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JOINT AAPM | COMP MEETING

A Path Predictive Algorithm for Metal-Artifact Reduction in Cone-Beam CT in Prostate Cases Without Thresholding.

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INTRODUCTION

Gold fiducials are placed in patients to ensure precise targeting during radiotherapy, Fig.1.

Fiducials, such as gold, have linear attenuation coefficients 10 times higher than soft tissue. This discrepancy causes streak artifacts in the reconstructed CT images, reducing image quality, Fig. 2. Making it important to have an algorithm to reduce the metal artifact in CBCT.

The proposed novel MAR technique predicts the location of fiducials in every projection, which is used to reduce the effects of photon starvation in reconstruction.

Fig. 1: Gold Fiducial [1]

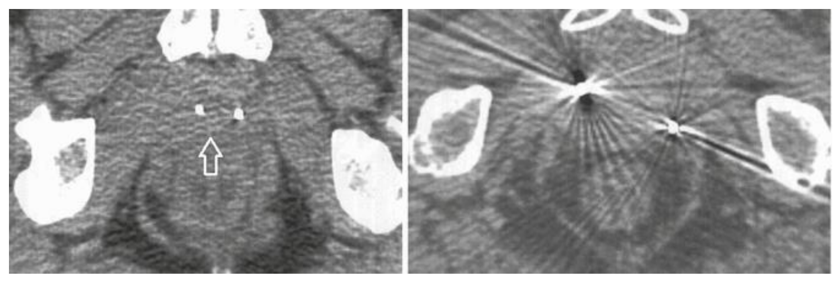


Fig. 2: CBCT projection showing implanted gold fiducials in a prostate case [2].

OBJECTIVE

To develop an open-source algorithm to analytically predict and track the path of the fiducials on the CBCT projection space.

Materials and Methods

This procedure was validated on:
- 10 prostate cancer cases
- Using 5 pairs of points per case across 50 gantry angles
- The manually selected points were compared to the predicted ones .

EXISTING APPROACHES

Several strategies exist for metal artifact reduction (MAR) in CT and CBCT, including projection interpolation and iterative reconstruction.

Projection-based methods typically mask metal and interpolate missing data, while iterative algorithms minimize reconstruction inconsistencies [3].

For this project, most of these general pipelines were implemented on parallel-beam CT using sample data on a computer, giving us the basic code.

Additionally, Zhang et al., 2007 [4] demonstrated that two-view triangulation can approximate fiducial positions, a strategy used here to track marker trajectories, see Fig 3.

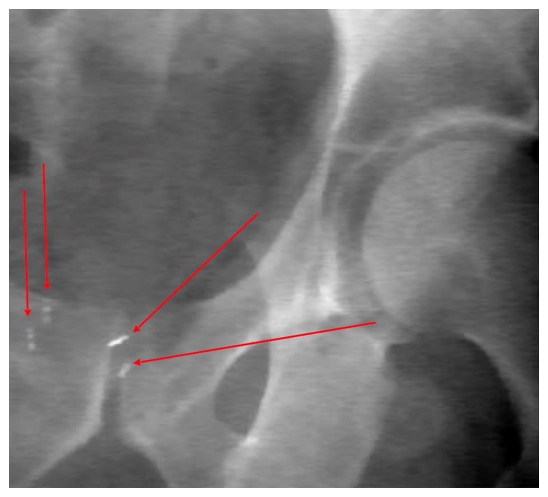


Fig. 3: CBCT projection showing implanted gold fiducials in a prostate case.

