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Structured light-based motion tracking in the limited view of an MR head coil

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ABSTRACT

A markerless motion tracking (MT) system developed for use in PET brain imaging has been tested in the limited field of view (FOV) of the MR head coil from the Siemens Biograph mMR. The system is a 3D surface scanner that uses structured light (SL) to create point cloud reconstructions of the facial surface. The point clouds are continuously realigned to a reference scan to obtain pose estimates. The system has been tested on a mannequin head performing controlled rotational and translational axial movements within the head coil outside the range of the magnetic field. The RMS of the residual error of the rotation was 0.11° and the RMS difference in the translation with the control system was 0.17 mm, within the trackable range of movement.

1. Introduction

Numerous methods for motion tracking (MT) in PET and MR brain imaging have been developed and tested, but head movement during scans pertain to be a significant problem causing artifacts and significantly reducing image quality. Methods include external tracking systems (such as Refs. [1,2]) as well as navigator sequences for MR (such as Refs. [3,4]). Former external tracking systems use markers attached to the subjectÕs head. This potentially introduce errors and complicates the process of preparing the subject for the scan, thus reducing the usability in clinical practice. Correspondingly, the image based navigator MT methods developed for MR sequences generally suffer from an inability to obtain high temporal and spatial resolution at the same time. These methods use navigator sequences to obtain transformation parameters of the subject and adjust the gradients in the following sequences accordingly. This makes the method very specific towards the scanning protocol and significantly increases the duration of the scan, reducing the usability in a clinical setting.

We investigate adoption of a markerless, external MT system developed and successfully demonstrated for use in PET brain imaging [5,6]. The main advantage of this system is that it is markerless and therefore does not suffer from the potential unreliable subject attachment associated with marker based systems. At the same time, MT can be performed without affecting the scan time independent of the MR sequence that is used. The performance of the system when faced with the limited FOV of the MR head coil is tested in order to evaluate the potential of the system for adaptation for use in PET/MR brain imaging.

2. Methods

The Tracoline system [5] reconstructs and tracks the facial surface using a structured light (SL) scanning principle. The SL is generated by a near-infrared light emitting diode and is, thus, invisible to the subject in the scanner. The projected SL pattern is captured by two cameras and a 3D point cloud representation of the forehead of the subject is generated using phase-shift interferometry. The head pose changes are then continuously estimated by aligning the point clouds to a reference surface.

The performance of the system has been tested outside the magnetic field of the Siemens Biograph mMR at Rigshospitalet, Copenhagen, with the restricted view of the head coil using a mannequin head mounted on a rotary motor stage (NR360S/M, Thorlabs) regulated by a programmable controller (BSC102, Thorlabs) and a movement platform (Respiratory Gating Platform, Standard Imaging, USA) performing controlled rotational and translational movements. The complete setup is illustrated in Fig. 1a. Translational and rotational axial movements were performed within a movement range from -40 to 40 mm and -25° to 25° in steps of 5 mm and 5°, respectively.

The positioning of the head of patients in the head coil varies somewhat from patient to patient depending on their size. However, it is desirable to have the head placed as far into the head coil as

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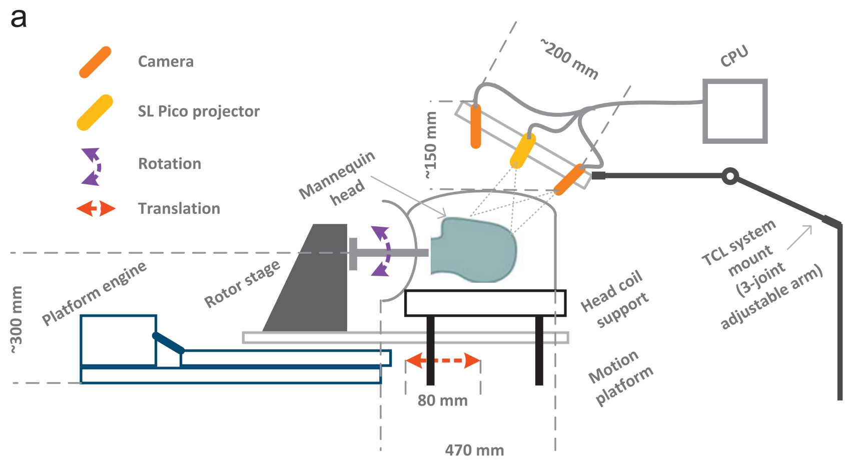

