MRI compatible-3D localization system for Real-Time catheter navigation

Olivia Garandeau[1], Maxime Bories[1], Fabrice Marquet[1], Remi Dubois[2], Pierre Jais[3], and Bruno Quesson[1]

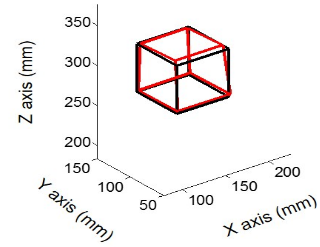
[1]*IHU Liryc/CRCTB Inserm U1045, University of Bordeaux, Pessac, Aquitaine, France,* [2]*IHU Liryc/CRCTB Inserm U1045, ESPCI Paris Tech, Pessac, Aquitaine, France,* [3]*CHU bordeaux, Pessac, Aquitaine, France*

Target: Clinicians/Physicists interested in performing interventional cardiac electrophysiology under MRI.

Purpose. Catheter-based electrophysiology (EP) aims at generating 3D Electro-Anatomical Maps (EAM) of the heart chambers and correlating these functional data with anatomical information obtained from cardiac MRI (e.g. presence of scars, fibrosis …). There is a growing interest in developing simultaneous EAM and MRI in order to (i) reduce procedure duration, (ii) monitor EP procedures with MRI (e.g. MR-thermometry) and (iii) improve the accuracy of multi-modal registration between the two techniques. Ideally, the 3D localization system should not depend on MR measurements (active tracking) but to ensure MR scanning time is devoted to acquiring relevant images for diagnosis or therapy monitoring. It is also expected to be able to locate the catheter in 3D with less than 5 mm uncertainty and be compatible with any MR-compatible catheter and all MR acquisition sequences. An active localization method relying on a voltage-based approach was previously published by Schmidt *et al* [1]. They demonstrated the technical feasibility of adapting a non-MR compatible commercial localization device to the MR environment. However, restrictions of use during MRI scanning, impeding continuous tracking of the catheter during rapid sequences (TR<32ms), were pointed out. In this work, we present a home-made, MR compatible device that allows 3D localization of the catheter simultaneously to MRI scanning without such restrictions.

Methods. The system consisted of three pairs of electrodes, positioned on the patient body surface in orthogonal directions [2]. Connected to 3 function generators, they simultaneously induced 3 oscillating electrical fields at different frequencies inside the thorax (ranging from 30 to 100 kHz). Each electrode was slit to reduce eddy currents and avoid potential skin burns, as suggested in [1]. We used a MR compatible ablation catheter for test purposes. With this technology, voltage amplitudes recorded by a given catheter electrode were dependent upon the catheter position relative to each emitting electrodes pair. Being potentially prone to MRI interferences induced by the Radiofrequency pulses and rapid gradient switching, band reject filters (tuned to 64 MHz) were inserted into voltage emission and reception circuits. The digitization of these measured electrical signals through catheter electrode (GaGe Applied Technologies, Lockport, Il USA, 12-bits resolution) was achieved by iterative acquisitions of 16384 points at a sampling frequency of 1 MHz. From these digital signals, voltage amplitudes were retrieved after Fourier decomposition, for each emitted frequency. Then, displacement were computed after calibrating the amplitude variations at several catheter positions derived from a set of MR images. A user interface was developed in Matlab to (i) select the emitting frequencies: the spectrum resulting from gradient switching of a given MR sequence could be recorded to select 3 emitting frequencies with minimal amplitude in the spectrum, (ii) locate the emitting electrodes onto the body surface and perform the calibration procedure (linear regression between measured voltages and MR 3D coordinates for a set of catheter locations), and (iii) compute and visualize the 3D catheter position in real-time at a typical frame rate of 25 positions/sec. The 3D localization method was evaluated *in vitro* in a tank filled with saline solution and then in pig with the catheter being inserted through the femoral artery and advanced progressively into the aorta by 10 mm steps. Typical MR acquisition sequences were (i) a 3D flash sequence with 400x300x320 mm FOV, 256x230x230 matrix, 1.48/200 msec TE/TR, 90 FA, 526 Hz/pixel BW for 3D reconstruction and visualization of the skin electrodes and catheter and (ii) a balanced-ssfp with 250x250 mm FOV, 128x128 matrix, 2.1/549 msec TE/TR, 45 FA, 1002 Hz/pixel BW used for simultaneous imaging during catheter manipulation.

