to a tumor to inhibit cancer cell growth. Treatment is planned by first acquiring a planning CT scan of the affected anatomy. A radiologist will contour the gross tumor volume (GTV) along with nearby organs at risk and prescribe a dose volume that kills the tumor while sparing the organs at risk. An optimizer, guided by simulated dose calculations, will compute a set of dose delivery instructions (beam geometry, linac positions/orientations etc.) that minimizes the difference between the simulated dose and the prescribed dose. Since the planning CT captures a snapshot of the tumor at a single moment in time, the outcome of treatment will be negatively affected if the tumors position is time dependent. This is of particular concern when treating lung tumors, where respiration induced periodic motion of the GTV needs to be accounted for.

One approach to motion compensation is to acquire projection x ray images of the thorax at some chosen frequency during treatment. From these images, the tumor is localized in 3D space. A predictive model of the tumors trajectory is interpolated from multiple images, and updates to the beam collimation are computed to compensate for the tumors changing position in the linacs FOV. These updates need to be computed on a millisecond timescale, this rules out the possibility of a human operator manually contouring the images as they come in. Instead, a computer vision system capable of differentiating the tumor from the rest of the image must be implemented. To simplify this task, gold fiducials are surgically implanted into the flesh of the tumor. These small gold particles have high contrast and are easy to detect programmatically, as such, they act as surrogates for the tumors position.

Fiducial implantation has its risks, however. One study reports that transthoracic fiducial implantation brought on pneumothorax (a condition where the lung partially collapses due to air leaking into the gap between the lungs and the chest wall) in 13% of patients that underwent the procedure [1]. As such, there is demand for an algorithm that can localize the tumor itself without using a fiducial as a surrogate.

Proposal:

For this project I will be using publicly available data from the AAPM (American Association of Physicists in Medicine) MATCH challenge (MArkerless lung Tumor Tracking Challenge). The data consists of pre-treatment 4D cone beam CT (CBCT) scans and intra-treatment kV radiographs of a phantom patient for 4 different motion traces varying in complexity and range. The goal of this project is to, first, design a program that automatically detects the target tumor and computes the 3D position of its center of mass. Second, after acquiring at least one breathing cycles worth of, construct a predictive model of the tumor trajectory, and continuously update it during treatment as new radiographs are taken.

Tumor segmentation is difficult in this case since fluoroscopic radiographs often suffer from poor image quality. To avoid segmenting the tumor, a 2D/4D template matching technique using cross correlation is popular. When a radiograph is taken during treatment, a template DRR (digitally reconstructed radiograph) is created from the 4DCBCT at each phase. The normalized cross correlation between an ROI in each DRR and the live radiograph is computed, and the tumor position is chosen from the DRR that was most correlated with the live image. The tumor position is obtained from the pre-treatment 4DCT at the chosen phase. This method assumes that the tumor trace in the planning 4DCT is constant across breathing cycles, and therefore does not require the construction of a predictive model. I will implement this method as a baseline to compare my novel algorithm with.

There are some issues with this method, however. It assumes the tumor and its trace are rigid. In reality, the surface of the tumor can deform in subtle ways, adversely affecting the efficacy of a cross correlation approach. Also, the phase difference between the tumor motion and the diaphragm can drift over time, degrading the correlation between phase and tumor location. As such, it would be better to be able to accurately segment the tumor from a radiograph and compute its center directly rather than relying on a pre-treatment 4DCT scan. Homma et al propose a method of tumor segmentation that works by decomposing the image intensity at each pixel into a tumor component and a background component. Using this method, I can construct a DRR for each kV radiograph that will be taken during treatment, compute the background component for each DRR, and then subtract this background from the live radiographs, making it easy to localize the tumor via image gradient or some other process.

At this point I will be able to localize a tumor in space and time from a single radiograph, but I will know nothing about the tumors position in between radiographs. To solve this problem, I will implement a model builder that predicts the tumors position from its known positions at different phases while the system is blind. I don’t have a particular method in mind at this point, I will look into this later down the road.

Time Table

Feb 24 - Mar 24:

-Implement 2D/4D template matching as a baseline method

-Implement Homma’s tumor segmentation method for each plan in the dataset

Mar 24 – April 24

-Implement model builder that takes the tumors position sampled at multiple phases and interpolates a continuous function f(x,y,z,phase) so that the tumors position can be tracked between radiographs

-Compare tracking results of baseline and novel tracking algorithms to ground truth. I will provide the following metrics: percentage of time the algorithm was within 2mm of ground truth, mean difference along each spatial dimension, and standard deviation of difference along each dimension (precision)

References:

1. Bibault, JE., Prevost, B., Dansin, E. *et al.* Image-Guided Robotic Stereotactic Radiation Therapy with Fiducial-Free Tumor Tracking for Lung Cancer. *Radiat Oncol* **7,** 102 (2012). https://doi.org/10.1186/1748-717X-7-102
2. Noriyasu Homma, Yoshihiro Takai, Haruna Endo, Kei Ichiji, Yuichiro Narita, Xiaoyong Zhang, Masao Sakai, Makoto Osanai, Makoto Abe, Norihiro Sugita, Makoto Yoshizawa, "Markerless Lung Tumor Motion Tracking by Dynamic Decomposition of X-Ray Image Intensity", *Journal of Medical Engineering*, vol. 2013, Article ID 340821, 8 pages, 2013. https://doi.org/10.1155/2013/340821