Development of a Stand-alone Comprehensive Collision Prediction System for Non-Coplanar Radiotherapy

Naveed Islam[1,2], Josh Kilian-Meneghin[1,2], Matthew Podgorsak[1,2]

(1) Roswell Park Comprehensive Cancer Center, Buffalo, NY 14263

(2) State University of New York at Buffalo, Buffalo, NY

MOTIVATION

Purpose

- Determination of potential collisions between patient, treatment accessories, and LINAC mechanical components during treatment planning is important
- Studies exploring use of non-coplanar 4π radiotherapy involving non-standard treatment couch and gantry orientations have demonstrated significant dosimetric benefits
- A stand-alone comprehensive collision prediction system (CPS) has been developed using a geometric model
- The CPS can be used in conjunction with a treatment planning system to predict collisions in 4π treatments prior to delivery

Project Vision

- Stand alone tool for treatment planning: Can be used to determine deliverable beam angles
- Patient specific model incorporated into CPS
- Post plan generation: Secondary independent safety check
- Comprehensive:
  - Incorporate MV and KV imaging devices
  - Patient immobilization devices and accessories
- Relatively easier to understand the underlying mechanics of collision model (Not a "black box" tool)

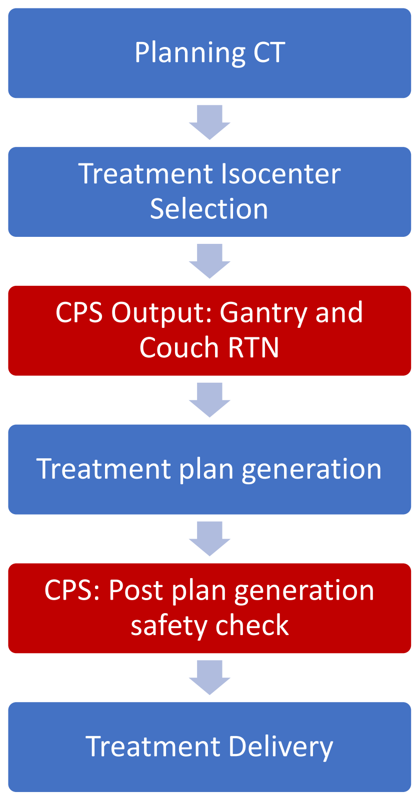


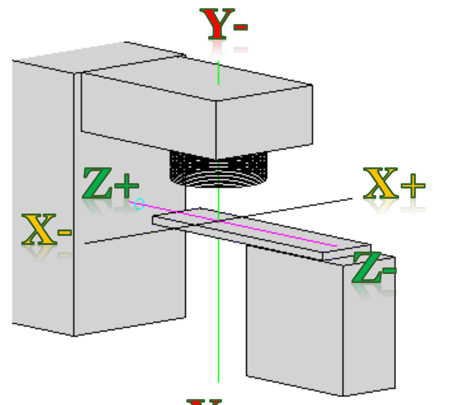
Figure 1: Integration of CPS into regular clinical workflow

METHODS

Approach and Implementation

- Geometric model in 3-D space
- Fixed coordinate system: IEC coordinate convention
- LINAC isocenter located at origin
- Implemented using MATLAB – 2017 version
- Object Oriented Approach
  - Couch class
  - Gantry class
  - Patient class
  - KV-Source and KV-Imager class
  - MV-Imager class
- GUI underdevelopment in MATLAB

Figure 2: CPS virtual model of LINAC and treatment couch



Couch and Gantry Model

- Couch model: Rectangular prism modeled using 8 corner points for couch top and additional points for turn table
- Gantry model: Collimator head modeled using 3 points

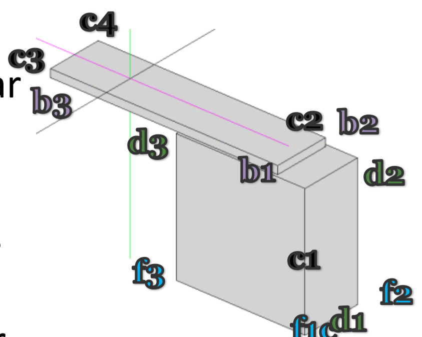


Figure 3: Geometric model of treatment couch

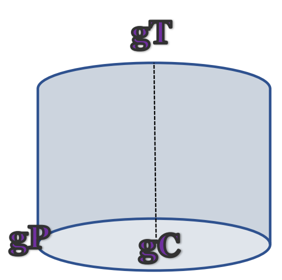


Figure 4: Geometric model of gantry head

Patient Specific Model

- Combination of planning CT Body contour and Microsoft's Kinect camera used to develop a full model of the patient
- A calibration image is used to appropriately transform from Kinect camera coordinate system into CPS coordinate system and apply the appropriate scaling factors

