Fast and Accurate Patient Specific Collision Detection For Radiation Therapy

Introduction: In external beam radiation therapy, it is desirable to find the configuration of a patient's setup which results in an optimal treatment. One of the variables that has posed a problem in treatment planning is the potential hardware collisions that can occur as a result of gantry and table motion. A system capable of calculating collision positive configurations of equipment and/or the patient could provide the information needed to calculate better treatment setups, prevent hardware damage, and improve patient safety.
Over the past few decades, there have been several tools (1-6) developed to help determine potential collision events between radiotherapy devices and the patient. The major drawback to each of these methods is that they are either not specific to a given patient setup, not designed to be used before treatment planning, or not fast enough to be used to calculate the entire collision space. The goal of this work is to demonstrate a framework which is both patient specific and fast enough to calculate the collision space prior to treatment planning.

Geometrical Models: The table geometry, being the simplest of the models used, was created using three rectangular cuboids for the base, stage, and table top. The dimensions of each cuboid were determined by in room measurements. The gantry geometry was modeled in Autodesk Softimage using orthogonal images taken of the accelerator. A front pointer was used to maintain the model geometry relationship with isocenter and dimensions of the model were then set using in room measurements.

The phantom model was created from contours generated in the treatment planning system. The contour point cloud was transformed and triangulated into a polygon mesh using a ball pivoting algorithm in MeshLab software. The position of isocenter relative to contour geometry was recorded and used to position the phantom geometry in the global coordinate system.

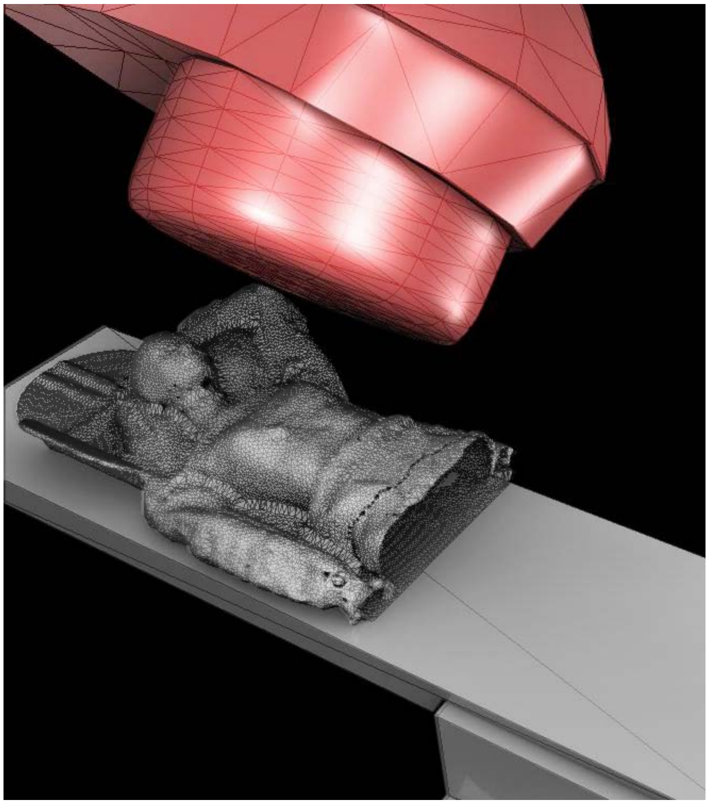

Figure 1: Rendering of model geometry in one state that resulted in a positive collision.

Geometrical Transforms: The ease of use of the framework developed was aided by the abstraction of complex transforms into five input variables: table vertical, longitudinal, lateral, rotational values and gantry angle. These variables were combined with functions to manipulate the 4x4 transformation matrix **T** of each model. Models were divided up into parent-child relationships which formed a model hierarchy. Final transforms were created by the multiplication of ascending transforms in the model hierarchy. In doing so, the child model transformed relative to its parent in a local coordinate system and the series of transforms resulted in vertex values in the global coordinate system. For any given vertex **v** then, the transform applied was

$$\boldsymbol{v}_{global} = \left(\boldsymbol{T}_{root} \ldots \left(\boldsymbol{T}_{parent}\boldsymbol{T}_{child}\right)\right)\boldsymbol{v}_{local}$$

Collision Detection: The collision detection was achieved using the Robust and Accurate Polygon Interference Detection (RAPID) library (7) developed in C++. RAPID takes two polygon models as inputs and can determine if any triangles are overlapping. The RAPID algorithm can be divided into two parts: 1) creation of a bounding box hierarchy and 2) testing for overlap of the bounding boxes. The hierarchical bounding box

(HBB) method essentially allows for a preliminary low resolution collision test using the outer most bounding box. If the test is positive, successive higher resolution tests can be performed, iterating down to a bounding box that encapsulates just a single triangle.

