Tracking Rotational Orientation of Catheter Using Transmit Array System

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INTRODUCTION: Even though many researchers introduced solutions for tracking problem of interventional devices such as biopsy needles and catheters, rotational orientation of a catheter is a relatively untouched subject (1). Previously, we proposed to use a circulating linear polarized RF excitation for separation of anatomy signal from the catheter using FLASH (2) and TrueFISP (3) sequences. In this abstract, determination of the rotational orientation of an inductively coupled RF (ICRF) coil is presented as a significant extension to the previous catheter tracking studies. This method paves the way of using rotationally asymmetric designs of catheters.

THEORY: In this study, modified RF excitation pulses are transmitted through a transmit array system (2,3). The body coil is used as a two-channel transmit coil without using the quadrature hybrid. Instead of creating a forward polarized field, linearly polarized RF transmit fields are applied with constant magnitude and varying phases (Figure 1a). This enables circulating linearly polarized RF excitation with 4 excitations per 2π circulation (Figure 1b). Assume S is the k-space matrix of an anatomy image without the circulating RF excitation. The excitation scheme in Figure 1b contributes a phase, $e^{ip\pi/2}$, to each column of S matrix, where p is the column number. As a result, the anatomy image shifts in phase encoding direction. On the other hand, orientation of the ICRF coil directly affects the resultant image. Assume that the surface normal vector of the ICRF coil makes θ angle with x-axis. Each linear excitation can be decomposed into two orthogonal excitations, parallel and perpendicular to the surface normal vector of the ICRF coil. Using Faraday's law of induction, it can be stated that only the parallel component induces a current on the ICRF coil, but the perpendicular one does not. In this case, each line of the S matrix is multiplied with $e^{i\theta}\sin(\theta + p\pi/2)$, where p is the index number of TR. In this case, not only the phase, but also the magnitude of the effective RF field changes in each TR. As a result, two copies of the ICRF image shifts in phase and anti-phase directions. Analytical expressions of the signal can be expressed as:

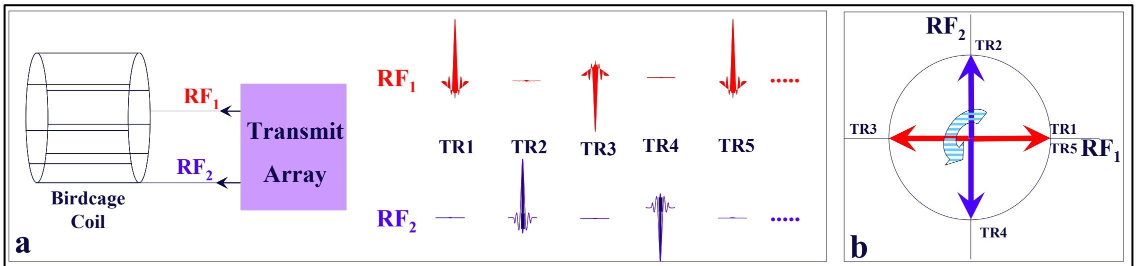

Figure 1: a) RF excitation scheme at each TR to feed two-channel birdcage coil using transmit array. b) Circulation of linearly polarized RF excitations. In this case, four excitations occur in one circulation.

$$S_{ICRF}(t) = \iint m_{icrf}\, e^{-i2\pi k_y\left(y - N_y \Delta y/4\right)} e^{-i2\pi k_x x}\, dx\, dy \Big/ 2 + \iint \left(m_{icrf}\, e^{i2\theta}\right) e^{-i2\pi k_y\left(y + N_y \Delta y/4\right)} e^{-i2\pi k_x x}\, dx\, dy \Big/ 2$$

, where N_y is number of phase encoding lines, m_{icrf} is the complex imaging parameters. The expression states that the phase difference between the two copies of the ICRF coil is directly related to the rotational orientation of the coil and exactly equal to two times of the orientation angle.

METHOD: In our work a 3 tesla Siemens TIMTrio and an 8-channel transmit array systems are used. Siemens spine matrix coils are used for reception. A MATLAB (ver. 7.6; Mathworks Inc., Natick MA) code is written for the reconstruction, calculation of the rotational orientation. The ICRF was 100-mm long and constructed on a 6F Teflon catheter using coated copper wire 0.4 mm in diameter; a heat shrink tube was used for isolation resulting in a prototype device with an outer diameter of 3 mm (9F). A rectangular 15×10×30 cm^3 oil phantom was constructed. Before each acquisition, the ICRF coils rotated 13°. FLASH sequence was modified in order to get circulating polarization vectors with following parameters: TR 9.8 ms, TE 4.1 ms, slice thick.:5 mm, flip angle 30°, FOV 300x300 mm^2, imaging matrix 256x256, FLASH experiment simulation was done for rotational orientation of the ICRF coil for proof of principle. Phase contrast algorithm (4) was used to find phase difference of the two ICRF coil images.

RESULTS: Figure 2 shows rotational orientation experiment result. The error is defined as the difference between the experiment and simulation results and found to be less than 10°.

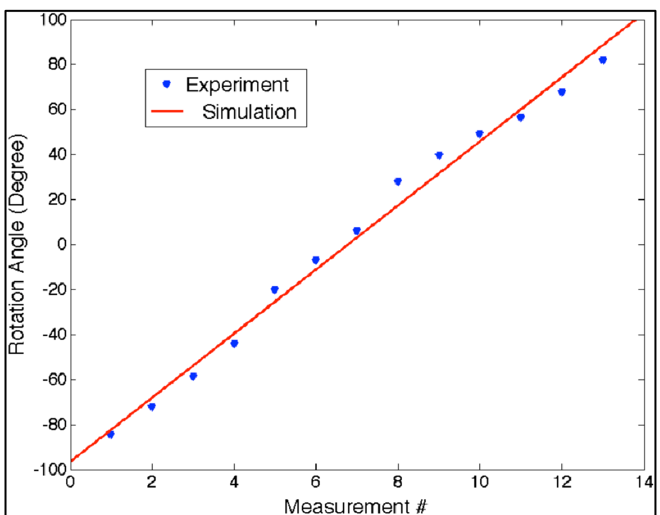

Figure 2: Phantom experiment and computer simulation.

DISCUSSION: The main problem of the method is that rotational orientation is π symmetric and the method cannot discriminate θ^o from $\theta^o + 180^o$.

CONCLUSION: This study presented a novel method to simultaneously acquire the rotational orientation of the inductively coupled RF coil and track the coil built on a catheter.

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