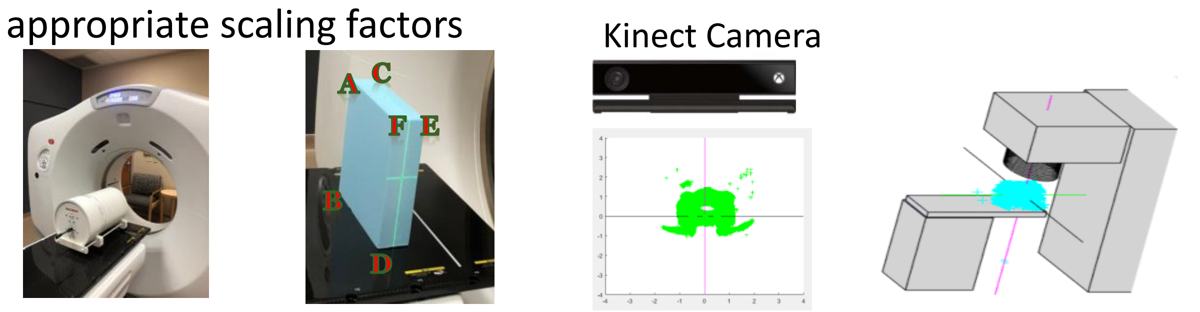


Figure 5: Left to right – (a) ArcCheck setup in CT room prior to acquiring Kinect image and CT scan (b) Styrofoam block used for Kinect calibration (d) Raw Kinect camera data points for ArcCheck (e) Virtual image of CPS after Kinect camera data for ArcCheck imported into CPS model

METHODS

Collision Detection Algorithm

To detect a collision the CPS iterates through test points in the model and checks whether it is inside the cylinder used to model the gantry using the following steps:

1. Consider the plane along the bottom face of the cylinder used to model the gantry (Figure 6)
2. Consider the vector from point gC to a particular test point P
3. Case A: Point on the "cylinder" side of the plane (Figure 7)
   - Dot product of vector gCgT and vector gCP will be positive due to the angle between the two vectors
4. Case B: Point on side of the plane without cylinder (Figure 8)
   - Dot product of the vector gCgT with vector gCP will be negative due to the angle between the two vectors
5. Apply same principle for top face of cylinder to determine if test point is on the "cylinder" side of the top plane
6. Calculate perpendicular distance from test point P to the vector gCgT to check if it is less than radius. If less than radius then a collision has been detected