Measured Data: To assess the accuracy of the collision prediction by the framework, a few couch angles, represented by colored lines in the following figure, were selected as the domains to map out the real collision space in the treatment room. Receiver operating curve analysis was used to determine the true positive **TP** (predicted true and true), true negative **TN** (predicted false and false), false negative **FN** (predicted false and true), and false positive **FP** (predicted true and false) collision spaces. This allowed calculation of a metric of accuracy defined by

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

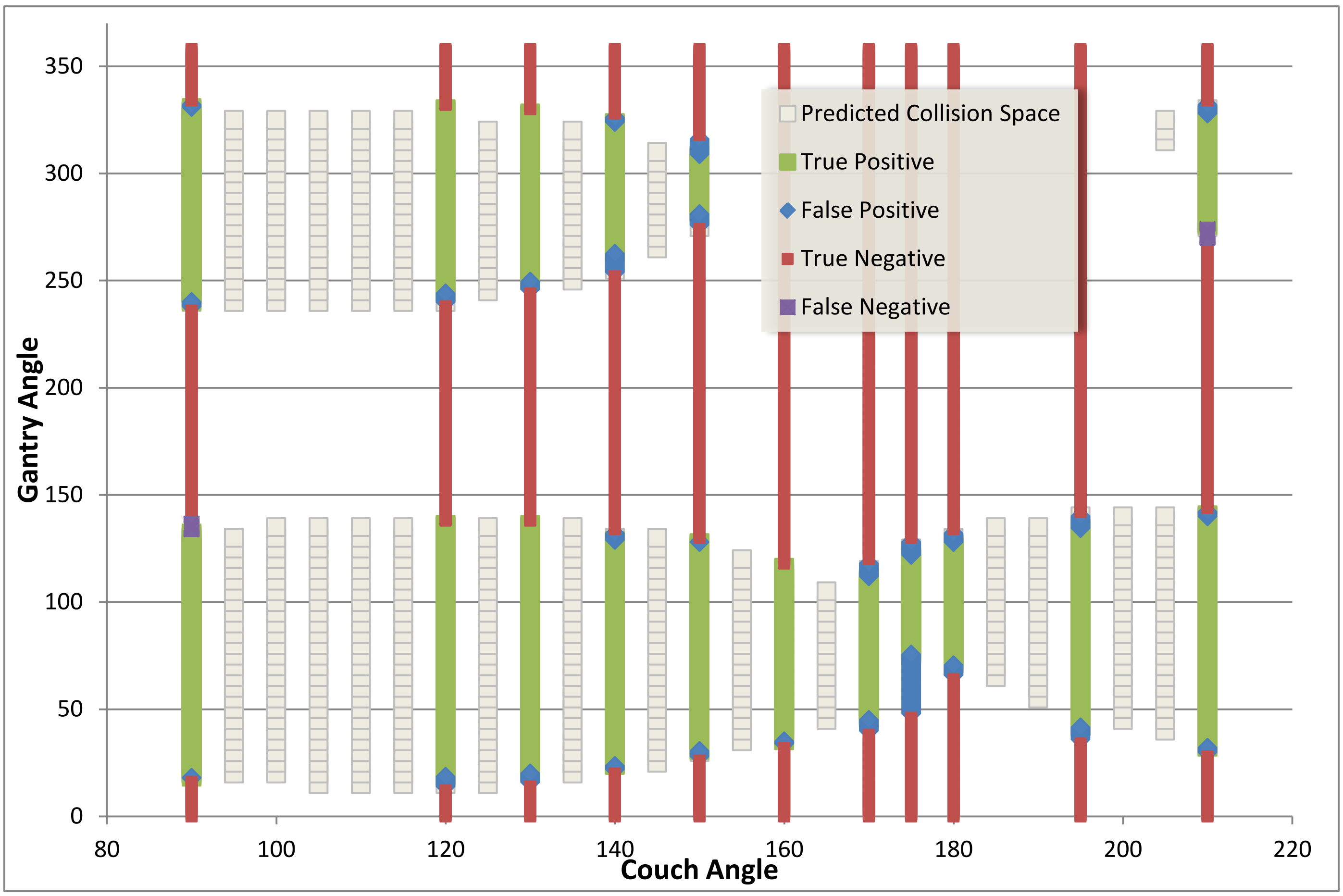

Figure 2 : The agreement of the physically measured collision space with the computer predicted collision space. Only a small sample of the predicted collision space (grey squares) was measured physically (colored lines).

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