# Phase-Encoded Resonant Marker Identification and Tracking

Marc Rea[1], Donald McRobbie[1], Francesca Galassi[2], Djordje Brujic[2], Mihailo Ristic[2], and Ian Young[2]
[1]*Radiological Sciences Unit, Imperial College Healthcare NHS Trust, London, United Kingdom,* [2]*Mechanical Engineering, Imperial College London, London, United Kingdom*

## Introduction

Interventional MRI procedures are often dependent on the localisation of objects or devices inside the scanner and many tracking schemes have been developed using either passive markers or micro-coil fiducials [1,2]. Fiducial markers or needles containing susceptible contrast materials often suffer from low contrast and low resolution; while active resonant micro-coils require separate receive channels with additional cabling potentially leading to increased complexity and patient risk. For devices with more than 3-DOF (Degrees of Freedom) multiple fiducials are required to localize the position and orientation of end-effectors, and tracking of multiple fiducial markers has been previously reported using, among other methods, active markers [3] and passive markers with up to ten 1-D projections [4]. Here we present a method of tracking passive (unconnected) micro-coils, using a dynamically orientated phase-encoding (PE) gradient along the device axis to differentiate the fiducial signals. This method is able to resolve multiple fiducials in 3-D using only three orthogonal projections; overcoming the problem caused by similar projected positions and reducing the minimum time required for localisation. This project forms part of ongoing development of clinical MRI-compatible robotics.

## Methods

Two micro-coil fiducial markers with coil dimensions of around 3mm and filled with a vinyl plastisol gel, were tuned to 63.8 MHz and fixed onto a plastic probe attachment with a separation of 35mm, as shown in Fig. 1(a). Movements in the scanner were actuated remotely in 5-DOF (excluding rotation around the long axis of the needle), accordingly only two fiducials were required for tracking the position and rotation in three dimensions.

A set of images were acquired to determine the initial position of the probe, the sequence shown in Fig. 1(b) was then used to follow subsequent motion of the probe. The sequence acquired three orthogonal projections with a non-selective RF pulse (flip angle = 0.5-2°, resolution=128, FOV=20cm). Prior to data collection, phase encoding was applied along the last known direction of the probe. The area under the PE gradient was calculated to match the distance between the fiducials and impose a relative phase shift of 90°. At 1.5T, and for a gradient pulse lasting 1ms, the required difference in applied field to cause a 90° phase shift is around 6uT. The data from the first echo was analysed to calculate the relative phase of the two fiducial signals. This was done by rotation of the complex data to achieve the maximum projections for each of the fiducial signals (which are also separated in frequency along this axis). The phase information was then used to filter the subsequent echoes projected along the two orthogonal directions, separating the signals by the required pre-calculated phase shift and allowing the unique positional information to be determined by maximum peak position alone, even in the usual situation where there was little subsequent rotation and the fiducials project with similar frequencies.

To test the system, a Signa HDx 1.5T scanner (GE Healthcare, USA), with a modified Gradient Echo pulse sequence (TR = 12ms, TE = 1.8ms, $\alpha = 1°$) was used; the raw data was sent to an external PC running MatLab (Mathworks, USA), which calculated and stored the positions of the fiducials allowing real-time sequence feedback to be used to adjust the gradient pulse amplitudes to the new direction before the next TR. Tests were performed with the probe in various positions and orientations to characterise the dependence of the relative phase angle and the ability to separate the fiducials for a range of rotations.

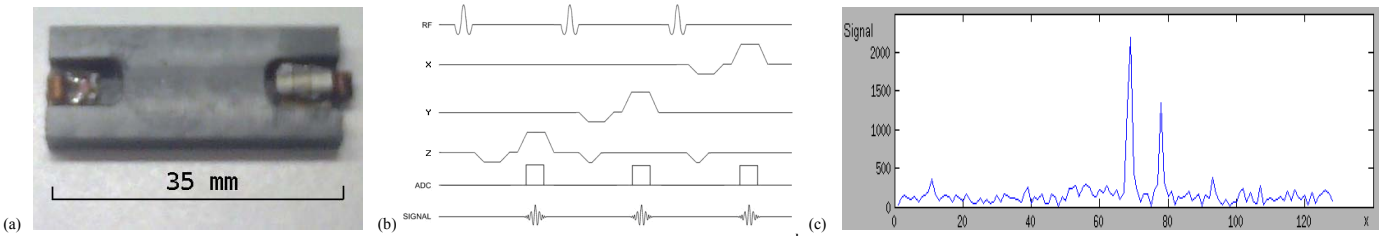


**Figure 1. (a) Holder containing the two fiducial markers. (b) The pulse sequence diagram before rotation. (c) The 2nd acquired echo before the phase filtering. The separation in frequency shows probe rotation.**

