A novel algorithm for fast 3D localisation of N fiducial markers from 1D projections

Djordje Brujic[1], Francesca Galassi[1], Marc Rea[1], and Michael Ristic[2]
[1]*Imperial College, London, UK, United Kingdom,* [2]*Imperial College, London, United Kingdom*

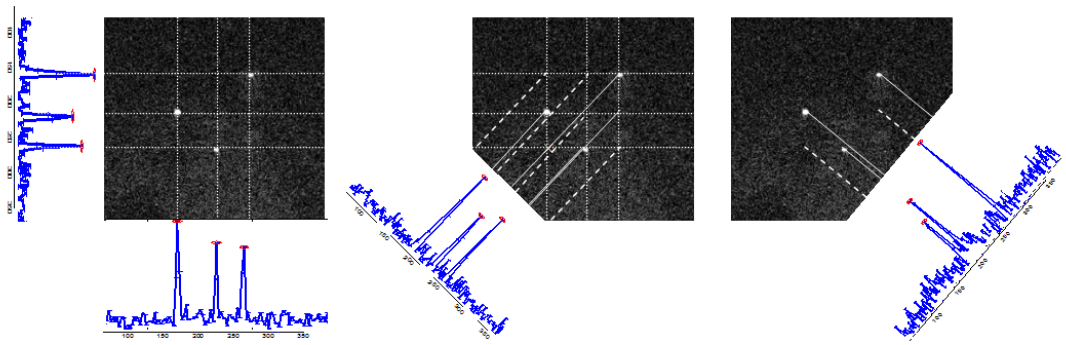
Introduction

MR image-guided interventional procedures frequently require real-time tracking of devices within the imaging volume of the scanner. Our target applications include prostate biopsy and Laser Interstitial Thermal Therapy (LITT) of liver tumours. Our aim is to develop a method for refreshing the 3D position of a device at a sustainable rate of 10 Hz, while maximising the accuracy and robustness. Systems for 3D tracking of devices involving the use of fiducial markers incorporated into them have been proposed. In order to achieve higher safety and reduce the system complexity, wireless fiducial markers have been developed (1, 2) and several methods have been proposed for their localisation. Flask (3) has shown that a method based on 1D back projections significantly increases the refresh rate in comparison with methods involving image processing or phase only cross correlation (4). Here we present a novel method for tracking fiducial markers based on a set of pre-determined 1D projections in space. The method computes the 3D position of N fiducial markers directly from 1D projections instead of deriving the 3D information from two orthogonal scan planes (3). It was verified through extensive simulation studies, implemented and tested using 3 wireless fiducial markers and a modified FLASH sequence. Significant improvements in robustness and computational efficiency have been achieved.

Materials and methods

Wireless resonant micro circuits, comprising 3 mm diameter inductors, were constructed to resonate at 123.5MHz (the proton Larmor frequency at 2.9T). The inductors were filled with Agar gel doped with 5% v/v Gadolinium in order to avoid saturation of the MR signal. A FLASH sequence was modified to acquire a set of pre-defined 1D projections in space and minimize the background signal while preserving the signal generated by the fiducial markers (TR = 4.57 ms, TE = 2.13 ms, BW = 390 Hz/pixel, FE=320, FOV=300mm, alpha=0.3).

The method to localise the fiducial markers entails the following steps. I)After 1D Inverse Fourier Transform of the signal, the most significant peaks are identified along each projection line. If the number of identified peaks is different than N, because of overlapping of the projection values or low SNR, the projection line is discarded. II) For each projection line, N parallel planes are defined. Each plane is normal to the projection line at one of the N projection values. III) Three sets of N planes each, defined by 3 projection lines, are selected according to a descending order of maxima of minimum distances between the peaks in the corresponding projection line. The intersection of these planes generate N^3 intersection points. IV) In order to select N points among the N^3 intersection points, additional projection lines are used and in this approach lies the major originality of our method. The projection values of the N^3 intersection points along a fourth projection line are computed and compared with the peaks previously identified along that direction. An intersection point is accepted if and only if its projection value is within a pre-defined tolerance distance from a peak, otherwise it is discarded. Tolerance is based on a maximum error in determining the peak position along the projection line and was set to 1mm. Other projection lines are considered until all the surplus points are discarded. This is illustrated in Fig. 1.a for 3 fiducial markers, in 2D for clarity.



a) b) c)

Fig. 1. Illustration of the method using real data for 3 fiducial markers in 2D. a) All the 9 intersection points are computed from 2 projection lines (planes in 3D). b) A 3rd projection is used to remove intersection points with projection value not within the tolerance interval (dash lines). Note that 2 of the most right points (solid lines) are closer to a peak than a tolerance and, consequently, they are both kept. c) All the surplus points are removed using a 4th projection.

Results and discussion

The localisation algorithm was implemented in MatLab (Mathworks Inc.) and simulated using more than 10,000,000 random fiducial sets. The number of successful reconstructions as a function of number of projections used is presented in Fig. 2. The total number of required projections varies, but the MR sequence programming constraints usually demand that the projections are predefined. The efficiency of the algorithm is improved avoiding the computation of a large number of clusters (3). Simulations have shown that our algorithm has an average computational time of 2.1ms for N=2, 5ms for N=3 and 10.8ms for N=4. Experimental trials were conducted on a Siemens Verio 2.9T scanner. The data flow of the scanner was modified in order to allow the streaming of the raw data (56 ms for a set of 9 projections) directly to our external workstation. We could reach a refresh rate of 10 times/s with a maximum error of 2.4.

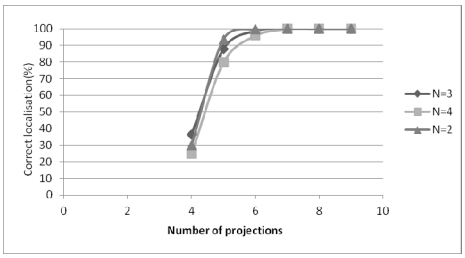


Fig.2 Performance of the algorithm with increasing number of projections for different N

Conclusions

Our results are in line with the requirements of interventional procedures in terms of accurate and fast targeting. In addition, our method eliminates a major problem inherent to the method developed by Flask (3), which occurs when two points have similar coordinate along the common axis of the two orthogonal planes.

References :

1) A. Kriegerand G. Fichtinger. *Design of a Novel MRI Compatible Manipulator for Image Guided Prostate Interventions.* IEEE. 2005
2) M. Rea and D. McRobbie. *System for 3-D Real-Time Tracking of MRI-Compatible Devices by Image Processing.* IEEE. 2010
3) C. Flask and W. Elgort. *A method for fast 3d tracking using tuned fiducial markers and a limited projection reconstruction fisp sequence*. JMRM. 2001.
4) De oliveira and M. Bock. *Automatic passive tracking of an endorectal prostate biopsy device using phase only cross-correlation*. JMRM. 2008