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Technical note

Construction of a conductive distortion reduced electromagnetic tracking system for computer assisted image-guided interventions

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ABSTRACT

Alternating current electromagnetic tracking system (EMTS) is widely used in computer-assisted image-guided interventions. However, EMTS suffers from distortions caused by electrically conductive objects in close proximity to tracker tools. Eddy currents in conductive distorters generate secondary magnetic fields that disrupt the measured position and orientation (P&O) of the tracker. This paper proposes a LabVIEW field programmable gate array (FPGA) based EMTS to reduce the interference caused by nearby conductive, but non-ferromagnetic objects upon the method developed in the authors' previous studies. The system's performance was tested in the presence of single/multiple nearby conductive distorters. The results illustrated that the constructed EMTS worked accurately and stably despite nearby static or mobile conductive objects. The technology will allow surgeons to perform image-guided interventions with EMTS even when there are conductive objects close by the tracker tool.

1. Introduction

There are four major types of navigation systems used in computer-assisted image-guided interventions: mechanical, ultrasonic, optical, and electromagnetic tracking systems [1]. Considering the working volume, the tracker's accuracy, and the non-line-of-sight requirement between the emitter and receiver, EMTS is the best solution to allow the surgical instruments, such as catheters and needles, to be tracked flexibly inside the patient's body [2,3]. Studies have demonstrated that commercially available EMTS are sufficiently precise to provide effective imaging information in clinical applications [3,4]. However, EMTS is susceptive to metals near the tracked medical instrument. Metals that distort EMTS are typically conductive or ferromagnetic. Ferromagnetic metals alter the shape of the magnetic field generated by the transmitting coils. The distorted fields are difficult to be analytically characterized [5]. Calibration can be applied to correct the static error caused by ferromagnetic metals in the operation room [6]. However, it does not help with a mobile ferromagnetic distorter. Approaches, such as placing a sensing coil array outside the patient body [7] or at least one side shielding of the sensor [8], have been claimed. However, additional hardware requires to be integrated into the EMTS.

In the alternating magnetic fields generated by emitting coils, the eddy currents induced in the conductive objects generate secondary magnetic fields. EMTS measures the voltages across the sensing coil in both alternating magnetic fields generated by emitting coils and conductive objects respectively. It causes the tracker's P&O estimations to be inaccurate [9]. A common method for electromagnetic tracking is to feed sine-waves into the emitting coils sequentially to produce alternating magnetic fields [10–12]. The P&O estimation of the sensing coil based on the electromagnetic dipole model [13,14]. From the known P&Os and other relevant parameters, such as area and turns of the emitting coils, the magnetic field generated by each emitting coil can be simulated. The P&O of the sensing coil is estimated by minimizing the differences between the simulated and measured magnetic field strength. The method works properly only when there is no conductive object neighboring to the sensing coil. Otherwise, the amplitude of the measured sinusoidal voltage is distorted by the secondary magnetic field generated by a nearby metal, which causes inaccuracy in the tracker's P&O estimation. In clinical workflow, when conductive objects, such as needles and hammers, are mobile during interventions, calibration cannot compensate for the dynamic distortions. Therefore, the accuracy of EMTS becomes lower when there are dynamic conductive objects close to the sensing coil.

The authors have previously developed an algorithm to reduce the conductive but non-ferromagnetic distortions for EMTS [15]. Instead of feeding sinusoidal signals into the emitting coils, quadratic-rectangular signals are utilized. The non-distorted voltage can be distinguished, and further used for P&O estimation. This

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paper presents a method to construct such an EMTS to reduce distortions caused by conductive objects.

2. Methods

2.1. Experimental setup

Commercially available EMTS does not provide the functionality to generate arbitrary magnetic fields; therefore, the experimental setup of an EMTS was developed for the research studies of the authors' group.

The most important element of the experimental setup was the PXI system (PXI 7854R and PXIe 8133, National Instruments, USA) that was used for signal generation, data acquisition, P&O estimation, and visualization. An FPGA within the PXI 7854R permitted the system to create arbitrary waveforms and fed them into eight current feedback amplifiers (LT1210, Linear Technology, USA). The currents were sequentially supplied into a field generator consisting of eight emitting coils placed at different positions and orientations to create different magnetic fields. A sensing coil (Aurora 5DOF sensor, Northern Digital, Canada) with a diameter of 0.5 mm and a length of 8 mm measures the voltages across the sensing coil caused by the alternating magnetic fields. A micropower amplifier (LT1168a, Linear Technology, USA) was used to increase the measured voltages across the sensing coil that was integrated into the tip of the catheter (Twin-Pass Dual Access Catheter, Vascular Solution, USA) [16].

