Evaluation of sub-pixel fiducial tracking using image processing

M. A. Rea[1], D. W. McRobbie[1], I. Young[2], H. Elhawary[3], A. Zivanovic[3], and M. Lamperth[3]

[1]Radiological Sciences Unit, Charing Cross Hospital, London, United Kingdom, [2]Electrical Engineering, Imperial College London, London, United Kingdom, [3]Mechanical Engineering, Imperial College London, London, United Kingdom

Introduction. Resonant micro-coil fiducial markers are increasingly being used to track devices within an MRI scanner [1,2]. Good results have been obtained with previously described methods of tracking such as multiple application of 1-D gradients [3,4]. Image processing has also been applied to track devices with 3D reconstruction [5]. In this report, we assess various image-processing algorithms in order to increase the precision with which a fiducial position can be determined. We show that sub-voxel sensitivity of inductively coupled fiducials can be achieved, and hence precise locations are obtained from relatively low-resolution rapidly acquired images. We then compare the performance of the techniques for both post-processing and real-time imaging.

Methods. Resonant fiducial micro-coils constructed by hand-winding 6 turns of 6 gauge enamelled wire around a 2mm former and connecting a 100pF capacitance were tuned to 63.8MHz. To generate a signal, the coils are filled with approximately 8mm^3 of a water-rich gel. A whole fiducial is around 3 x 3 x 5mm in size.

To image the fiducials, we used a Siemens Vision 1.5T scanner running a 2D FLASH sequence with 256 matrix, 200mm square FOV (pixel size 0.78mm x 0.78mm), and 1^o flip angle to reduce signal from the phantom. Ten slices of thickness 5mm were taken with fiducials mounted on a software-controlled manipulator arm. Images were processed using MatLab. The manipulator translations ranged from 0.1 to 40mm and real displacements were measured using high precision optical encoders.

Series of images were taken with various displacements of the fiducials. An automatic error detection routine was first applied to identify and remove erroneous pixels due to artefacts. The image data were then analysed using five detection algorithms, (1) detection of the Maximum Intensity Pixel (MIP), (2) detection of the MIP from a Subtracted image (SIP), (3) Linear Interpolation between pixels (LI), (4) quadratic Curve Fitting (CF) to pixel values, and (5) quadratic Correlation-Coefficient Fitting (CCF) using a submatrix around the MIP [6]. In Figure 1 it can be seen how higher precision is achieved by reconstruction of the curves in CF and CCF. Figure 2 shows the correlation between calculated and measured distances at large and sub-pixel distances, as well as fiducial SNR variations for rotations of the manipulator.

Results.

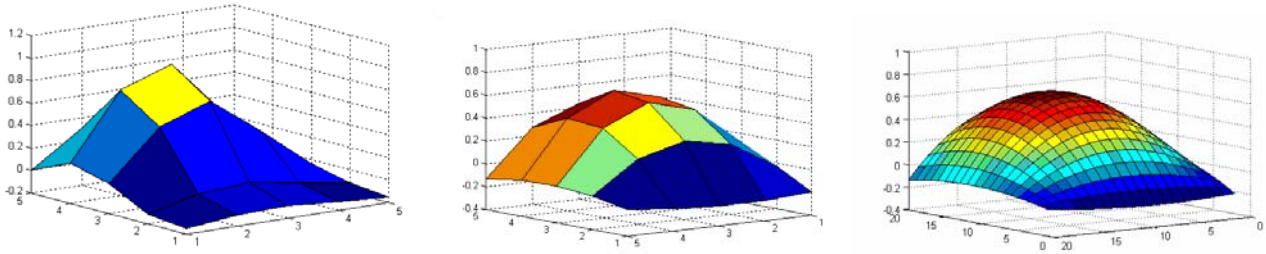

Fig 1. A graphical demonstration of bi-quadratic curve fitting algorithm. Increasing the reconstructed matrix leads to increased accuracy. An original 5x5 matrix is shown (left), along with reconstructions of size 5x5 (middle), and 20x20 (right).