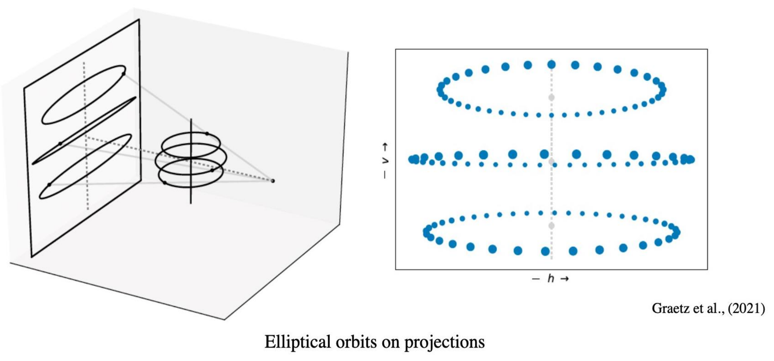


Fig. 4: Elliptical orbits on projections.[5]

CHALLENGES SPECIFIC TO CBCT

In CBCT, the 2D projected path of a 3D fiducial motion is elliptical [5], see Fig 4. This complicates artifact modeling, as conventional 2D sinusoidal detection methods like Steger's are insufficient for accurately tracking marker trajectories. For our case, this is not enough, since the fiducials follow an elliptical helical path in 3D projection space.

Trajectory Model

A two-view triangulation formula was used to predict the fiducial paths for other gantry angles, see Fig. 5.

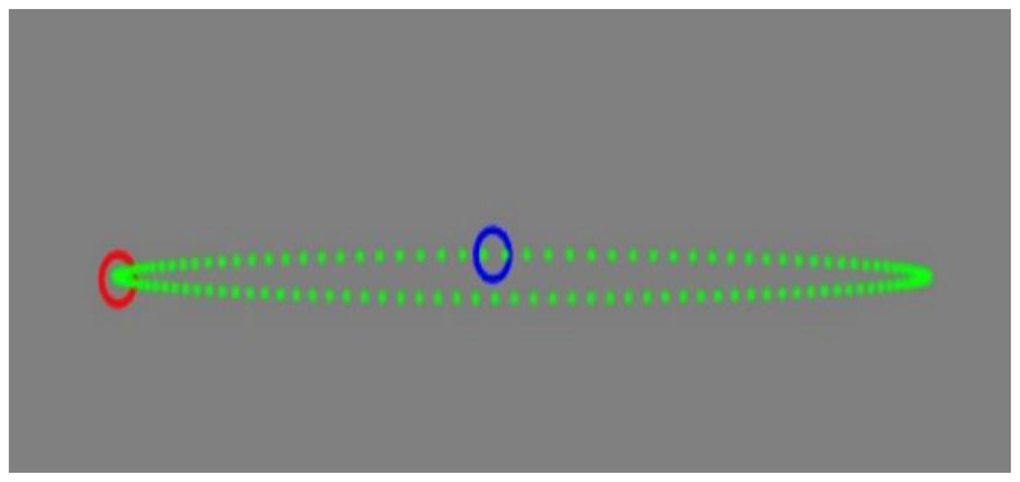


Fig. 5: Elliptical orbits on projections.[4]

Inspired by prior work [4], Laplacian inpainting was applied along these paths to reduce artifact interference.

Unlike approaches such as [4] who describe the triangulation step as not admitting a straightforward closed-form expression in previous frameworks, the method used here provides a compact analytical solution suitable for rapid point estimation.

The derivation is based on a two-stage formulation:
1. Parallel-beam surrogate: The problem is first expressed in an equivalent parallel-beam geometry, giving us a solution in the simplified case.
2. Perspective mapping: The parallel-beam solution is then mapped back to cone-beam geometry using a perspective projection, relating the actual projection coordinates to the 3D location of the marker.

The trajectory model follows the analytical description provided by Marchant et al. (2012) [6], which gives the expected 2D elliptical path traced by the marker when projected across the CBCT views.

By combining the closed-form triangulated coordinates with Marchant's trajectory equation, the expected 2D seed position can be predicted for all remaining projections, forming the basis for later path-based masking and interpolation

