Automated Fiducial Tracking During VMAT Using Beam's-Eye-View Images

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Motivation

Patient motion during radiotherapy can cause divergences between the planned and delivered dose to the target area. For tumor sites where large internal movement is expected due to a patients' heartbeat or breathing pattern, implementing real-time tracking to locate the tumor during treatment could allow for better treatment accuracy, dose conformity and sparing of healthy tissue. For tumors located in the liver, pancreas or prostate fiducials are often implanted to provide a high contrast object to facilitate correct patient positioning. These objects are a convenient surrogate to perform real-time tracking.

Data

- 7 liver SBRT patients
- 2 fractions of images were collected for each patient
- Images collected using a prototype multi-layer electronic portal imaging device [1]
- FF and DF corrected images grabbed by Varian iTools
- Images collected in ciné mode
- Frame rate of ~10 images per second

Algorithm

The tracking algorithm is based on a previously developed markerless tracking algorithm [2], with an additional fiducial detection step. The core of the algorithm is based on template matching; for each fiducial a cluster of templates is generated which are then tracked by calculating the normalized cross-correlation (NCC) with subsequent images. Information about each cluster is used to maintain the tracking integrity for each fiducial, allowing them to be tracked independently. The algorithm is summarized below:

Initialization (first image in sequence)

I. Image processing: aperture masking + variance calculation
II. Fiducial detection
III. Template generation + grouping

Tracking (subsequent images)

I. Image processing: aperture masking + variance calculation
II. Template Matching
III. Verification
IV. Template Updates (IF NCC values drop below threshold)
V. Fiducial Detection (IF # of tracked fiducials is less than expected)

Fiducial Tracking Algorithm

Collected Image

- Ciné MV images
- DF and FF corrected
- Analyzed retrospectively

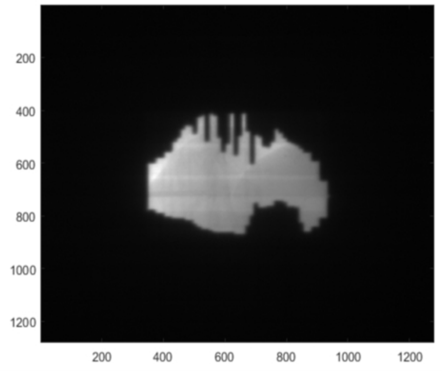
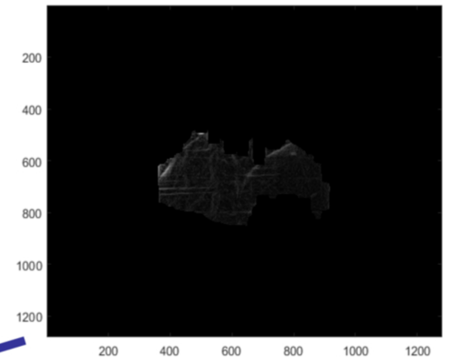


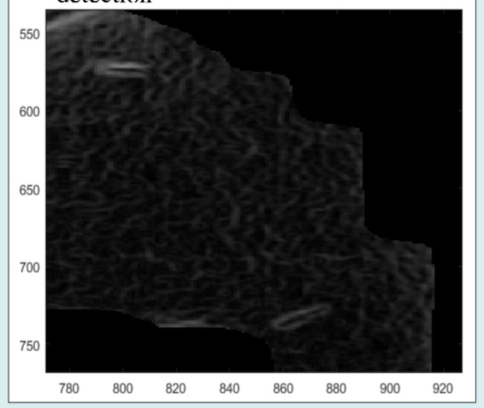
Image Processing

- Smoothing (average filter)
- Aperture masking
- Calculation of the variance image



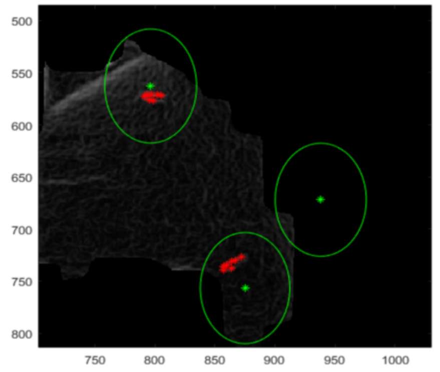
Fiducial Detection

- ROI = regions of high variance
- Inspect shape of object for fiducial detection