2.2. Signal generation and data acquisition

In the proposed algorithm, the EMTS fed quadratic-rectangular signals into the eight emitting coils sequentially. A look-up table (LUT) inside the FPGA stored the unique waveform. Each of the eight emitting coils was firstly fed with a quadratic signal. Until the system response to the quadratic excitation reached a steady state, a rectangular signal was looked up and supplied into the emitting coils. In the LUT, the quadratic signal was stored in different addresses. Looking up the quadratic and the rectangular waveforms at separate rates allowed them to be generated during different periods. Within the implementation, the periods of the quadratic signal and the rectangular signal were 0.625 ms and 25 ms, respectively. The amplitudes of the quadratic signal and the rectangular signal were 0.5 V. The parameters were not fixed, but a set of values that suited the experimental setup. In order to measure the large voltage due to a quadratic excitation, the period of the quadratic signals was defined to be very small. However, the system response to a rectangular excitation reached its steady state slowly. Therefore, a long period for the rectangular excitation signal was selected.

The EMTS utilized time division multiplexing. The eight emitting coils worked sequentially to ensure the generated magnetic fields of every emitting coil do not interrupt each other. Additionally, the FPGA generated eight digital output signals to control the on-off state of the eight emitting coils. In order to track the P&Os of the sensing coil continuously in real-time, the data acquisition process was synchronized with the signal generation. The parameters for data acquisition, such as sampling frequency and the number of samples to read per measurement, were pre-defined before the data acquisition process. (Fig. 1)..

Fig. 2 presents the workflow of signal generation and data acquisition program for all of the eight emitting coils. After the program had began, the system waited to begin the lookup processes until "DO 0" was at its rising edge. The waveforms were looked up and outputted through the analog output terminals from "AO 0" to "AO 8" sequentially, passed through the current feedback ampli-

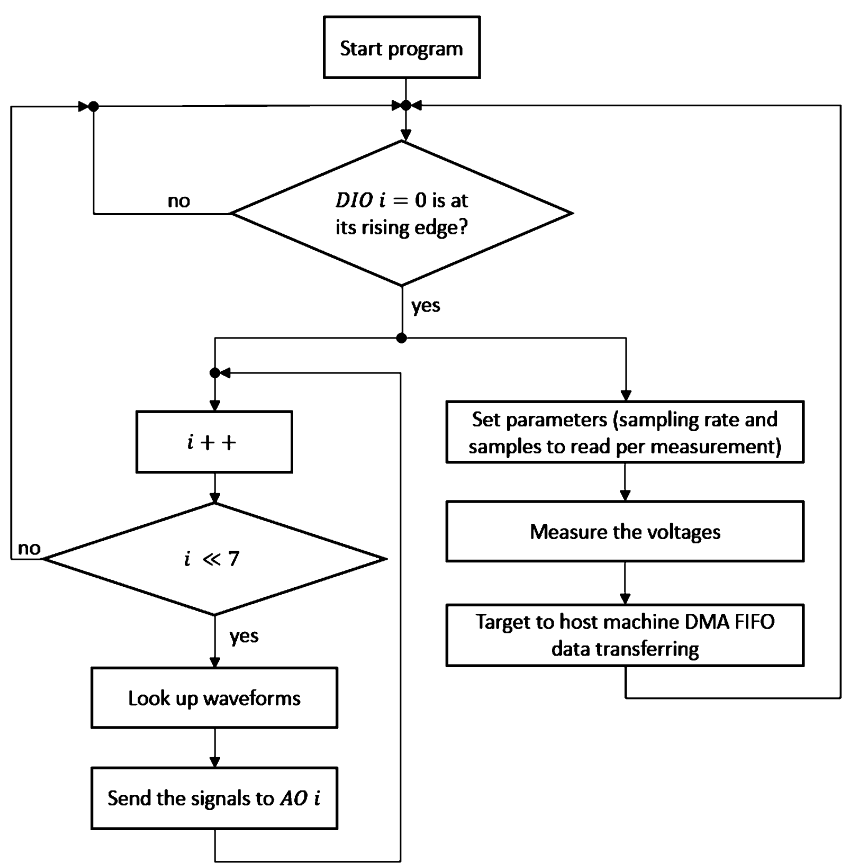

Fig. 1. Flow diagram of signal generation and data acquisition in FPGA.