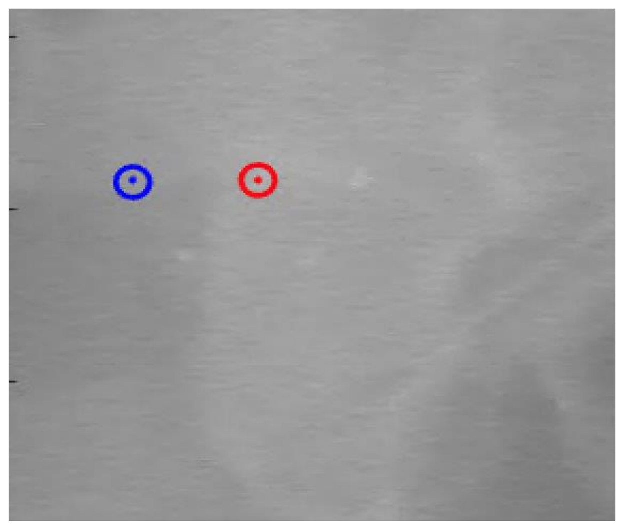


Fig. 6: Two manually selected points

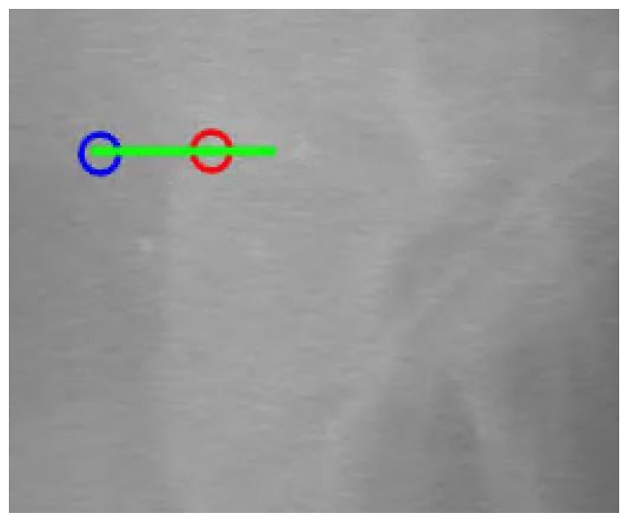


Fig. 7: The path through the manual selection and the predication

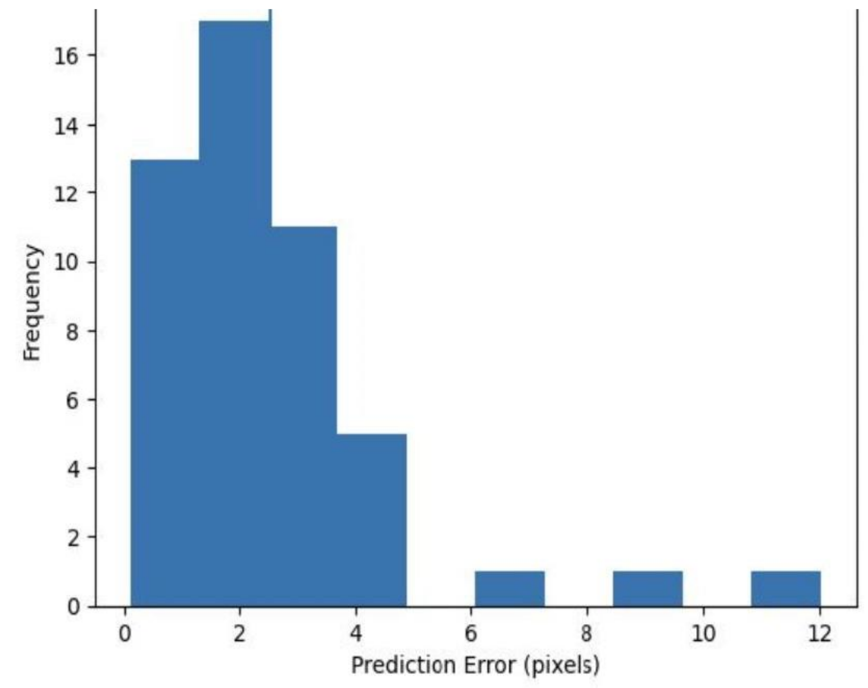
RESULTS

Mean fiducial localization error: 2.52 ± 2.13 pixels (0.98 ± 0.83 mm); improved to 2.13 ± 1.19 pixels (0.83 ± 0.46 mm) after excluding 3 geometric outliers (n = 47).

