A Clinical Application for Real-Time Motion Verification and Monitoring During Proton Treatment

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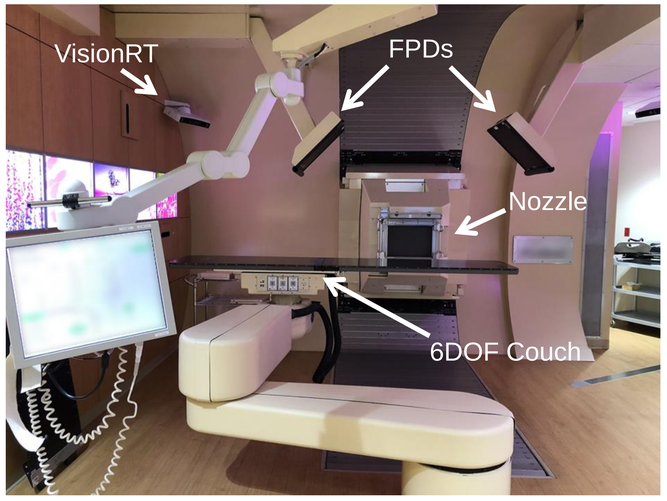
Introduction

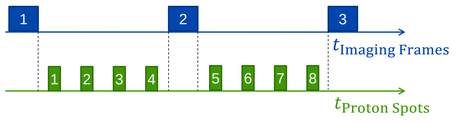
Respiratory motion management is crucial for spot-scanned proton therapy, where motion-induced dosimetric "interplay" effects can severely perturb the planned dose distribution. Our proton therapy vendor developed a stereoscopic kV x-ray image guidance platform along with a 3D/2D image matching algorithm for 6 degree-of-freedom patient positioning with a robotic couch (6DOF couch). However, this **vendor-provided imaging platform lacks the capability to adequately handle real-time kV fluoroscopy**, which is crucial for aspects of motion management.



Patient treatment room at Mayo Clinic Proton Center (Rochester)

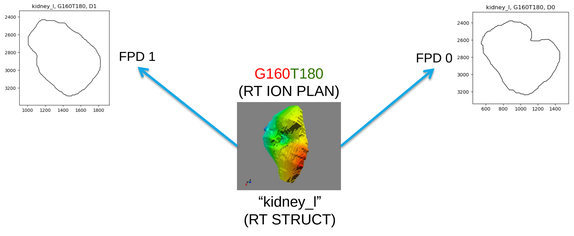
Objectives

- ***Real-time Handling of Pulsed Fluoroscopy***



  - Interleave imaging frames with proton spots
  - Allow real-time internal organ motion verification
  - Reduce imaging dose to the patient

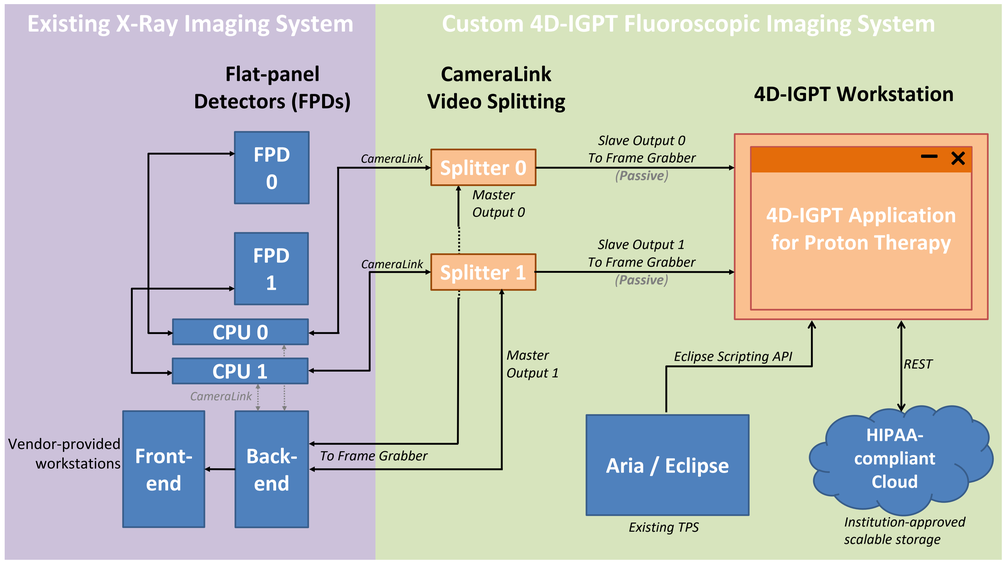
- ***Accurate Overlay of DICOM RT-STRUCT Contours***



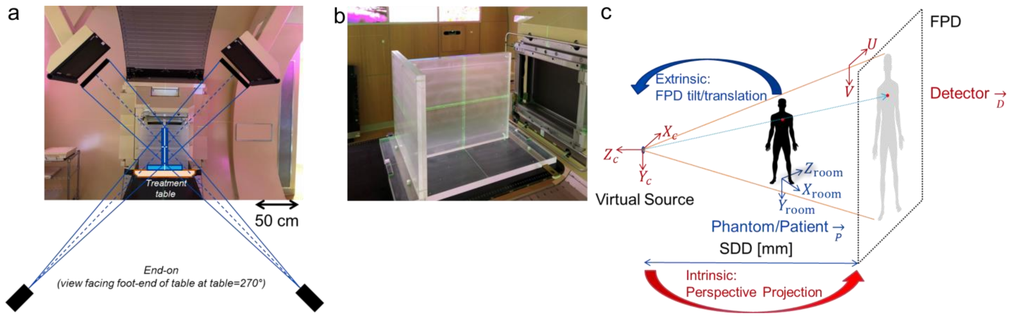
  - Overlay structures (e.g. ITVs) on top of live fluoroscopy
  - Correct geometrical errors in FPD placement

