MRPen – 3D Marker Tracking for Percutaneous Interventions

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Introduction

In percutanous MR-guided interventions passive markers are used to delineate the position or the trajectory of rigid instruments. In particular, for linear instruments such as puncture needles cylindrical markers are favorable, as the instrument can be safely accommodated in their interior. Cylindrical markers can be localized rapidly if their approximate position is known [1]; however, only the symmetry axis of the instrument is determined and the rotation angle against the axis, which can be important e.g. to avoid needle deflection, is not known.

In this work, a modified passive marker is proposed. The 3D position and rotation of the marker is estimated in real time, and an imaging slice is adjusted and orientated accordingly. Through the integration of a rotation-invariant linear structure, additionally the marker rotation is detected in two steps using a dedicated phase-only cross correlation algorithm.

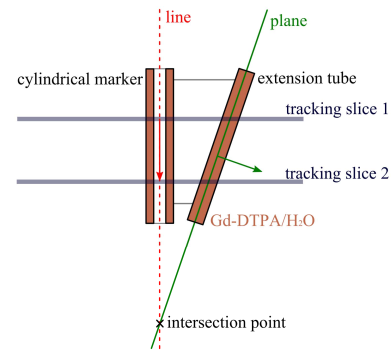

Fig. 1: *Cylindrical marker and extension tube filled with contrast agent solution (brown), straight line through cylinder and its direction vector (red), auxiliary plane and its normal vector (green).*

Materials and Methods

All experiments were carried out on a clinical 1.5 T whole body MR system (Magnetom Symphony, Siemens, Erlangen, Germany) using conventional imaging RF coils and no additional active tracking RF hardware.

Passive MR Pen Marker: The passive MR pen marker (*MRPen*) is a modification of a commercially available passive cylindrical marker (Invivo GmbH, Schwerin, Germany) designed for prostate biopsies. The cylindrical marker has a central opening (3 mm) for the insertion of a puncture needle. An additional plastic tube is attached to the cylinder at an angle of 15° so that their symmetry axes define an intersection point (Fig. 1). Both tubes (diameters: 12 mm and 7 mm, lengths: 80 mm) are filled with contrast agent solution (Gd-DTPA/H_2O 1:100). 3D localization of the marker can be achieved with two parallel tracking slices orientated perpendicular to the cylinder's symmetry axis.

Passive Tracking Pulse Sequence: Based on an existing automatic tracking pulse sequence [1] a modified phase-only cross correlation algorithm for 3D tracking and rotation estimation was developed. Two parallel tracking slices orientated perpendicular to the marker direction (Fig. 1) are acquired (*FLASH*, parameters: TR/TE = 5.3/2.8 ms, $\alpha = 45°$, FOV: 256×256 mm, matrix: 256×166, partial Fourier: 6/8). Each slice shows the combined marker as a ring structure and a point. Positions of both rotation invariant objects are detected subsequently: firstly, the ring (Fig. 2) is detected [2] based on an adapted mask. Then, the position of the point (Fig. 2) is determined. To accelerate the algorithm, determination of the dot is restricted to an area near the ring (distance range: 10-45 mm). Finally, sub-pixel accuracy is achieved by center-of-mass calculations. After processing both tracking slices, the four distinct coordinates undergo a plausibility check, and are then used to define the orientation of the real-time tracking images acquired between two marker image acquisitions.

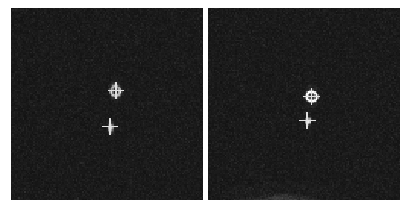

Fig. 2: *Tracking slice 1 and 2 (cf. Fig 1) containing ring structure and dot. Positions are marked by white crosses.*

The normal vector of the imaging slice (trueFISP, TR/TE = 5.3/2.8 ms, $\alpha = 75°$, FOV: 256×256 mm, matrix: 256×166, partial Fourier: 6/8) is calculated based on the estimated needle axis and the more distant position of the extension tube. In particular, the intersection point (cf. Fig. 1) is defined, which is then used to calculate the geometries of all 3 slices (2 tracking, 1 imaging). The distances of the tracking slices with respect to that intersection point are 67 mm and 103 mm respectively. The tracking slices are centered on the symmetry axis of the cylinder. The center of the imaging slice (Fig. 3) is placed on the same axis 25 mm distant to the intersection point.

Experiment: The precision of the detection of the cylindrical marker has already been evaluated [1], and, as cylinder and extension tube are separately detected, these results remain valid. For evaluation of the accuracy of the 3D tracking algorithm, the marker was tracked under two different scenarios. In a fixed position, tracking was repeated for 100 times. A mean normal vector of all acquired imaging slices was calculated and the angle of each normal vector with respect to that mean normal vector was evaluated. In a second experiment, tracking during through-plane marker motion was assessed. The marker was moved along a distance of 9 cm in direction parallel to the cylinder's symmetry axis.

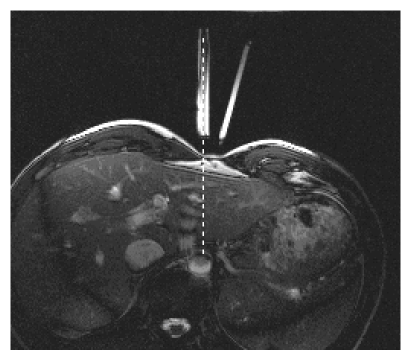

Fig. 3: *Imaging slice showing marker and theoretical needle trajectory (FOV: 300×300 mm, no partial Fourier).*

Results and Discussion

A mean angular deviation of the normal vectors at a fixed marker position of 0.6° ± 1.7° was found. The marker was always entirely visible in the imaging slice. If the marker is rotated too fast during the measurement, the extension tube is not always visible. Immediately after stopping rotation, an accurate detection was retrieved. The standard deviation of the tracked position was 5 mm (Fig. 4). When moving the marker along the symmetry axis of the cylinder (perpendicular to tracking slices) marker tracking was lost 7 times (total number of tracking repetitions: 44) which could successfully be corrected by plausibility checks.

In contrast to a cylindrical marker alone, the proposed combined marker design is only suitable for percutaneous interventions due to spatial restrictions. Compared to previous implementations [1,3], the *MRPen* algorithm technique has two major improvements. Firstly, it is possible to rotate the imaging plane by rotating the marker. Thus, the choice of an optimal needle trajectory in percutaneous interventions is highly facilitated and under manual control of the operator, and no manual input on the scanner console is needed. Secondly, the imaging slice is not used for 3D tracking, since all calculations are based on the estimated coordinate points in the tracking slices. Hence, the imaging parameters of the actual imaging slice are not restricted to certain contrast conditions or SNR levels and can be separately adjusted for optimal contrast of the target lesion.

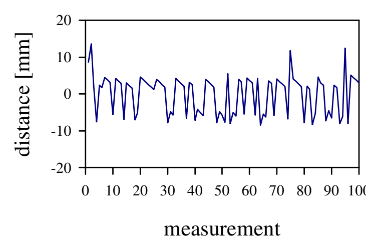

Fig. 4: *Plot of z position accuracy.*

References

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[2] Chen Q, *et al.* IEEE Trans Pattern Anal Mach Intell 16(12):1156-1162, 1994.
[3] de Oliviera *et al.* In: Proc 16th Annual Meeting ISMRM, Toronto, 2008.