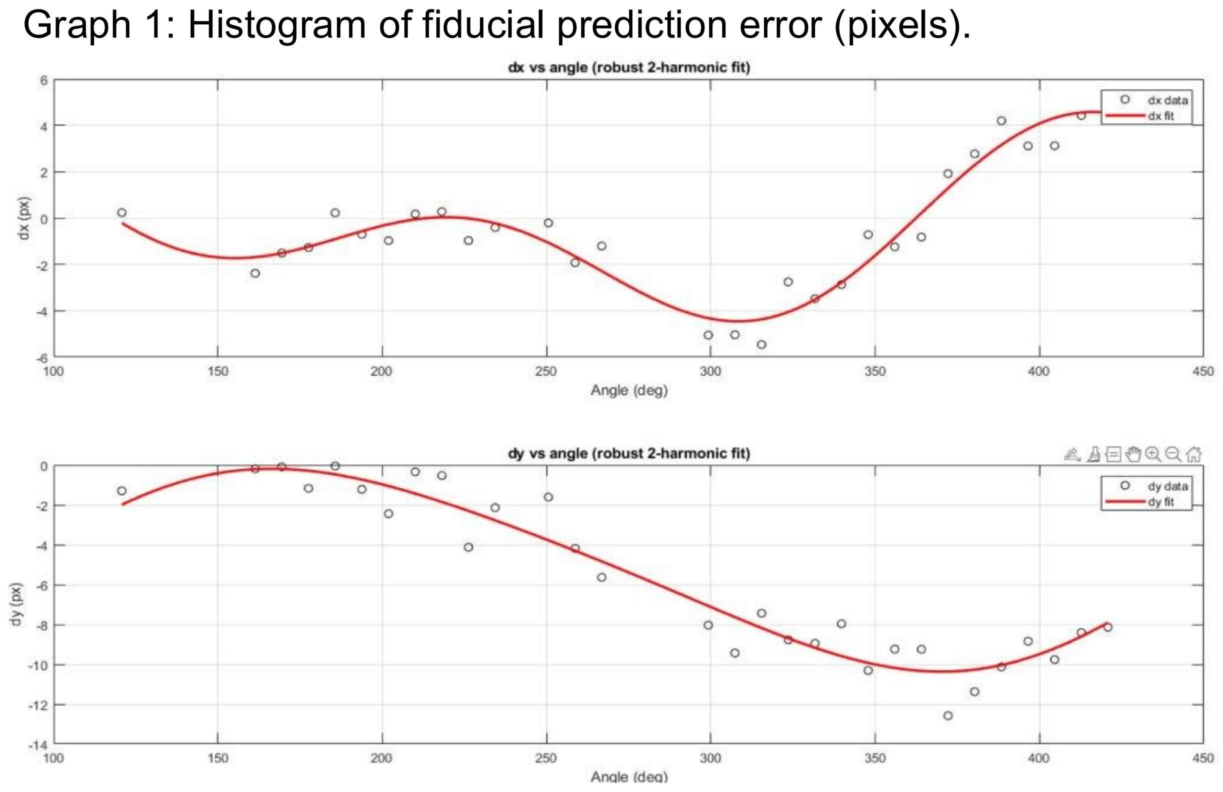
RESULTS…

Three >5 pixel outliers were consistent with unmodeled gantry sag, supporting a mechanical rather than algorithmic source of error.

Artifact reduction improved reconstruction quality while preserving structural fidelity and sub-millimeter tracking accuracy across gantry angles.



Graph 1: Histogram of fiducial prediction error (pixels).



Graph 2: Example of fiducial localization error in X and Y directions for an outlier patient. Systematic deviations suggest geometric effects (e.g., gantry sag).

FUTURE DIRECTIONS

Account for the potential sag effects in the model to make it universal. Extract radiomics features to further explore the benefits of MAR reconstructions on radiomics studies.

CONCLUSIONS

The proposed path-predictive algorithm achieved sub-millimeter fiducial localization accuracy under ideal geometric conditions.

This result demonstrates the feasibility of the fiducial path predictive approach for accurately estimating fiducial marker locations in CBCT projections.

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