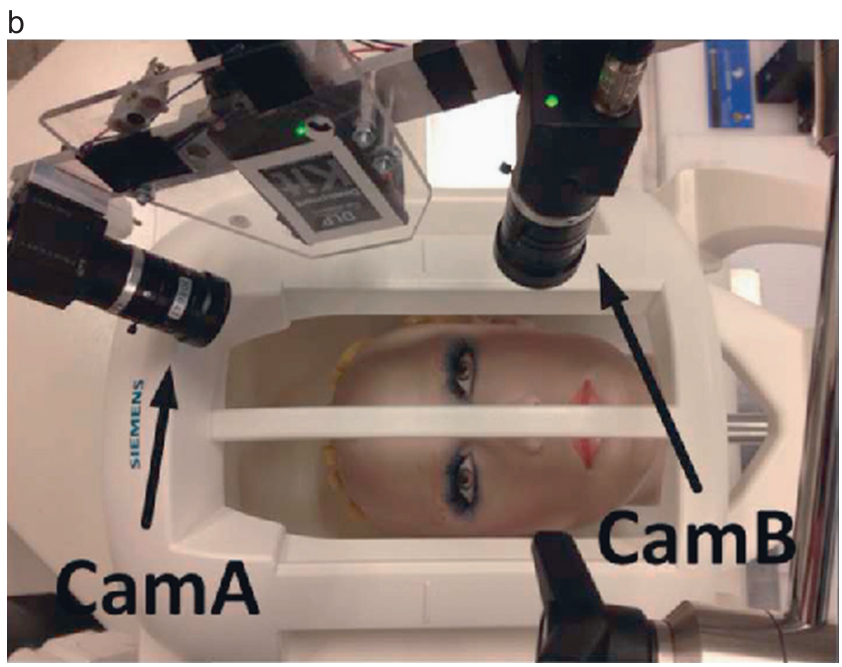

Fig. 1. Illustration of the base position (0 degree rotation, 0 mm translation), the Tracoline system and conventions for naming cameras, (a), and diagram illustrating the complete setup used for the mannequin measurements, (b).

possible. Since it was expected that the position of the Tracoline system and base position of the mannequin head would influence the results of the mannequin experiments, the base position of the head was approved by the clinical personnel normally operating the scanner, as a suitable base position (see Fig. 1b).

3. Results

Fig. 2a illustrates the full range of movement that can be covered by the system when using camA, camB or both. The movement range has been determined quantitatively based on the RMS value of the point-to-point distance between the reference surface and the point cloud after alignment. Surfaces providing RMS values >0.5 mm were excluded (black regions), since experience has shown that larger RMS values generally indicate unsuccessful alignment of the two surfaces. As can be seen, camA makes it possible to cover a movement range from -40 to 40 mm translations and from -25° to 15° rotation. Using an extra camera (camB) only expands the range with positions $(10,-30)$, $(5,-30)$, $(5,35)$, $(-15,-40)$ and $(-25,-25)$ (rotation, translation) illustrated with light red colors in Fig. 2a. The reference surface used for alignment of the point clouds is limited so it only covers the lower part of the forehead, the cheekbones and the nose bridge in order to exclude the areas around the cheeks and the mouth which are sensitive to facial expressions. However, by increasing the size of the reference surface to include the mouth region and a larger part of the cheeks and forehead, it is possible to increase the movement range for positive translations (light orange region in Fig. 2a).

The pose estimates provided by the system has been compared to ground truth movements from the rotor stage and the movement platform. In order to cover the largest movement range possible, estimates from both camA and camB have been included. The mean of the pose estimates from the two cameras has been used in regions covered by both cameras. Only estimates from the specific camera has been used in regions covered by a single camera only. The resulting residual errors of the rotation and translation pose estimates (after calibration of the measured motion platform positions) are illustrated in Fig. 2b and c. The RMS of the residual error of the rotations was 0.11° and the RMS of the residual error of the translations was 0.17 mm, which is a