A



B

	Edge length of the cube (mm)		
	40	60	80
Position error (mm)			
x	1,1	1,6	3,4
y	1,2	2,8	5,5
z	0,6	2,5	3,2

Figure 1. Evaluation of the Navigation system *in vitro*

A. Theoretic cubic trajectory (black) versus catheter cubic trajectory (red).
B. Table showing catheter position uncertainty.

Results. Figure 1A displays the actual (black) and computed (red) trajectories when the catheter was displaced by 60 mm in a water tank using a robotic motion device outside of the MR environment. The calibration values were 1.8, 2.2 and 1 mV/mm for the X, Y and Z axes, respectively. The 3D trajectory was repeated for several distances ranging from 40 mm to 80 mm and errors in position for each direction were computed and reported in Table 1 (Figure 1B). During balanced-ssfp acquisition, the maximal voltage amplitude recorded by the catheter was 2V, resulting in a voltage resolution of 1 mV (4V/12bits resolution) and therefore in millimetric resolution after applying calibration values. Voltage variations before and during balanced-ssfp scanning with the catheter at a fixed location were below 2 mV (<2 mm after conversion). Experiments performed in animals revealed no artifact induced by the skin electrodes nor skin burns. The slit electrodes stuck on the skin together with the catheter could be visualized on 3D reconstruction data (Figures 2A and 2B). Displacement of the catheter in the aorta by 10 mm steps (Figure 2C) resulted in a nearly linear curve after computing the trajectory from the recorded voltages.

Discussion. The uncertainty in 3D localization depended on the distance covered by the catheter. However it remained below 6 mm for 80 mm displacement amplitudes (below 3 mm for 60 mm displacement range). More sophisticated calibration process may overcome the current limitation in localization precision. The 3D localization system can be operated with different acquisition sequences, even during rapid gradient switching. The emitted frequencies for catheter localization can be tuned to a specific MR acquisition sequence after simple recording of the acquisition spectrum into the user interface. 3D active catheter localization during MR imaging was possible at the cost of a maximal 2 mm offset observed during scanning that may also be integrated into calibration in future developments.

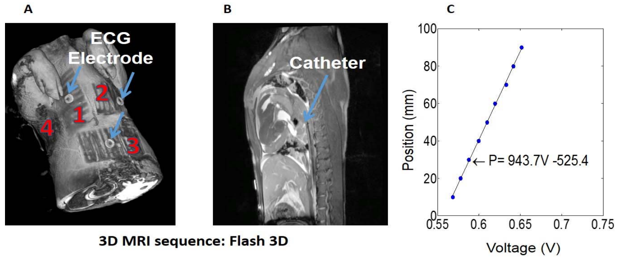


Figure 2. Evaluation of the Navigation system in pig.

A. Stripped skin electrodes (1, 2, 3, 4). Blue arrows outline MR-compatible ECG electrodes for skin electrode centre determination.
B. Catheter visualization on 3D flash image of pig.
C. Experimental data (dots) and linear fit of the catheter position measured by MRI versus voltage amplitude recorded by the localization device.

Conclusion. This study demonstrates the possibility to retrieve the 3D position of the catheter using voltage recordings during MRI acquisition. The proposed device is compatible with any MR-compatible catheter and requires MR images only during the calibration process. Several electrodes positions could be tracked depending on the number of available channels of the acquisition card. Once calibration is performed, this 3D localization system works independently from the MR. It could therefore be used for 3D EAM and for 3D slice tracking with any sequence, providing that the 3D slice position can be updated in real-time.

References: [1] Schmidt EJ et al. Magn Reson Med. 2013. [2] Wittkampf FH et al. Circulation. 1999.