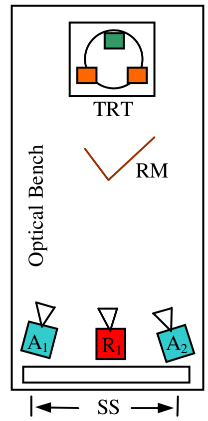
Performance of stereo vision and retro-grate reflector motion tracking systems in the space constraints of an MR scanner

B. Armstrong[1], B. Andrews-Shigaki[2], R. T. Barrows[1], T. P. Kusik[1], T. Ernst[2], and O. Speck[3]

[1]Electrical Engineering and Computer Science, UW-Milwaukee, Milwaukee, Wisconsin, United States, [2]Medicine, University of Hawaii, Honolulu, Hawaii, United States, [3]Biomedical Magnetic Resonance, Otto-von-Guericke University, Magdeburg, Germany

Introduction: Subject motion tracking and prospective motion compensation provide one approach to reduce motion artifact in Magnetic Resonance Imaging (MRI) and spectroscopy (MRS) scans [1]. Optical motion tracking (OMT) systems, including stereo vision (SV) and Retro-Grate Reflector (RGR), provide one means of obtaining the needed real-time motion-tracking data, and have the desirable characteristics of 6 Degree of Freedom (DOF) motion tracking (translations and rotations), location of the camera(s) outside the bore to minimize interference and achieve mechanical stability of the camera(s), an MR compatible body marker (motion-tracking tag), and adequate update rate for real-time, prospective motion compensation. However, the geometric constraints of an MR scanner limit the possible placement of motion-tracking camera(s), and volume constraints within the head coil limits the possible size of the body marker (BM), and thus OMT systems can not be expected to perform with the accuracy achieved in unrestricted spaces. Therefore a study has been undertaken to assess the performance of SV and RGR OMT systems in the space constraints of an MR scanner.

Materials And Methods: An infrared SV system (ARTtrack3, A.R.T. Gmbh, Weilheim in Oberbayern, Germany) and an RGR [2,3] OMT system were tested. Test motions were presented using a YUASA 550 precision tilting rotary table (TRT) (Yuasa Corp, Tokyo, Japan). Each data set comprised 81 poses with the TRT moved through a range of -40 to +40 [deg] of pitch angle and -40 to +40 [deg] of yaw angle. The 81 poses swept a volume of 150x150x120 [mm] translations and 160x140x120 [deg] rotations with a precision of ± 0.040 [mm] and ± 0.033 [deg]. Three body markers (BM) were used: *1)* a BM for the SV system provided by A.R.T., this BM provides a baseline of SV performance, but is too large to be used inside a head coil, *2)* a specially prepared BM adapted for use with a bite-bar and within the space of a head coil, and *3)* an RGR BM, which is a multi-layer structure producing moiré patterns that enable single-camera, 6-DOF motion tracking. Tests were conducted on a 3.5 meter optical bench, illustrated on the right. A steel frame rigidly supported the two SV cameras, shown at A_1 and A_2, and the RGR camera, shown at R_1. The TRT and SV room marker (shown at RM) were likewise rigidly mounted to the optical bench. Six values of stereo separation (shown at SS) were tested. Accuracy was determined by estimating $T_{R \rightarrow O}$, the pose of the room coordinates of each OMT system in the optical-bench coordinates, and $T_{B \rightarrow m}$, the pose of the BM on the TRT motion stage (12 DOF fit to 486 DOF data). The residual is interpreted as the accuracy of the system. Relative accuracy was estimated by fitting $T_{R \rightarrow O}$ to each data set. Absolute accuracy was estimated by fitting $T_{R \rightarrow O}$ to 6 data sets.



Results: Results are presented in figures 2 (translation) and 3 (rotations). Repeatability is shown on the left, and is the degree to which OMT system readings vary when a pose is reproduced. The SV system utilizes room and body calibration. SV repeatability is shown with and without repetition of these calibrations between data sets. RGR operates with a single camera, and has no equivalent to room calibration. Also, the RGR BM is calibrated once, at the time of manufacture. RGR performance for X and Y translations and 3 rotations is indicated as "RGR 5D". Measurements including Z translation are shown as "RGR 6D." Next in figures 2 and 3 are six groups of accuracy results for the SV system, corresponding to stereo separation (SS) angles of $23.8^o \ldots 8.3^o$. Finally, 6D and 5D accuracy results for RGR are shown.

