

Accuracy of prospective motion correction in MRI using tracking markers on repositionable dental impressions

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Abstract

Magnetic resonance imaging (MRI) is a non invasive tool for clinical diagnosis and neuroscience to examine the anatomy of the human brain. Functional MRI (fMRI) even allows studying the neural activity. MRI at ultra high field MRI, such as 7T, offers the possibility to acquire high-resolution MR images. Unfortunately, higher resolution requires longer measurement times, which makes the scans particularly prone to motion artefacts, as motion is more likely to occur over longer scan periods. By using prospective motion correction, artefacts due to patient motion during the measurement can be avoided. If a marker based tracking system is used, automatic registration of multiple scans taken on different days is possible, if the marker can be attached to the subject at the exact same location for every scan. Markers on dental impressions offer this possibility, because they are individually manufactured to match the subject's teeth, which allows a precise repositioning in the upper jaw. This study examines the accuracy of automatic registration of MRI scans with prospective motion correction using an optical tracking system and a passive marker mounted on a dental impression.

1 Introduction

It is a well known problem in clinical and neuroscientific magnetic resonance imaging (MRI) that patient motion during an MRI measurement causes artefacts like blurring and ringing, which reduce the effective resolution of the data and might render the images useless. To exploit the higher SNR of ultra high field (UHF) systems such as 7T for high resolution imaging, longer scan times are necessary, which makes the appearance of patient motion more likely. Typical scan times for high resolution scans (0.4-0.6 mm) are 10-30 minutes and can easily reach several hours for very high resolution MRI (0.1-0.4 mm) of a full brain volume. Even for trained volunteers, it is impossible to remain motionless for so long.

Prospective Motion correction in MRI not only allows correcting for subject motion to avoid artefacts during the measurement; by activating inter-scan motion correction, different scans of the same subject can be aligned to each other automatically. This is useful for follow-up examinations or long time studies with multiple scans, which are usually realigned retrospectively. Inter-scan prospective motion correction also offers new applications such as registering scans from different imaging systems (e.g. MR, CT, PET) if they are equipped with a motion correction system. It would also allow exact repositioning for radiation treatment planning or surgery planning.

If necessary, a scan could also be paused, and could be continued later. Currently, interrupted scans have to be repeated. With this option, very long scans can be performed by acquiring the data in several short rather than in one very long session.

When optical tracking is used, this technique requires the ability to reposition a tracking marker to the same location on the subject relative to the scan volume for every scan. As the upper jaw is rigidly connected to the skull, a dental impression tightly fixed to the subject's teeth offers this possibility. Several systems for prospective motion correction using optical tracking systems such as infrared based stereoscopic tracking of retro reflective markers [3, 7], single camera based systems based on moiré phase tracking [2, 5] or tracking using features like 2D patterns [1] have been presented. In these studies the markers are attached to the subject on goggles [1, 2] or are attached to the subject's skin at the forehead [5] Both options make exact repositioning very difficult if not impossible. Dold *et al.* [3] and Zaitsev *et al.* [7] have used dental impressions, but as they didn't do inter-scan alignment, exact repositioning was not required.

This study examines the accuracy of intra-subject registration by prospective motion correction using an optical tracking system and a tracking marker on a dental impression.

2 Materials and methods

This section describes the data acquisition, the motion correction system and the analysis of the image data. The calculation of the residual registration error was performed using a Matlab (The MathWorks, Natick, MA, USA) implementation of statistical parametric mapping (SPM8, Wellcome Trust Centre for Neuroimaging, UCL, London, UK).

2.1 Image acquisition

MRI Measurements were performed on a 7T whole body MRI (Siemens Medical Solutions, Erlangen, Germany) using a 32-channel coil (Nova Medical, Wilmington, MA, USA) and the following sequence parameters for two subjects: imaging matrix = $224 \times 224 \times 72$,

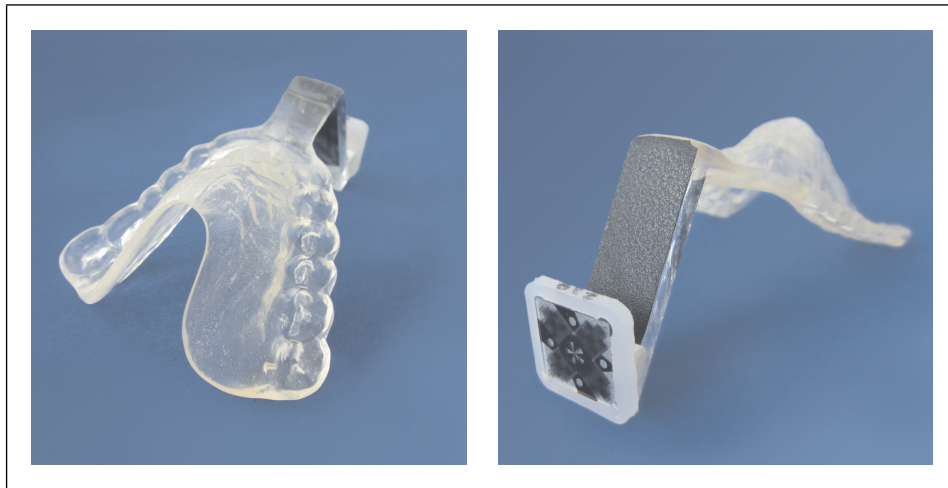


Figure 1: The dental impression (left) individually created for one of the subjects and the MPT marker attached to the retainer (right).

