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Innovative analytical 4D IGRT for lung SBRT with multiple implanted fiducial markers

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Objectives: The outer edge of fiducial markers for stereotactic body radiation therapy (SBRT) image guided radiation therapy (IGRT) of lung tumors are often contoured on the Maximum Intensity Projection (MIP) four dimensional treatment planning CT (4DCT). Treatment setup is visually verified if the current fiducial image is within its corresponding volume envelope plus margin. This process is user and display dependent, not quantitative, subject to imaging artifacts, and not suitable for automation. This work describes an innovative analytical process based on the 4D trajectory coordinates of the fiducials defined by the planning 4DCT and an orthogonal fluoroscopic image set over many
breathing cycles in the treatment position. Methods: A standard 4DCT is acquired at simulation and binned into ten phases. The center of each fiducial is assigned a position coordinate at each phase, i.e. the point set P = [i(x,y,z), b] where i is the fiducial index commonly 1 to 3 and b is the phase from 1 to 10. Treatment IGRT begins with a CBCT to an average 4DCT six degrees of freedom (6DoF) rigid body registration of a structure such as spine. Orthogonal fluoroscopic images are then obtained over many breathing cycles. The center of each fiducial is assigned a position coordinate at a preset frequency of 0.5 seconds on each view forming the point set F = [i(x,z), i(y,z), t] where i is the fiducial number, (x,z) and (y,z) are the position coordinates on the two orthogonal projections with a common z axis, and t is the time. Since the goal is to treat the target continuously all points must be considered equally weighted. A simple center of mass approach will bias the registration towards the most common position. The well-known Axis-Aligned Bounding Box (AABB) algorithm is an expression of the maximum extent of a data set. For example, if we consider a lateral fluoroscopic fiducial image, then AABB produces a box with sides at the maximum/minimum Sup-Inf positions and maximum/minimum Ant-Post positions. The box contains ALL data points. The next step is to compute the center of the bounding box for each fiducial both for plan point set P (Pc) and fluoroscopic images F (Fc). The translation registration (TR) is then computed such that TRi(Fc) = Pc for each fiducial. The mean TR is then applied to the patient. A successful registration is defined such that ALL transformed fluoroscopic points are within the plan point set plus margin, commonly 3 to 5 mm. Registration error metric is RE = TR(Fc) - Pc averaged for all fiducials. Cases with target deformation or rotation relative to normal anatomy can have large RE. A congruence Index (CI) is defined to quantify the distortion as the variation of the distance between fiducials either as a function of time on the fluoroscopic images or Fc relative to Pc. Results: The procedure was implemented without special software or hardware requirements. Results for a variety of cases indicate: 1. 4DCT tends to underestimate both the amount and variability of the fiducial

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motion. 2. CI correlates well with the required margin. 3. RE is significantly improved with the analytical process compared to visual estimates. 4. Fluoroscopic images with exceptional time and spatial resolution are superior to CBCT for fiducial registration. Conclusion: An innovative analytical process has been developed which can improve 4D IGRT accuracy for lung SBRT with multiple implanted fiducials.