PRE-CLINICAL VALIDATION OF OPEN SOURCE TOOLS TO CALCULATE AND TRACK MR DISTORTION USING BOTH SMALL AND LARGE FIELD OF VIEW PHANTOMS

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Introduction

MR simulation for Radiation Therapy (RT) is desirable due to its superior soft tissue contrast when compared to CT [1,2,3]. However, inherent spatial distortions in MRI have been found to exceed 5 mm in regions away from isocenter, which is not ideal for RT planning. Thus, measuring and tracking this distortion is necessary for treatment planning with MRI. Availability of open source algorithms may allow centres to independently test and compare results from vendor provided software during the commissioning of an MRI QA program.

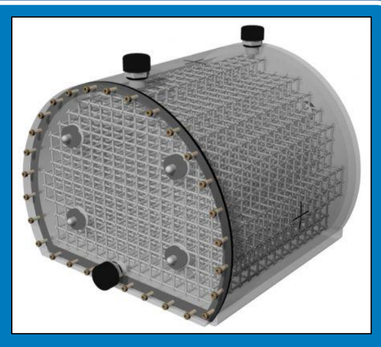
Objectives

To develop and validate an open source software solution for calculating, visualizing, and tracking MRI distortion on anthropomorphic grid phantoms.

Methods and Materials

The phantoms used in this study are the CIRS MRI distortion phantom for SRS (Model 603A) and the CIRS Large Field MRI distortion phantom (Model 604), as seen in Figure 1. Both phantoms contain 3D orthogonal grids of rods whose intersections are used as principle points for CT and MR image comparison. The SRS model also contains anthropomorphic skull features.

603A Phantom



604 Phantom

Figure 1: For the 603A the grid spacing is 15mm, For the 604 the spacing is 20mm.

High resolution CT images of the phantoms were taken on our GE LightSpeed CT system. MRI images were obtained using our 3T Siemens Skyra MRI system using a three dimensional image sequence. These image are processed using modules developed in 3D Slicer, as shown in Figure 2.

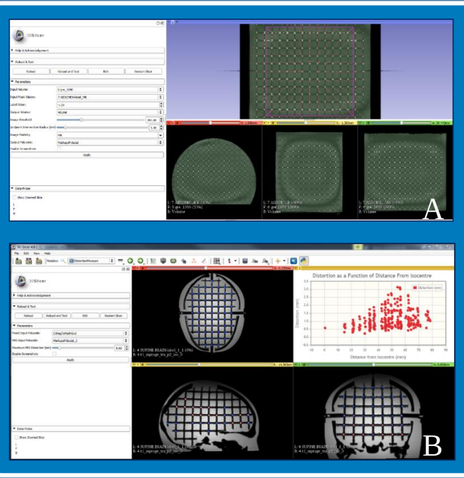
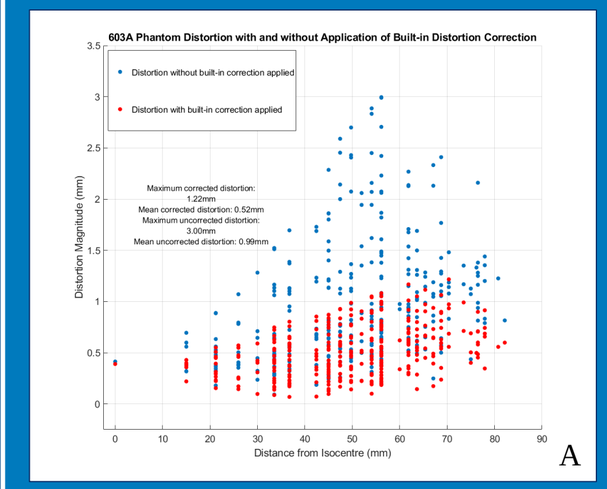
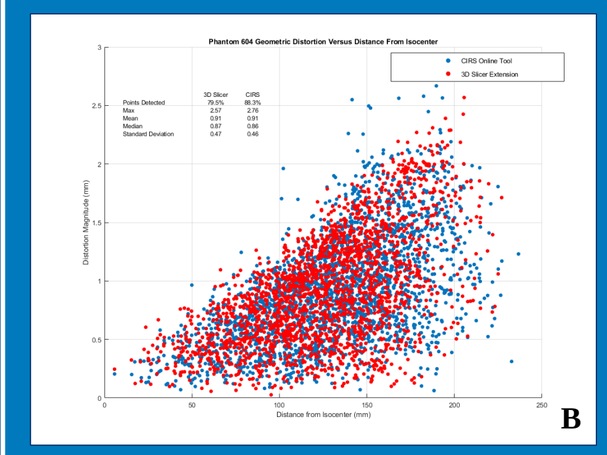


Figure 2: MR images are DICOM imported into 3D slicer, and using the Gridpoint Detection Module (A) the grid intersection locations are calculated. Using the CT images as reference, a distortion plot is displayed using the Distortion Calculation Module (B)

Methods for MRI distortion measurement are based on those outlined by Stanescu et al (4). A 3D Slicer Extension was drafted in Python. In one module, VTK and ITK filters as well as built-in Slicer functions were used to threshold the images and isolate the gridpoint intersections. In a second module, CT and MR gridpoint positions are compared to produce a plot of distortion magnitude versus gridpoint distance from isocentre. See Figure 4 for process details.