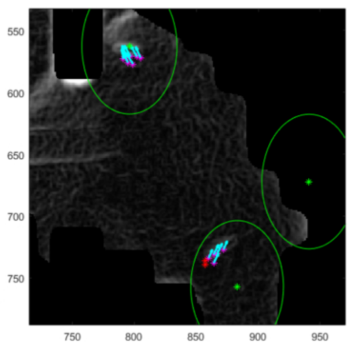
Template Generation

- Each detected fiducial is described as a cluster of templates
- Templates are generated along lines of high variance



Feature Tracking

- Each fiducial is tracked independently on subsequent images.
- The cluster of templates describing each fiducial is evaluated as a group, considering:
  - Preservation of relative orientations of the templates
  - Realistic motion
  - Stability of individual templates
  - NCC values (individual and average)
- Fiducial is tracked if cluster passes required score
- Update stage if required:
  - Template is updated to current image IF fiducial is tracked AND NCC value is low
  - New fiducial detection IF # tracked fiducials is less than expected



… continue to subsequent image …

Truth Data

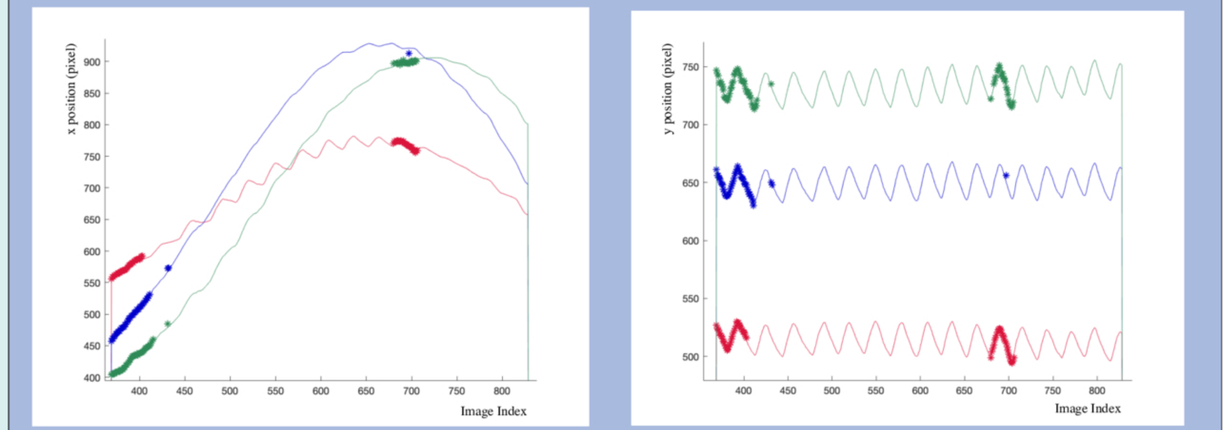


Fig. 1. Fit output (solid line) against manually tracked positions (stars) for 3 fiducials across a single treatment field.

Results

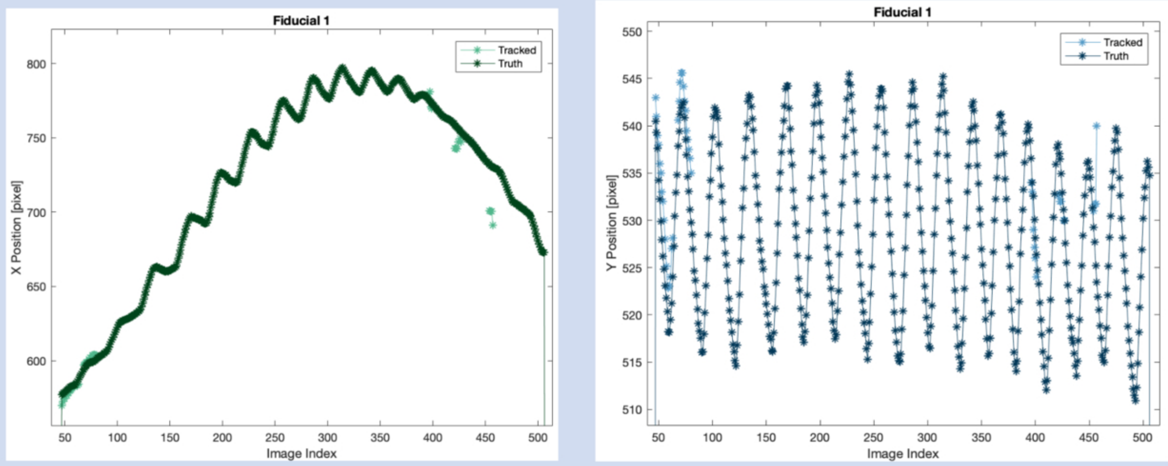


Fig. 2. Position output on MV imager plane at isocenter (left; x direction, right; y direction) of the fiducial tracking algorithm (light stars) against truth data (dark stars) for a single fiducial across a single treatment field.

