Real-time markerless tumor tracking with MV imaging and a DMLC

Innovation/Impact: Robust real-time aperture adaptation for lung tumors during radiation therapy promises better local control while more healthy tissue can be spared. In this context we present the first implementation of a real-time adaptive therapy system using soft tissue localization (STiL) on continuously throughout the treatment acquired cine EPID images to maintain a dynamic treatment aperture centered on the current tumor location during the entire breathing cycle.
This approach is superior to other proposed tumor localization methods that rely on implanted fiducial markers (pneumothorax risk), additional imaging dose, external surrogates that may be poorly correlated to the tumor location and/or non-optimal imaging perspectives [1].

Methods: Portal images are continuously acquired during treatment delivery the current tumor location on each frame is extracted in real-time by an in-house developed soft tissue localization algorithm described below. The position coordinates are fed to the DMLC server to adapt the aperture position of the treatment field accordingly and keep the aperture centered on the moving target.

The *soft tissue tumor localization algorithm* continuously reads beams-eye-view images acquired with an electronic portal imaging device (EPID) operated in *cine* mode. Our approach circumvents the inherent problems of tracking a deforming and rotating 3D object on 2D projections by tracking multiple landmark regions which are automatically identified on an initialization image. The GTV's centroid position is then calculated from the average position of all landmarks. The algorithm consists of 4 steps:

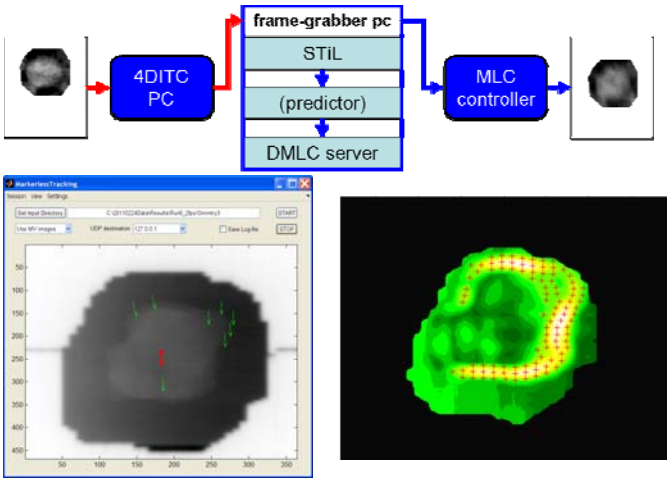

Figure 1 *(top):* Workflow of setup (prediction was not used for this study). *(middle)* Graphical user interface of STil component. *(right)* Variance filtered initialization image with landmark candidates (red crosses).

0. Initialization: a feature detector first finds a set of landmark candidates on the first image (local variance). Then this set is constrained to landmarks assumed to be suitable for tracking
1. A robust and fast tracking algorithm relocating the landmarks on each image within their respective search window by maximization of a similarity measure (NCC)
2. The set of new landmark positions is constrained by a geometric regularization criterion.
3. The remaining landmarks are used to calculate a mean centroid position

The *DMLC component* is described and characterized in detail in [2]. It receives the real-time input from the localization component, calculates the new leaf positions and communicates them to the MLC controller. The component depends on the Varian platform.

Experimental setup: The combined system of frame-grabber, soft tissue tumor localization and DMLC adaptation was tested with a 4D dynamic chest phantom (Washington University) equipped with a tumor mass modeled after the GTV extracted from a patient's CT and manufactured by rapid prototyping from a flexible resin [3] as the target.

Images were acquired with a Varian AS-1000 portal imager operated at 12.86 fps and a resolution of 512 x 386 pixels. The LINAC was a Varian TX equipped with a Millenium120 MLC operated at nominal beam energy of 6 MV and 600 MU/min dose rate.
To characterize the inherent system latency, i.e. the observed time lag between moving target and aperture position, the phantom was driven by a 20 mm superior-inferior sinusoidal motion with T = 4.5 s breathing cycle time. The latency was then calculated from the phase shift between two sinusoidal data fits to tumor and mask position, respectively (cp Figure 7). Timestamps were recorded in the image processing software to evaluate the contribution of image acquisition, localization and DMLC adaptation to the total latency.
To estimate the geometric error in a clinical application, the phantom was driven by patient data (recorded with the help of fiducial markers during the delivery of radiotherapy to the lung).

Results: The system latency is determined to be δt = 221ms. The overall lag time consists of about 70 ms for the tumor localization and 150ms for image acquisition and DMLC component.
The geometric accuracy for the STiL component alone is RMSE = (0.57±0.28)mm [4]. The geometric accuracy of the entire latency test setup improves from RSME = 7.1±6.9)mm without tracking to RMSE = (2.0±2.2)mm with tracking (but no use of any prediction).
The average geometric rms-error on a patient cohort of 11 patients and 172 beams induced by latency alone calculates to (1.8±0.0)mm (cp Figure 2).

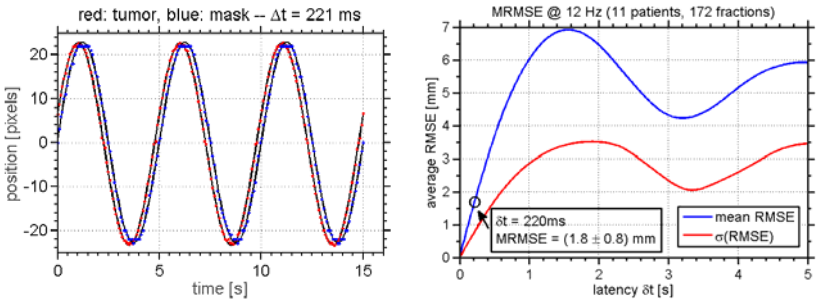

Figure 2 System latency and resulting RMSE. The *(left)* shows the measured tumor (red) and mask position (blue) with overlaid data fit recorded at 12.86 fps and 20 mm sup-inf sinusoidal driving motion. The *(right)* simulates expected mean RMS error for patient data [Hokkaido-ref] based on this.

Conclusions

We have developed the first prototype of a real-time adaptive therapy system integrating automatic soft tissue localization with dynamic multileaf collimator (DMLC) adaptation. The system was successfully tested and system latency measured. Even without the use of a prediction algorithm, the geometric error caused by system latency is < 2mm (RMSE). Use of a prediction algorithm will be able to reduce latency induced geometric errors further.

References

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