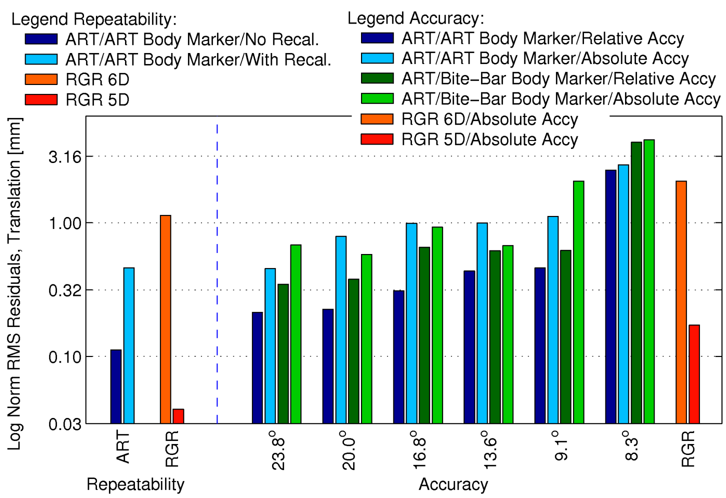


Figure 2. Norm of the rms translation errors, plotted on a log scale.

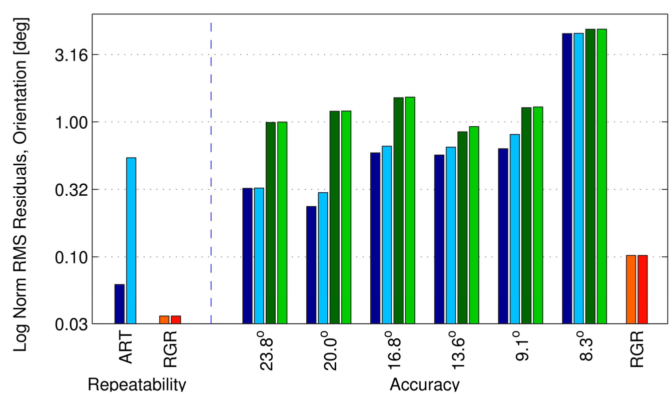


Figure 3. Norm of the rms orientation errors, plotted on a log scale.

Discussion: Both SS and BM size are restricted within the confines of an MR scanner. Additionally, the layout of the magnet room may restrict camera position. SS is limited to angles of 16.8^o and 9.1^o in 3T and 7T magnet rooms at UH and OvGU, respectively. Under these conditions, relative accuracy of ± 0.66 [mm] and ± 1.10 [deg] is achieved. These values show somewhat more error than is achieved with wider SS or with the ART BM. When co-registration of the OMT and scanner is performed each time the OMT system is recalibrated, the relative accuracy result is the best indicator of OMT performance for adaptive MR imaging. Comparison of SV repeatability and accuracy shows that repeatability w/o recalibration is 2-5 times more accurate than the best SV accuracy measured. Repeatability appears not to be a valid proxy for accuracy with OMT systems. The bite-bar BM, with reduced baseline between landmarks, shows 2-3 times greater orientation errors than the ART BM. The RGR system shows an accuracy of ± 0.18 [mm] and ± 0.10 [deg] for 5 DOF measurement, with very good repeatability. RGR functions with a single camera, so there is no issue of stereo separation. For 6DOF measurement, the Z-axis translation measurement shows errors of ± 2.0 [mm]. A single-camera approach with 2 mirrors and 2 lines-of-sight is under development to realize high-precision 6DOF measurement in an MR bore. Current-generation scanners can benefit from OMT accuracy at the level of 0.1 [mm] and 0.1 [deg], so OMT performance remains a challenging issue for prospective motion compensation.

References: [1] M. Zaitsev, *et al.*, NeuroImage 2006;31:1038-50. [2] B. Armstrong *et al.* ICRA, pp.2938-43. [3] B. Armstrong *et al.* ASB, P9-9.

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