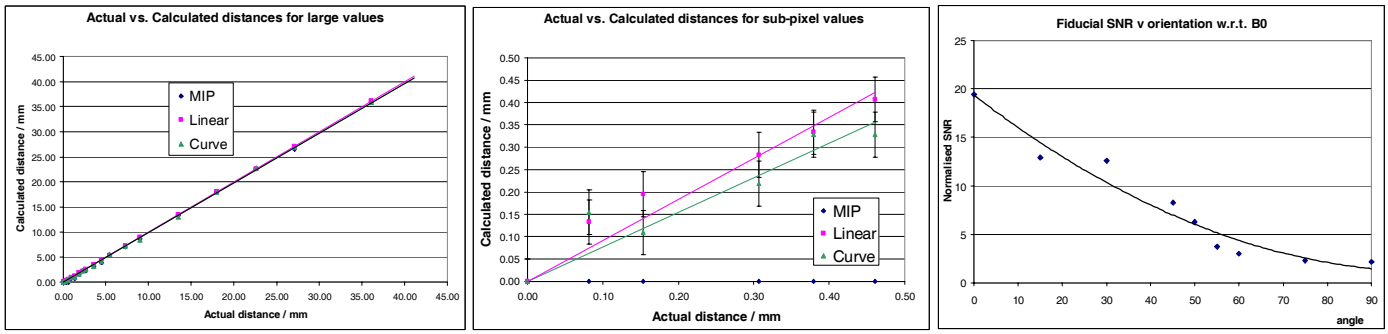

Fig 2. (Left) Linearity of the three processing algorithms at large and (middle), sub-pixel values. (Right) Variation of SNR as the fiducial is rotated in the field.

Discussion. Application of the MIP algorithm produces good results at relatively large movements, but as expected it cannot produce an accuracy greater than 0.5 pixels. SIP is no better than MIP at measuring displacements. In fact it performed worse for small movements (less than 1 pixel), as it highlights the trailing edge of the fiducial instead of the centre. In summary, Figure 3 shows that LI produces excellent results, with good correlation between the calculated distance and that measured by the linear encoders, even at sub-pixel distances. Similar results were produced by CF and CCF using 20 x 20 reconstructions. The LI method uses a simple algorithm and hence has a faster computation time, thus at present it appears the most suitable to be used in real-time tracking of manipulator arms for prostate biopsy. However for applications requiring better precision, where time is not critical, there may be value in applying another algorithm. The SNR of fiducials reduces with angle to B_0, but is acceptable up to rotations of around 60^o, after which the signal level falls off. Further work will improve precision at small distances, and also assess tracking between slices and the effects of rotation on accuracy.

Algorithm	Large Scale (>1 pxl)		Small Scale (<1 pxl)		Approximate Runtime / ms
	Linearity	R^2	Linearity	R^2	
MIP	**0.99**	**0.99**	**0.00**	**-**	**15**
LI	**1.00**	**1.00**	**0.92**	**0.94**	**16**
CF	**1.00**	**1.00**	**0.94**	**0.87**	**62**
CCF	**1.00**	**1.00**	**0.95**	**0.92**	**79**

Fig 3. A summary of the results.

References

[1] Coutts GA *et al*, Integrated and interactive position tracking and imaging of interventional tools and internal devices using small fiducial receiver coils, *Magn Reson Med,* 1998, 40(6):908-13.

[2] Krieger A *et al*, Design of a Novel MRI Compatible Manipulator for Image Guided Prostate, *IEEE Transactions on Biomedical Engineering*, Vol. 52, No. 2, 2005.

[3] Dumoulin CL, Souza SP, Darrow RD. Real-time position monitoring of invasive devices using magnetic resonance, *Magn Reson Med,* 1993; 29:411–415.

[4] Bock M *et al*, Active Catheter Tracking Using Parallel MRI and Real-Time Image Reconstruction, *Magn Reson Med,* 2006; 55:1454–1459.

[5] Flask C *et al*, A Method for Fast 3D Tracking Using Tuned Fiducial Markers and a Limited LPR-FISP Sequence, *Journal Mag Res Med,* 2001; 14:617–627.

[6] Bing P *et al*, Performance of sub-pixel registration algorithms in digital image correlation, *Meas. Sci. Technol* 2006; **17**:1615-1621.

Grant Support: The project of which this work is part of is funded by DH-NEAT Grant D 083.