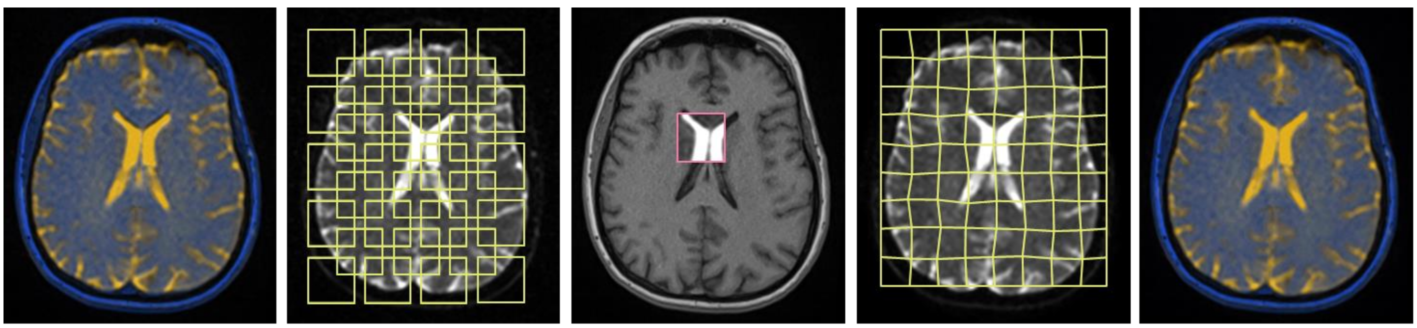
Cranial Distortion Correction

Technical Background

Magnetic Resonance Imaging (MRI) is intrinsically prone to geometric image distortions, which arise due to hardware- and patient-related disturbances of the magnetic field homogeneity. Since these inhomogeneity-induced distortions are not known *a priori*, it has been reported by many clinical researchers that employ MRI during image guided surgery (IGS), stereotactic interventions (SI) and stereotactic radiosurgery (SRS) that retrospective correction is required. The proposed method allows robust, retrospective correction of cranial MRI data, like based on DTI (using echo planar imaging, EPI), yielding an image fusion improvement of **(0.95 ± 1.0) mm** without the necessity of prior MRI scanner knowledge or additional scans. Therefore, this method significantly enhances the geometric accuracy during image fusion and thus increases the precision of treatment planning.



rigid fusion of anatomic T1w MRI and DTI data showing mismatches | subdivide the distorted image into overlapping window patches | find optimal alignment between MRI and DTI for each patch by means of affine transformation | calculate a deformation field based on the local affine transformations | apply the deformation field to DTI data and thereby provide increased image fusion accuracy

Fig. 1 Schematic illustration of the Cranial Distortion Correction method applied to DTI and based on T_1-weighted MRI data.

Introduction: The susceptibility to image distortions depends on the applied MRI sequence and on the magnetic field strength. In particular, diffusion tensor imaging (DTI) data acquired based on echo planar imaging (EPI) or ultra-high field MRI (i.e. ≥7 Tesla) show clinically significant geometric distortions[1,2]. Except for local signal alterations in EPI, image distortions result in smooth and large-scale deformations across the MR image (up to 3 cm)[2]. Since clinical interventions, like IGS and SRS, require high geometric accuracy during the process of image fusion[3,4], a generic method was developed, which is capable of reducing image distortions, i.e., correction of EPI based DTI data using T1-weighted MRI scans or correction of high-field MR images (≥ 3.0 T), by using less distorted lower-field MRIs (e.g. 1.5 T) or undistorted CT images.