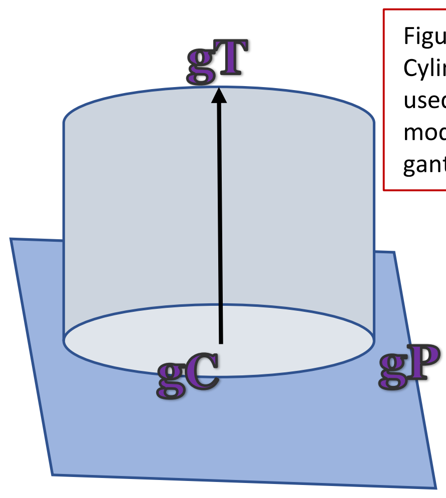


Figure 6: Cylinder used to model gantry head

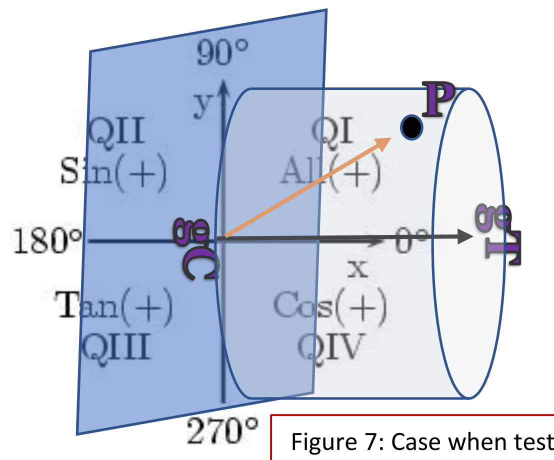


Figure 7: Case when test point on "cylinder" side of plane

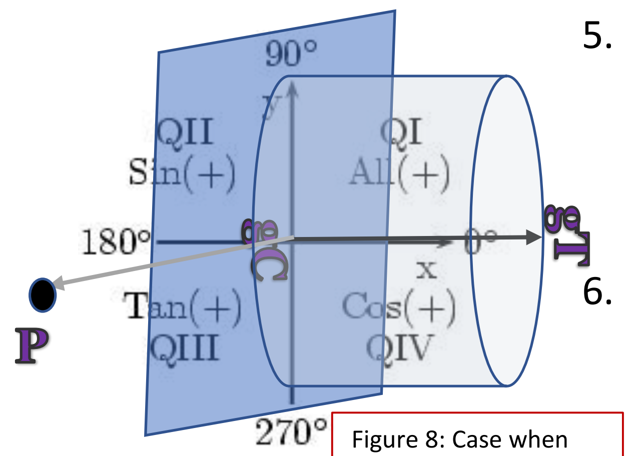


Figure 8: Case when test point not on "cylinder" side of plane

Validation of CPS

- Systematically test wide range of collision scenarios: Compare model prediction vs. reality

RESULTS

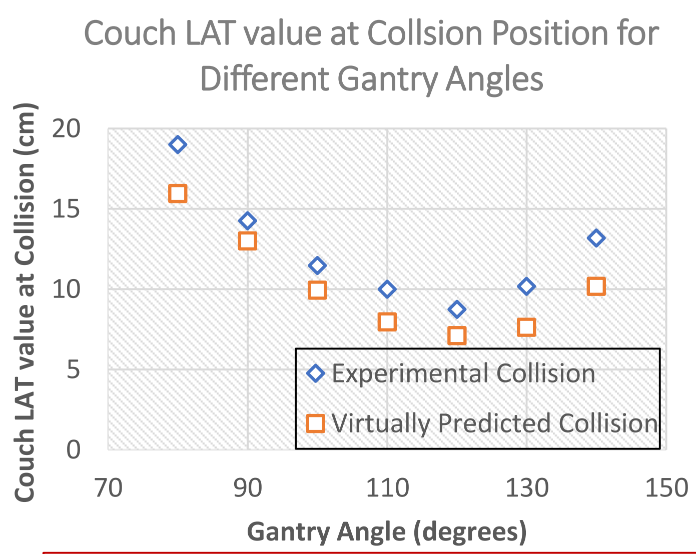


Figure 10: Exp. 1 – Couch LAT value at collision position for different gantry angles

Experiment 1:

- Gantry rotated to specific angles and the couch was then moved laterally until there was a collision
- Couch LAT value was recorded and compared with the LAT value position predicted by the CPS
- Average error in prediction was 2.14 cm.
- The collisions in this experiment occurred between the treatment couch and gantry.

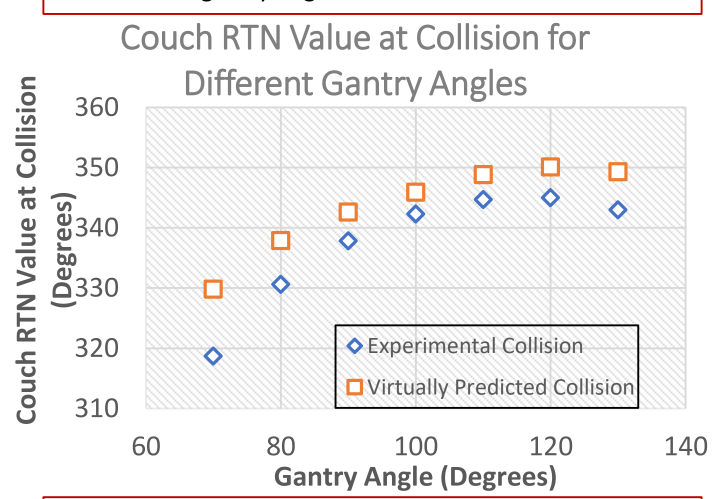


Figure 11: Exp. 2 – Couch RTN value at collision position for different gantry angles

Experiment 2:

- The gantry was rotated to specific angles and the couch was rotated until there was a collision.
- The couch RTN value was recorded and compared with the RTN value position predicted by the CPS
- The average error in prediction was 6.04 degrees.
- All collisions in this experiment also occurred between the treatment couch and gantry.