voxel size = $1.0 \times 1.0 \times 1.0 \text{ mm}^3$, flip angle $\alpha = 5^\circ$. The repetition time and echo time (TR/TE) were different for both subjects: subject 1: TR/TE = 9.8 ms/3.38 ms; subject 2: TR/TE = 14.0 ms/9.0 ms. For each subject the scan was repeated 5 times. Between every scan, the subjects were removed from the scanners bore, the head coil was opened, the subject moved the head out of coil to remove the mouthpiece and repositioned it. The position of the head in the coil was not observed, there were no specific actions taken for an exact repositioning of the head. This procedure and the preparation for the next scan took approx. two minutes, which was chosen as the time between two scans.

2.2 Prospective motion correction and volume alignment

Schulze *et al.* [6] have tested three different optical tracking systems. A single-camera in-bore system based on moiré phase tracking (MPT) (University of Wisconsin-Milwaukee, Milwaukee, WI, USA) showed best accuracy and was used to accomplish the motion tracking in the study presented here. The standard deviation of position-data of the X, Y- and Z- axes are below $4 \mu\text{m}$.

The tracking marker was attached to a small retainer with a dental impression (Figure 1), which was individually manufactured for both subjects and tightly fixed to the subject's upper jaw.

The coordinate systems of the tracking system and the MRI scanner were carefully co-registered prior to the MR session by using a non-iterative cross-calibration algorithm described by Kadashevich *et al.* [4].

At the beginning of the first scan, the position of the marker (i.e. the dental impression) relative to the camera of the tracking system was saved as reference. For the four following scans, the scan volume was adjusted to match this reference position by recalculating the scanners gradients and frequencies in real time. Thus the differences in marker positions between the first and the subsequent scans were corrected during the measurement, which enables intra- and inter-scan motion correction.

2.3 Calculation of residual registration error

To calculate the residual registration error, the data were processed using the realign function of SPM8. The first scan was taken as a reference, scans two to five were aligned to the first scan. Pre-processing the data by performing a brain extraction with the Brain Extraction Tool (BET) of FSL 4.1.2 (www.fmrib.ox.ac.uk/fsl) did not show any significant change in the error calculation, thus the data shown here were calculated on the full MRI volumes.

3 Results

One slice from each of the five volumes taken from subject 1 is shown in Figure 2. Differences are hardly noticeable. Figure 3 shows the result of the SPM realign calculations with a residual error clearly below one millimetre for translation on all three axes. The total length of the translation vector is shown in table 1. The rotational components differ in the range of approx. 1 degree. It is noteworthy that these values represent the error of the whole motion correction system. This includes the noise of the tracking data, residual errors in the cross calibration between tracking system and scanner and the misplacements of the mouthpiece.

4 Discussion

The results show that automatic alignment of intra-subject scans is possible with a good accuracy. The misalignment is below the level of motion often observed at patient scans. With this method, clinical scans that had to be interrupted for any reason, could be paused and continued with only minor artefacts. This would reduce the need for repeated scans and thus improve clinical workflow, make the examination more convenient and save costs.

For interrupted high resolution imaging, where a single scan does not generate a full data set due to the long scan times, additional retrospective registration might be necessary to correct for the residual misalignment. This will be much easier, as the technique ensures that the volume of interest will be almost completely covered by multiple successive scans. The evaluation of these applications will be subject to following studies.

A better separation of the different error sources (tracking noise, imperfect cross calibration, misplaced marker) would be desirable. This could be accomplished by comparing the results of this study to those from scans consecutively taken with motion between the scans, but without repositioning of the dental impression.

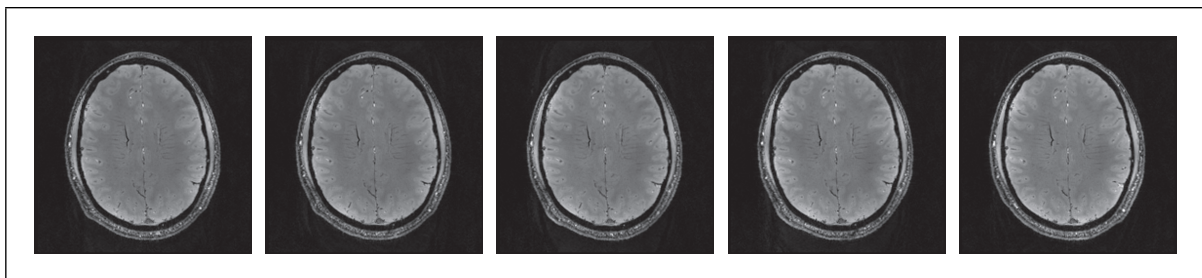


Figure 2: The same slice from the five scans taken from subject 1 in chronological order (left to right). The image on the left shows the reference scan.