Method: By using the patented Brainlab Synthetic Tissue Model and MRI sequence detection, the method automatically identifies the fusion scenario and subsequently defines a scenario-specific image sub-volume (e.g., only when CT data is used are the skull bones included). Afterwards, this sub-volume is further sub-divided into (3×3×3) cm^3 overlapping window patches (**Fig. 1**). Based on an initial rigid fusion between the fused datasets, rigid patch-wise registrations are performed for every 3D patch in order to locally align the imaged anatomies and thus to account for local mismatches. Subsequently, the local registrations are interpolated in order to generate a single, continuous deformation field that maps one of the datasets onto the other, while bringing the local correspondences to a match.

Reliable fusion is accomplished by an outlier detection applied to the patch-wise fusions. To demonstrate the robustness and effectiveness of this method, comprehensive evaluation based on retrospective patient data was performed. The evaluation is divided into a quantitative and a qualitative pathway, while using clinically representative MR-DTI, CT-MR and MR-MR image data obtained at different scanners and with varying contrasts and spatial resolutions. The data was chosen to correspond to the following specific use cases:

Medical procedure	Pathology or indication	Fusion scenario
cranial planning	High-grade Glioma	MR-CT; DTI-MR
	Low-grade Glioma	MR-CT; DTI-MR
	Meningioma in eloquent areas	DTI-MR
	Meningioma in skull base	MR-CT; DTI-MR
stereotactic Biopsy	High-grade Glioma	MR-CT; DTI-MR
	Low-grade Glioma	MR-CT; DTI-MR
SRS planning	Single brain metastases	MR-CT
	Multi brain metastases	MR-CT
	Vestibular schwannoma	MR-CT
stereotactic DBS	Parkinson disease etc.	MR-CT; DTI-MR
other	other	MR-to-MR

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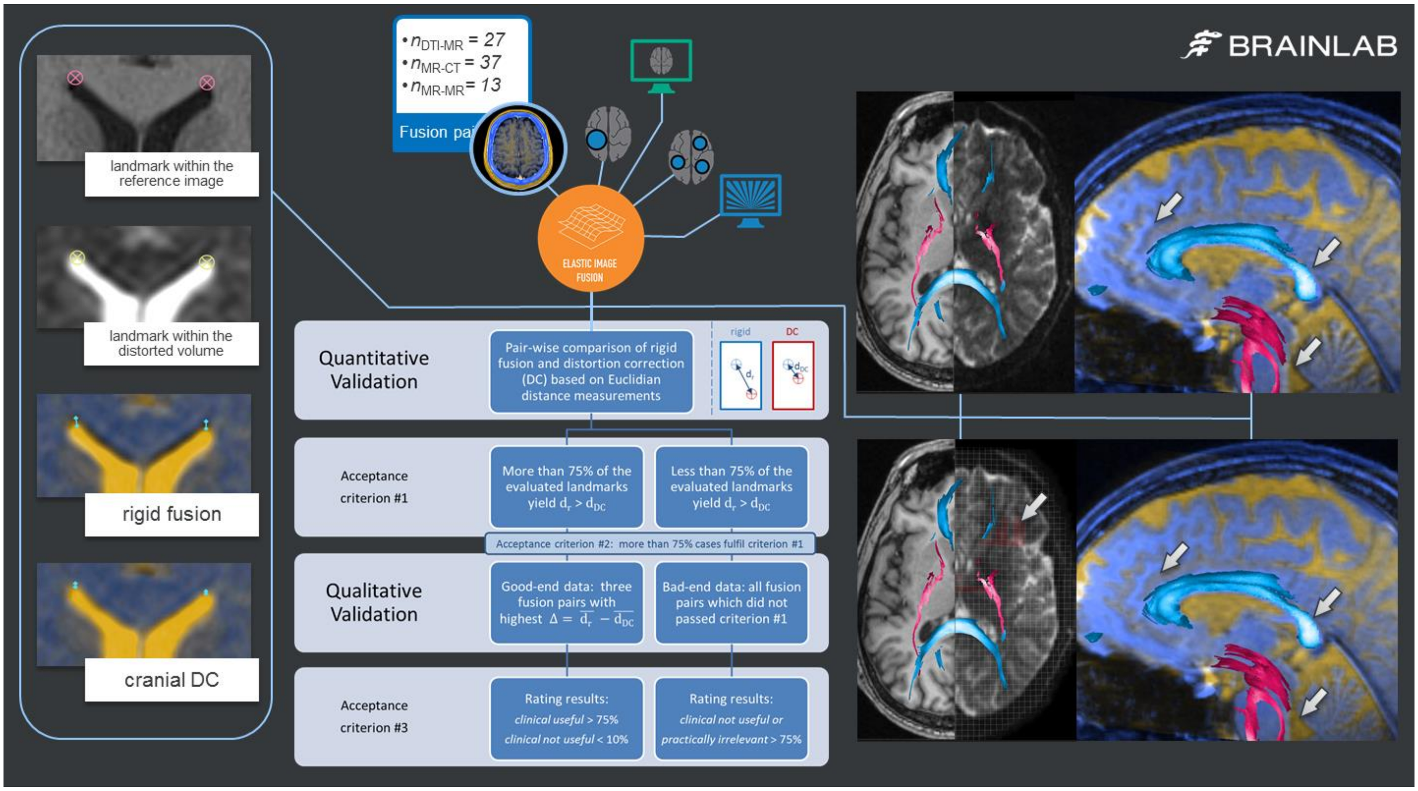