RESULTS

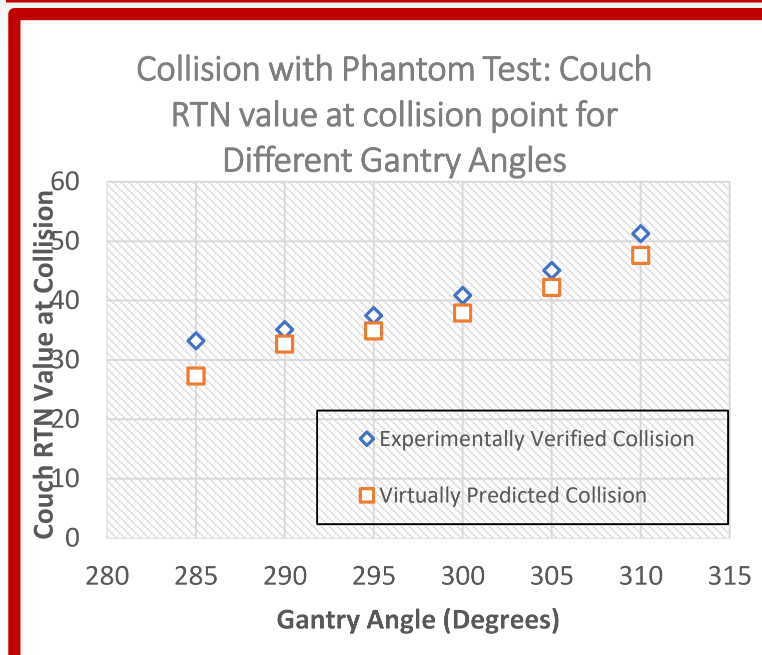


Figure 12: Exp. 3 – Couch RTN value at collision position for different gantry angles. Note: Collison with phantom

Experiment 3:

- Prior to proceeding the experiment, the couch was shifted with the ArcCheck phantom to ensure a collision occurs with the phantom.
- The gantry was rotated to specific angles and the couch was rotated until there was a collision.
- The couch RTN value was recorded and compared with the RTN value position predicted by the CPS
- The average error in prediction was 3.41 degrees.
- All collisions in this experiment occurred between the phantom and gantry

Summary

- 52 different gantry and couch positions were evaluated for collisions
- CPS model positive predicative value = 0.83
- CPS model negative predictive value = 1

	CPS: Virtual Collision	Observed Physical Collison
True Positive	Yes (√)	Yes (√)
True Negative	No (×)	No (×)
False Positive	Yes (√)	No (×)
False Negative	No (×)	Yes (√)

Table 1: Table summarizes the ROC formalism applied to evaluation of CPS model

	Number of Test Cases
True Positive	35
False Positive	7
True Negative	10
False Negative	0

Table 2: Summary of 52 different gantry and couch positions that were evaluated for collisions

Example of CPS output after selection of treatment isocenter

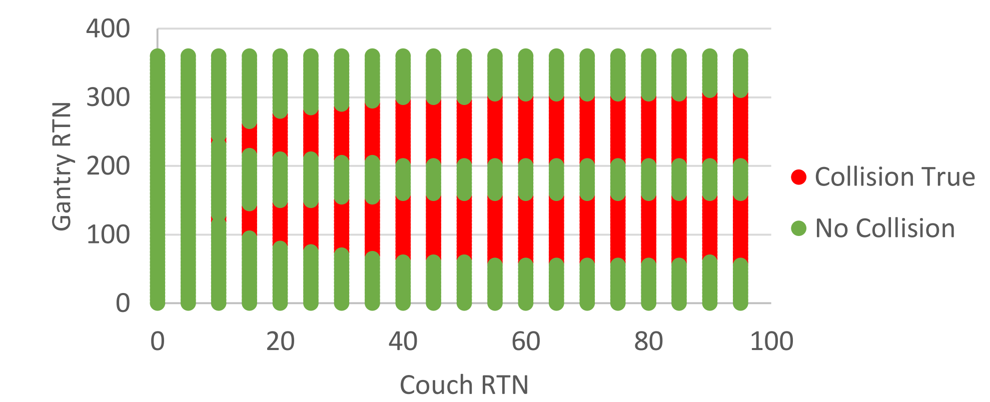


Figure 13: The treatment isocenter was chosen inside ArcCheck phantom. The CPS output various combinations of gantry and couch rotation values that are collision free

CONCLUSION

- The framework for a comprehensive collision prediction system has been developed
- CPS model validation experimental results have been acceptable
- Model refinements are in progress and should result in improved accuracy
- In its completion, the CPS will serve as:
  (1) Valuable tool for efficient treatment planning workflow
  (2) Post plan generation quality assurance: Secondary safety check
- This work can serve as a valuable reference to clinicians who seek to apply same principles to develop in-house collision prediction system

Acknowledgments

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