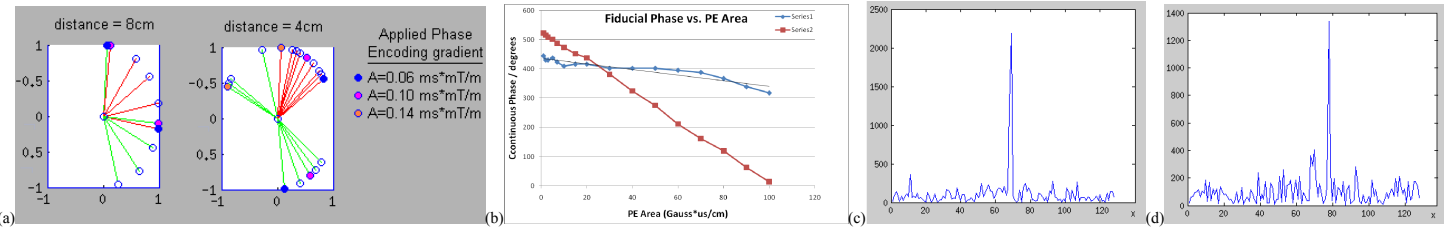


**Figure 2. (a) Calculated phase angles plotted for fiducial 1 (green) and fiducial 2 (red) show anti-clockwise rotation with increasing phase-encoding area (Note the appearance of some negative values). The proximal fiducial is located at approximately 8cm from the origin in the left graph, and at 4cm in the right graph. The relative angle remains approximately constant. (b) Plot of the phase shifts experienced with different PE Areas for the two cases in Fig 2(a). (c, d) The data shown in Fig 1(c) when phase filtered using the applied phase shift of 90° separates the two fiducial signals .**

## Results

Separation of the fiducial signals proved fairly robust using a 90° phase shift. The result of the phase analysis was often rotated by 180°, which limited the maximum useful separation space to half of the polar plane. The 3D projection data was acquired with a minimum time of 12ms. The phase filtering and subsequent projection calculations were timed at 19ms and the feedback to the scanner executed in around 5ms giving a minimum TR time of around 32ms and a potential rate of 30fps. The tracking sequence could be interleaved with a dynamic image acquisition to show the movements of the probe with update rate of greater than 1fps depending on the image properties. Repeated testing showed the calculated position of the fiducials was found to be accurate to 0.8(±0. 3)mm with no cases of misinterpretation.

## Discussion

This work demonstrates how phase-encoding may be used to distinguish signals from multiple micro-coil fiducials using a low flip angle real-time pulse sequence and just three orthogonal 1-D projections. The method is applicable to real-time device tracking once the initial positions of the fiducials are known, which may be achieved by initially using more projections. The capability to identify the fiducials using just a 60° phase shift should allow the method to simultaneously localise three fiducials by selecting an appropriate axis for phase encoding which still provides equal separations of phase. This should then permit full 3-D 6-DOF tracking of devices. Further work will examine this, quantify the limits of rotation and translation speeds, and examine the effects of surrounding tissues on the performance of the sequence.

## References

[1] Dumoulin CL, Souza SP, Darrow RD. Real-time position monitoring of invasive devices using magnetic resonance, Magn Reson Med, 1993; 29:411–415.
[2] Burl M *et al,* Tuned fiducial markers to identify body locations with minimal perturbation of tissue magnetization, *Magn Reson Med*, 1996; 36(3): 491-3.
[3] Coutts GA *et al*, Integrated position tracking and imaging of interventional tools using small fiducial receiver coils, Magn Reson Med, 1998, 40(6):908-13.
[4] 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.