3D Slicer and CIRS Distortion Plots





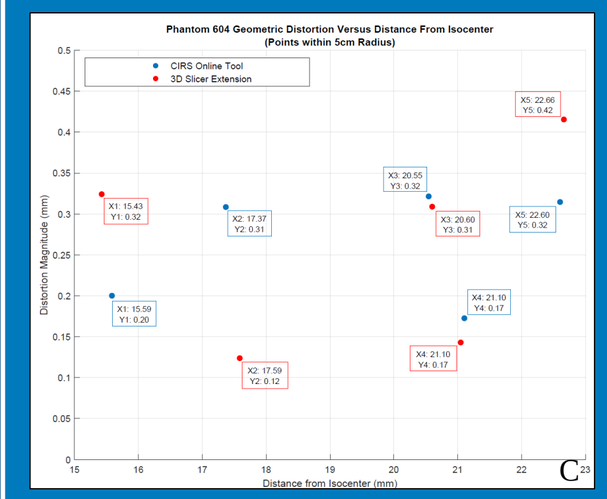


Figure 3: (A) Distortion with and without built-in MR correction algorithm (B) Comparison of CIRS and 3D Slicer distortion (C) Magnified section of (B)

Image Processing Workflow

Image Registration
- Deformable or rigid registration of MR images to CT images

Image Preprocessing
- N4ITK MRI Bias Correction
- Invert intensity values
- Mask ROI
- Define threshold values and gridpoint radius

Image Thresholding
- Sharpen image
- Apply 1-D Gaussian filters in RAS directions and sum
- Apply mean adaptive threshold with user-defined threshold offset value

Calculation of Gridpoint Locations
- Filter objects based on size and shape
- Calculate centroids of objects for gridpoint locations

MRI Distortion Calculation
- Find nearest MR gridpoints to reference gridpoints
- Calculate distance between MR and reference gridpoints

MR and Reference Gridpoint Comparison
- Calculate distance of matched reference gridpoints to MRI isocenter
- Plot distortion as a function of distance from isocentre

Figure 4: Flow chart describing image processing steps used in the 3D Slicer Extension

Results

Siemens' built-in distortion correction significantly reduced the maximum distortion from 3 mm to under 1 mm. For the 604 phantom, our software in this example calculated 79.5% of the gridpoints accurately and found a maximum and average distortion of 2.57 mm and 0.91±0.47 mm. The calculation time for the open source algorithm over the 604 phantom was < 2 minutes, and < 1 minute for the 603A phantom. Initial comparisons between our open source calculated results to CIRS Inc. beta online software yielded similar results (we observed a relative difference of ~10% in the number of points identified).

Conclusions and Future Work

The 3D Slicer module is an open source tool to calculate and track distortions map over a variety of phantom sizes. In comparison to CIRS online Distortion Check tool, we have demonstrated there is a good agreement between the two calculation methods. We are currently working towards, eliminating the need for users to find a suitable image threshold, an and automatic registration of reference grid-points and MRI grid-points.

References

1.Chen, Lili, Robert A. Price, Lu Wang, Jinsheng Li, Lihong Qin, Shawn McNeeley, C.-M. Charlie Ma, Gary M. Freedman, and Alan Pollack. "MRI-Based Treatment Planning for Radiotherapy: Dosimetric Verification for Prostate IMRT." *International Journal of Radiation Oncology* Biology* Physics* 60, no. 2 (2004): 636–47.

2.Johnstone, Emily, Jonathan J. Wyatt, Ann M. Henry, Susan C. Short, David Sebag-Montefiore, Louise Murray, Charles G. Kelly, Hazel M. McCallum, and Richard Speight. "A Systematic Review of Synthetic CT Generation Methodologies for Use in MRI-Only Radiotherapy." *International Journal of Radiation Oncology*Biology*Physics*, September 8, 2017. https://doi.org/10.1016/j.ijrobp.2017.08.043.

3.Mah, Dennis, Michael Steckner, Alexandra Hanlon, Gary Freedman, Bart Milestone, Raj Mitra, Himu Shukla, et al. "MRI Simulation: Effect of Gradient Distortions on Three-Dimensional Prostate Cancer Plans." *International Journal of Radiation Oncology* Biology* Physics* 53, no. 3 (2002): 757–65.

4.T. Stanescu, H. S. Jans, K. Wachowicz, and B. G. Fallone, "Investigation of a 3D system distortion correction method for MR images," J. Appl. Clin. Med. Phys., vol. 11, no. 1, 2010.

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