Design of a geometric distortion characterization method in 3D MRI: stereotactic application

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Introduction

Magnetic Resonance Imaging (MRI) is increasingly being used for purposes of radiosurgery and radiotherapy planning[1]. Indeed, it is the most powerful technique for morphological and functional brain exploration. However, MR images are inherently subjected to geometric distortions because of hardware design limitations that result in failure such as inhomogeneity of the static magnetic field and non-linearity of the gradients fields[2,3]. Consequently, measuring and correcting these distortions is a major issue in clinical routine. In this study, we present the design and setup of a distortions measurement method 3D MRI and its use in the frame of stereotactic application.

Materials and method

The method is based on a 3D-printed phantom made up with 3621 control points (CP). CPs are 5mm-diameter spheres that are equidistantly positioned following a cylindrical configuration (170x170x170mm). The CPs positions ($\mathbf{XYZ_{ref}}$) are yielded by the computer-aided design and used as ground-truth.
Principle: The points positions are measured from 3D MRI scans of the phantom ($\mathbf{XYZ_{irm}}$). Distortions are assessed as the difference between the ground-truth positions and MRI-based measurements ($\boldsymbol{\delta} = \mathbf{XYZ_{ref} - XYZ_{irm}}$).
Data analysis: An analysis algorithm was developed in MATLAB in order to extract the CPs positions. It mainly relies on structure detection based on voxels' connectivity. Eventually, CPs positions are provided by the barycenters of the detected structures.
Validation: The algorithm was validated through a numerical simulation approach. A varying amplitude [2mm-18mm] deformation field was applied to a numerically modeled volume containing the control points. Accuracy was assessed by comparing measurements from the numerical data with the applied deformations.
Clinical application: Our method was applied in the frame of stereotactic MRI-based radiotherapy treatment planning (brain exam, Siemens Avanto 1.5T, brain array coil) using dedicated 3D sequences (Inversion/Recovery 3D gradient echo, TR/TE/TI=1940/2.95/1100ms, voxel=1x1x1mm^3). Data were acquired with and without using the distortion correction option provided by the manufacturer. Maximum tolerated distortion is ±1mm.

Results

As a result for the validation experiment, the algorithm's accuracy was higher than 97%. Clinical routine measurement with the 3D stereotactic MRI sequence are: without correction $\mathbf{-1.41mm < \delta < 0.38mm}$; with correction $\mathbf{-1.1mm < \delta < 0.32mm}$.

Conclusion

Since the control points are not filled with liquid material, our method's phantom is more likely to be time-stable unlike some previously published methods[4,5]. Besides, it enables a highly accurate distortions measurement. It is suited for quality assurance purposes and helps optimizing clinical practice. Further works involve the assessment of the method's robustness to noise and reproducibility as well. In addition, we are developing a module for the correction of MR images subsequently to the distortion characterization.

References

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