Methods

1. Fast video-splitting to passively copy fluoroscopic frames from vendor platform

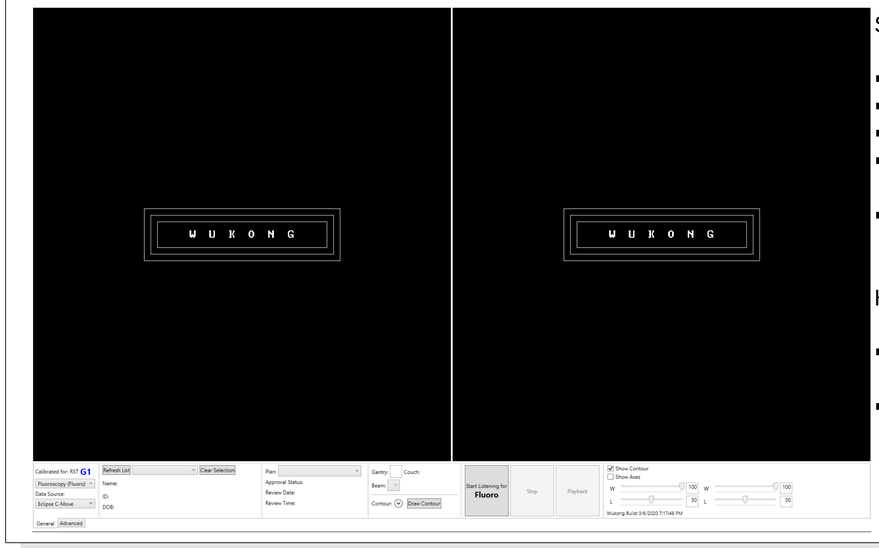


2. Custom acrylic phantom with steel BBs for room-specific geometry calibration



- Largely based on the **Tsai method** (Tsai, IEEE J. Robot. Autom., 1987) for camera calibration
- Converts the frame-of-reference of the 3D CT volume to that of the 2D imager plane

3. User interface integrated with treatment planning system (TPS)



Software:

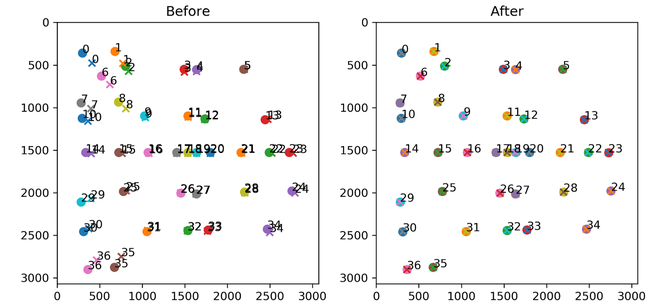
- C# 8.0
- .NET Core 3.1
- WPF
- Embedded Python
- Varian Eclipse Scripting API

Hardware:

- Camera Link Frame Grabber
- Windows PC

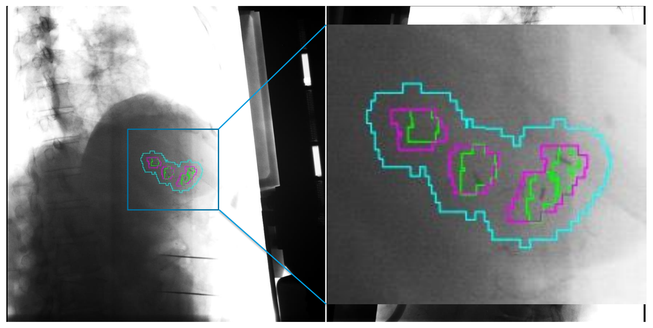
Results

1. Projective geometry calibration

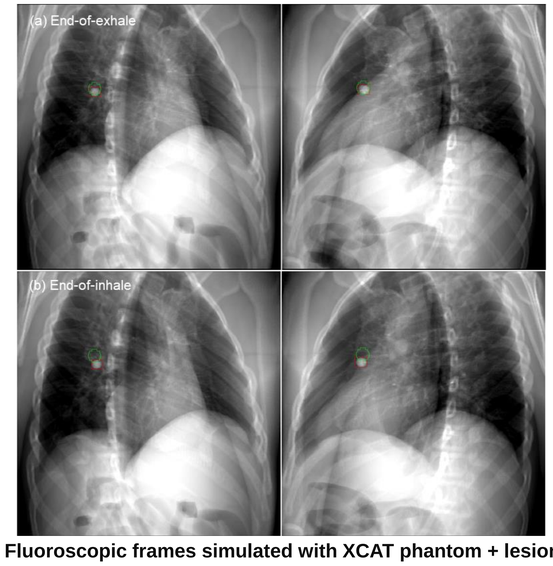


- Mean-squared Error at iso-center: ~0.015 cm

2. End-to-end verification with clinical liver fiducial case



3. Preliminary results for marker-less lung target tracking



Fluoroscopic frames simulated with XCAT phantom + lesion

Conclusions

- We built a Windows GUI application for reliable high-speed acquisition and real-time processing of fluoroscopic x-ray frames from wall-mounted FPDs.
- The accompanying custom phantom and calibration routine were developed to correct the positional deviations of the FPDs from specification.