3D Real-time tracking using passive fiducial markers and image processing

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Introduction

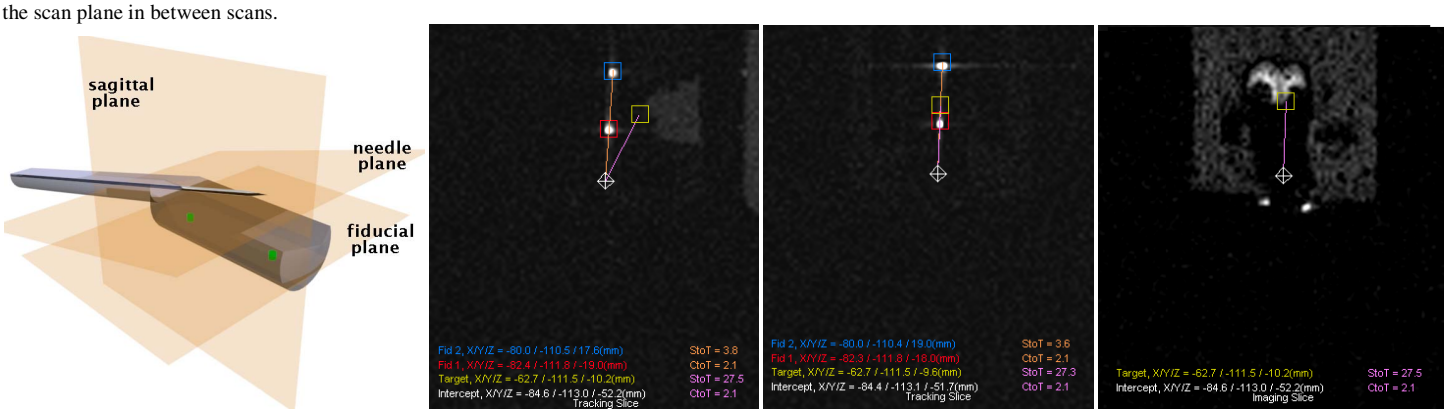
The localization of interventional instruments inside MRI scanners is an area of current research which is closely linked to MRI-compatible robotics. The simplest form of localization is passive markers or needles containing susceptible contrast materials, however these suffer from low contrast and low resolution. A more useful approach uses resonant micro-coil fiducial markers for signal enhancement. Active fiducial marker coils connected into a receive channel on the scanner record position dependent signals and can be easily detuned during the RF excitation, ensuring that they do not compromise images [1]. However, for internal devices additional risk and inconvenience are introduced to the patient by the necessary cabling, and external hardware is also required to process the signals. Tracking and centring of passive fiducial markers using image processing has recently been reported with a sub-pixel accuracy of 0.4mm [2] for use in interventional procedures which require added flexibility without compromising patient safety. Here we report how a suitable selection of image planes and real-time processing and feedback [3] allows automatic slice alignment and target projection. The work was done in conjunction with the development of a clinical endorectal prostate biopsy robot, probe and needle.

Methods

Two single-resonant micro-coil passive fiducial markers [4] were constructed with a length of 3mm and a diameter of 2.5mm, and were tuned to 63.8 MHz. The coils were filled with vinyl plastisol gel to generate a signal, and then fixed inside the endorectal probe along the central axis with a separation of 35mm. Since the probe operates with 5-DOF, constrained to zero rotation along its own axis, only two fiducials were required for tracking the position and rotation in three dimensions.

Two imaging planes were used for tracking; initially both were manually aligned to include both fiducials as in figure 1(a). The *sagittal plane* was coincident with the sagittal plane of the probe and constrained to rotate between the patient's sagittal and transverse planes. The *fiducial plane* was constrained between the patient's coronal and transverse planes. The sagittal and fiducial plane images are shown in 1(b) and 1(c). Using a Siemens Avanto 1.5T (Siemens Medical Solutions, Erlangen, Germany) with a Fast Low-Angle Shot (FLASH) pulse sequence (TR = 9.1ms, TE = 4.8ms, $\alpha = 2^{o}$, slice thickness = 5mm, matrix 128^2) modified to include image-processing and real-time feedback; the current positions of the fiducials were calculated and stored by the image reconstruction program. The calculations account for large positional errors in the slice direction by using the more accurate positional data from the other slice, and the known distance between the fiducials. The updated positions of the two planes were then sent back to the scanner before the next set of slices were imaged. Graphical overlays projected a schematic representation of the probe, needle, fiducials, and the intersection point onto each slice. Optionally, the *needle plane* was then imaged with a flip angle of 30^{O}, as shown in figure 1(d).

To quantify the accuracy of the system, two 3mm diameter spherical rubber targets were suspended in a prostate phantom made of agar gel, and placed in a silicon phantom replicating the anus and rectum. The tracking system was used to aim a biopsy needle at the centre of the hypointense target, before firing the needle through the rectal wall using the robotic manipulator. The resultant actual position of the needle tip was then measured using a Microscribe G2 3D digitizer (Immersion, CA, USA) with a given accuracy of 0.38mm. To test the maximum velocity; the speed was increased up to the point where the fiducials were lost as they had moved out of the scan plane in between scans.



(a) (b) (c) (d)

Figure 1. (a) 3D graphic of the endorectal probe showing the orientation of the three planes. The fiducial and sagittal planes used as tracking slices are also shown in (b) and (c). The needle plane (d) is an optional image plane which shows the needle trajectory against the edge of the target prostate phantom. The two bright dots in the middle of (d) are not the fiducials, but signal from the 'anus' surrounding the entrance to the phantom rectum.

Results

The FLASH sequence updated the tracking images every 1.8 seconds, which was sufficient to track probe movements in real-time with a maximum speed of 4mm/s. The maximum speed could be increased to 7mm/s by using a slice thickness of 10mm. The accuracy of the fiducial position calculations was recorded as 0.36(±0.17)mm. The calculated position of the needle tip was found to be accurate to 0.5(±0.3)mm against the position measured in free space; when deployed inside the phantom the resultant needle accuracy was 2.2(±1.5)mm.

Discussion

This abstract has shown that real-time device tracking using passive micro-coil markers is feasible for interventional procedures using a small number of slices to track fiducials in orthogonal planes. While this method is neither the most accurate, nor the fastest available, it provides a tracking system which is independent of external hardware, and it can easily and quickly be configured to track various devices through the sequence user interface. Although update rates cannot match that of active fiducial tracking, further increases may be expected by using a reduced rectangular FOV and a smaller matrix size. Currently the sequence is only implemented on a Siemens MRI scanner, but it could be adapted to run on other systems. The accuracy of the needle positioning is, in principle, as good as active tracking systems, but was reduced inside the phantom because of the flexibility of the biopsy needle; however the 5mm thickness of the silicon rectal wall was not anatomically representative; therefore better results are expected with an improved phantom or *in-vivo*.

References

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