Fig. 2 Validation pathway based on clinically representative patient data inlcuding different DTI-MR, MR-CT and high-to-low field MRI fusion pairs. The quantitative evalution is based on Euclidian distance measurements (left) and showed significant improvements (as reported below). The qualitative pathway confirmed that the spyglass (axial images) and blending verification tool (sagittal images) provided by the Elements Cranial Distortion Correction* allow reliable localization and evaluation of fusion-induced image deformations. The application is also capable of automatically correcting fiber tracts as well as segmented objects.

Validation: The spatial correlation between rigidly and elastically fused images – the latter performed by means of Cranial Distortion Correction – was assessed by Euclidian distance measurements between label points defined in reference image space and the same landmarks defined in rigidly (d_r) and distortion corrected images (d_{DC}; as illustrated in **Fig. 2**, left). The subsequently performed qualitative evaluation by (N=15) medical experts was based on a subset of quantitatively assessed fusion pairs and addressed the two most relevant questions arising during the interpretation of elastic fusion results: (a) *Is the notion of the proposed method in line with the mental model of the user?* And (b) *Is the user able to detect registration artifacts?* To this end, fusion pairs showing strongest corrections and correction-induced artifacts were selected, respectively (**Fig. 2**, middle). The latter represents an important aspect during evaluation of safety and effectiveness of the device since registration artifacts are in the nature of elastic image fusion (due to limited SNR, image resolution and image quality).

Results: The quantitative analysis yielded that the proposed method is capable to significantly increase the image fusion accuracy of DTI data by **0.95 ± 1.02 mm** (d_r = 3.03 ± 2.29 mm vs. d_{DC} = 2.07 ± 1.99 mm; $p < .05$), while the correction of 1.5/3.0 T MRI data (with respect to CT) is less prominent: **0.41 ± 0.95 mm** (1.70 ± 1.21 vs. 1.29 ± 1.15 mm; $p < .05$). By using 7 Tesla MRI data, the enhancement of the image fusion accuracy is about **0.69 ± 1.06 mm** (1.78 ± 1.06 mm vs. 1.09 ± 0.64 mm; $p < .05$), which is most likely due to pronounced distortions present at ultra-high field MRI machines. Medical expert reviews indicated that typical user groups acknowledge the elastic deformations by Cranial Distortion Correction and that users are easily able to identify and localize image registration artifacts.

Conclusion: Elements Cranial Distortion Correction is capable of significantly improving image fusion accuracy and thus improves patient treatment planning for stereotactic procedures, like image guided surgery or radiosurgery.

References

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*FDA clearance pending