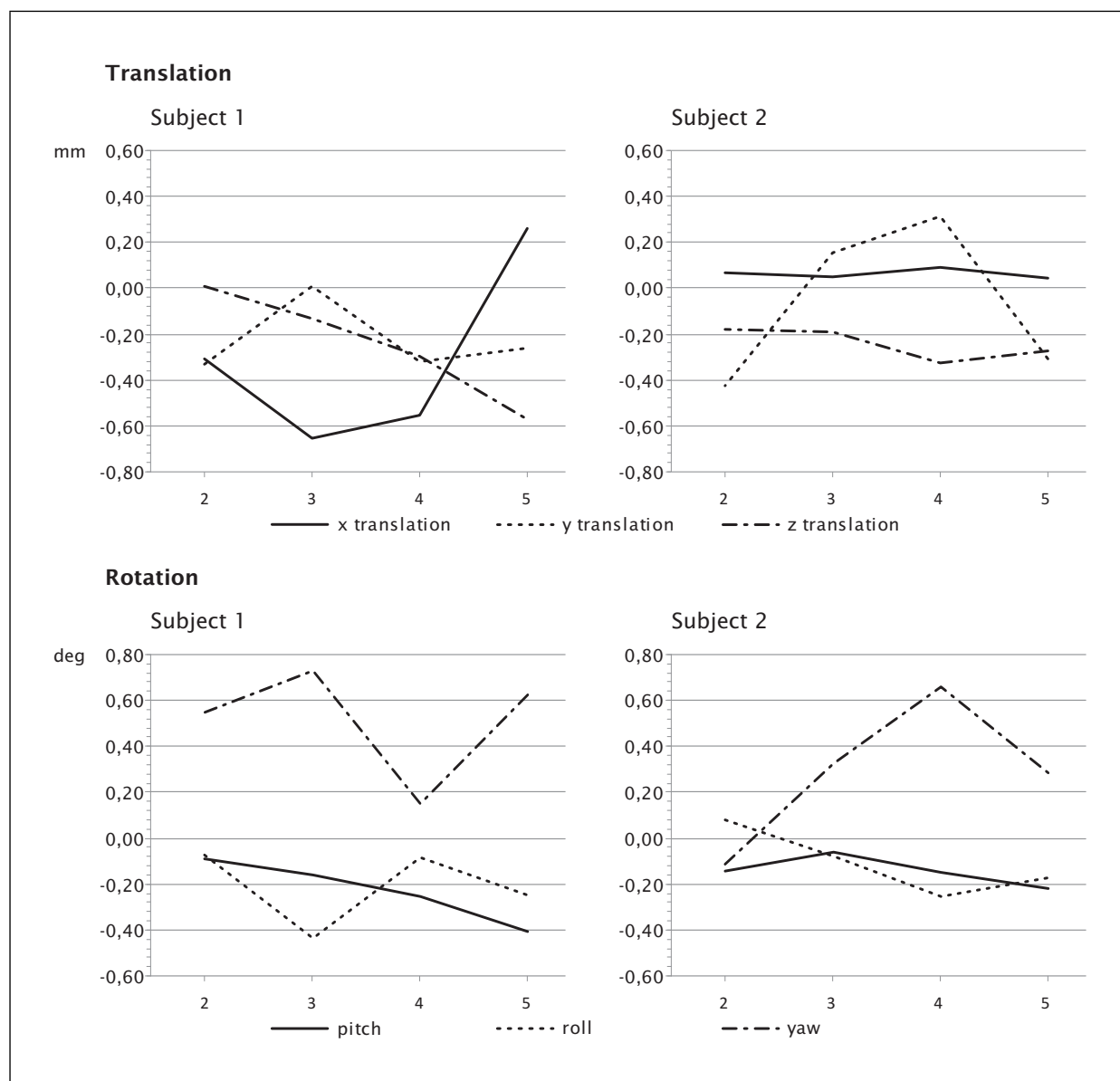


Figure 3: Residual registration error calculated by SPM8. The graphs show the calculated difference between scans 2 to 4 and the first scan. Errors in x-, y- and z-translation (upper row) and pitch, roll and yaw rotations (lower row) for two subjects.

		Subject 1	Subject 2
Total 3D translation (mm)	Mean	0.63	0.40
	Standard deviation	0.12	0.10
pitch (deg)	Mean	-0.23	-0.14
	Standard deviation	0.14	0.07
roll (deg)	Mean	-0.21	-0.11
	Standard deviation	0.17	0.14
yaw (deg)	Mean	0.51	0.29
	Standard deviation	0.25	0.32

Table 1: Mean and standard deviation of the translational (3D vector length) and rotational components of the registration error.

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