A Fully Automatic Passive Marker System Localization Algorithm with Sub-pixel Precision

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Introduction

In closed-bore MRI systems percutaneous interventions are difficult to perform, because access to the target organ is restricted due to the limited space in the magnet. To overcome this limitation an assistance system has been developed, which can position and orient a medical instrument (e.g. a needle) precisely by a robotic arm. Passive markers filled with contrast agent are attached to the assistance system for device localization in the MR images.

Compared to the localization with active MR marker coils [1] passive markers do not require any additional rf hardware and do not lead to device heating due to the introduction of conducting structures [2]. In this work we developed a combined, fully automatic algorithm to localize passive markers with sub-pixel precision.

Materials and Methods

Marker localization was performed using a clinical 1.5T whole body MR system (Siemens Symphony, Erlangen, Germany) and the fully MR-compatible robotic assistance system Innomotion (Innomedic, Herxheim, Germany). The assistance system consists of a pneumatically driven robotic arm, which is mounted on an arc to fit into the 60-cm bore of a solenoid MR system. Position and orientation of the arm, which has an instrument holder at its end (Fig. 1), are continuously measured by the hardware using optical sensors for five of the six degrees of freedom.

To localize the four 10 and 15 mm-diameter markers (filled with Gd-DTPA:H_2O 1:200) 30 mm-thick slices (one transverse, two sagittal) were acquired to encompass the whole markers. A FLASH pulse sequence with following parameters was used for image acquisition: $\alpha = 40°$, TR= 10.3 ms, TE = 5.03 ms, FOV = 256 mm, matrix = 256². Images were acquired with the manufacturer's correction for gradient non-linearity (large FOV correction).

In the images the position of the markers was quantified using a combination of two algorithms: First, the position of each individual spherical marker was determined with a precision of one pixel using a phase-only cross correlation (POCC). The POCC was calculated from the acquired image I and a synthetic image of an ideal marker M:

$$POCC(x,y) = FT^{-1}\left(\frac{FT(I)}{\|FT(I)\|}\cdot\frac{(FT(M))^*}{\|FT(M)\|}\right)$$

Here, FT denotes the forward (and FT^{-1} the backward) discrete Fourier transform. Ideally, the POCC image has a maximum at the location (x_{POCC}, y_{POCC}) of the marker. To improve the position estimate a center-of-mass (CoM) calculation was then performed only in a square region around this coordinate:

$$CoM = \frac{\sum_i r_i \cdot m_i}{\sum_i m_i}$$

Localization accuracy and stability of the algorithm were investigated for 10 y-positions and 10 x-positions in steps of 1 mm by moving the robot arm. To apply the results to an interventional scenario where a needle is to be inserted into the human body, the needle tip position was calculated from the four marker positions. For comparison, a contrast-agent-filled glass tube was positioned in the needle holder (Fig. 1), and the distance between marker system central point and needle tip was 143.5 mm. The initial position of the robot was selected in such a way that the needle tip was placed at $x_{iso}=0$, $z_{iso}=0$ and $y_{iso}=10$ mm with regard to the iso-center. The calculated needle tip positions were compared to positions measured manually in the MR image.

Results and Discussion

As an example the x-(L/R), y-(A/P) and z-(H/F)-coordinates of the needle tip are shown in Fig. 2 where the robot was moved along y. The data points are all close to zero meaning that they do not differ significantly from the estimated values ($x_{iso}=0$, $z_{iso}=0$ and $\Delta y_{iso}=10$ mm). The measurement uncertainty is within the precision of the robotic assistance system of about 1 mm.

Mean values and standard deviation of the presented algorithm and the direct measurement are given in Tab. 1 for all coordinates. It can be seen that the values do not vary more than 0.8 mm. The needle tip location is calculated from the positions of the 4 markers and therefore the total uncertainty is expected to exceed that of the individual markers (e.g. a position error of 1 mm for one marker causes the needle tip to deviate by 3.5 mm). Nevertheless, the results show that the fully automatic algorithm within short time provides needle tip coordinates that are comparable to direct image-based measurements.

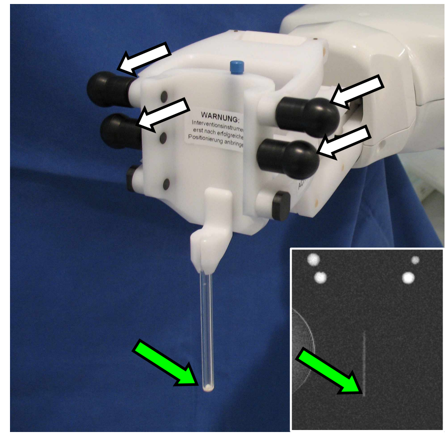

Fig.1: Robotic assistance system. The white arrows show the passive markers, the green arrow marks the needle tip. Right: MR image of the system.

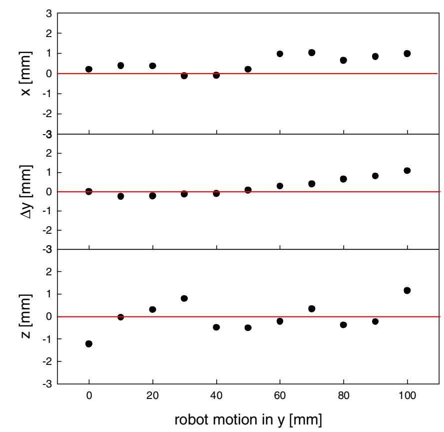

Fig. 2: x-, y-, and z-position of the needle tip vs. y position of the robot arm. The central plot shows the difference Δy between tip and y-position of the robot.

	POCC/CoM algorithm	**direct measurement**
	deviation [mm] (variation in x)	
x	0.02 ± 0.80	-0.08 ± 0.35
y	0.05 ± 0.21	-0.37 ± 0.40
z	0.61 ± 0.58	-1.09 ± 0.31
	deviation [mm] (variation in y)	
x	0.48 ± 0.40	0.01 ± 0.42
y	0.23 ± 0.43	-0.31 ± 0.49
z	-0.05 ± 0.63	-0.79 ± 0.53

Tab.1: Mean and standard deviation of the tip position for different x and y positions of the robot arm calculated from the markers (left) and determined directly in the MR image (right).

References

[1] Bock, M. et al., JMRI **19**, 580-9 (2004)

[2] Ladd M., Quick HH., Magn Reson Med **43**, 615-9 (2000)