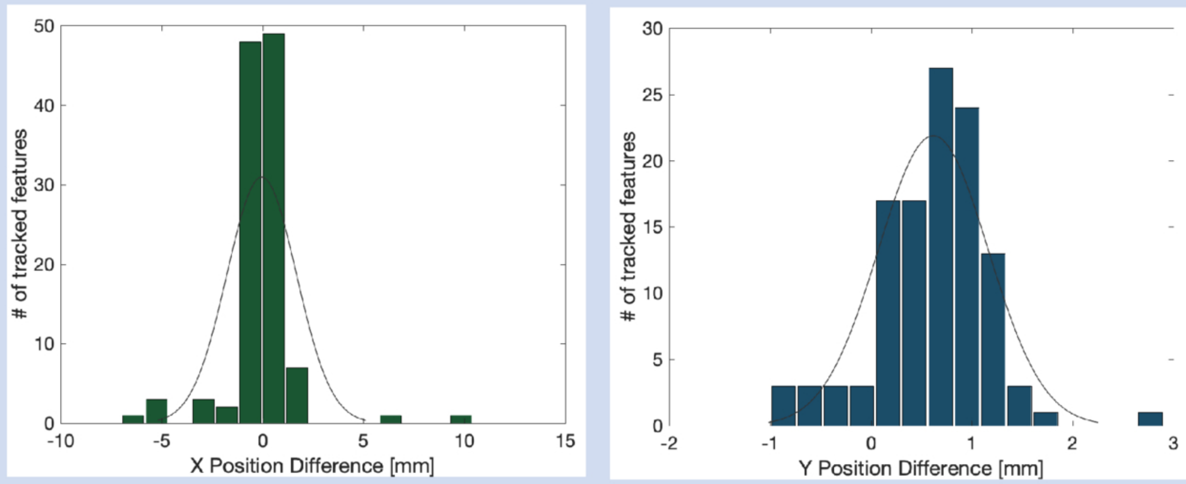


Fig. 3. Fit to histograms of differences between truth and tracked positions for all fiducials across all treatment fields for a single patient.

Truth Data

- True position data is required to evaluate the tracking accuracy.
- Hundreds of cine MV images can be acquired during a single treatment field.
- During treatment, the patient's breathing trace is recorded.
- The AP motion is used to generate a 3D motion model, which is fit to a handful of manually tracked positions (Fig. 1).
- Synchronization between the 3D breathing model and the MV images is performed by aligning gantry angle information.
- Biases from the fit are evaluated by fitting a gaussian to the difference in known positions and combining the mean and width in quadrature.

Results

- A subset of available data was used to evaluate the tracking performance.
- The tracker output is compared to the generated truth data (Fig. 2).
- To generate a numerical metric the differences between the tracked and truth position of each fiducial is calculated in both the x and y direction of the imager, backprojected to isocenter.
- Each tracked fiducial on each image generates a set of differences.
- These values are plotted as a histogram (Fig. 3) which is fit with a gaussian, the mean and width of which is combined in quadrature to give a value for the tracking error. The tracking error was found to be ***1.91 mm***.

Conclusions

A fiducial tracking algorithm using MV portal images has been developed to be robust to features moving in and out of view, enabling the method to be used for different treatment modalities, for example, VMAT.
This algorithm has been demonstrated on liver SBRT patients with a tracking error of 1.91 mm, comparable with uncertainties demonstrated by others in the literature. Further evaluation is planned for images collected during treatments for prostate and pancreatic cancer.

References & Acknowledgements

[1] Myronakis M, Hu YH, Fueglistaller R, et al. Multi-layer imager design for mega-voltage spectral imaging. Phys Med Biol. 2018;63(10):105002.
[2] Ferguson D, Harris T, Shi M, et al. Automated MV markerless tumor tracking for VMAT. Phys Med Biol. 2020;10.1088/1361-6560/ab8cd3. doi:10.1088/1361-6560/ab8cd3

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