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FMMD controller and software for MPI system based on mechanical FFL movement

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Abstract

We describe FMMD(Frequency Mixed Magnetic Detection) controller and software for MPI(Magnetic Particle Imaging) system based on mechanical FFL(Field Free Line) movement. MPI based on mechanical FFL movement requires signal processing such as signal excitation, amplification, filter, and acquisition. And it is essential to synchronize the acquired signal with the mechanical FFL movement. For signal processing, FMMD controller that can adjust the attenuation and amplification factors and filtering frequencies of signals in real time was used. The signal acquired from the controller was transferred to the host PC, and the synchronization between the signal acquired from the MPI device and the mechanical FFL motion was processed, and the frequency analysis of the synchronized data was performed in software. Without using various commercial signal processing equipment, we were able to develop MPI system by using the controller and software.

I. Introduction

MPI is a next-generation medical imaging technology that is being continuously researched. To perform MPI, a FFL/FFP(Field Free Point) region in which a magnetic field disappears is made in space, and the distribution of NMP(Nano Magnetic Particle) in 3D space is imaged while moving the FFL/FFP mechanically or electronically[1,2]. To configure the MPI system, various analog and digital equipment such as signal processers, signal generators, signal filterers, signal amplifiers, and DAQ are required. Instead of using external devices for signal processing and acquisition, we used FMMD controller. The controller enables signal excitation, acquisition and processing in one device. Using this controller and the mechanical FFL movement structure, we developed the MPI device with a simple structure [3].

II. Material and methods

Fig. 1 shows FMMD controller and 40mm FMMD coil are used to acquire signals from FMMD-based MPI equipment. The FMMD coil consists of an excitation coil and a detection coil, and the excitation coil can apply a high/low mixed frequency to improve the signal to noise ratio of detection signals [3, 4]. The detection coil is designed with a differential coil structure to attenuate the signal transmitted directly through the excitation coil and to acquire only the signal by NMP.

To perform MPI with mechanical movement, the rotation stage moves from 0 to 180 degrees. It moves in units of 1 to 20 degrees according to the characteristics of the sample, and the translation stage performs a linear repetitive motion for each unit angle. During the linear movement, the detection signal of the FMMD coil is received. The raw data (sinogram) acquired by repetitive rotation and linear movement is restored to a 2D image by applying inverse radon transform. While the sample

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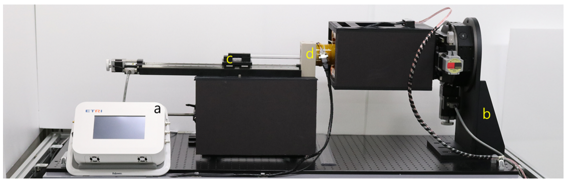

Figure 1: System configuration – a) FMMD controller, b) mechanical movement R-T stage, c) sample translation stage, d) FMMD coil

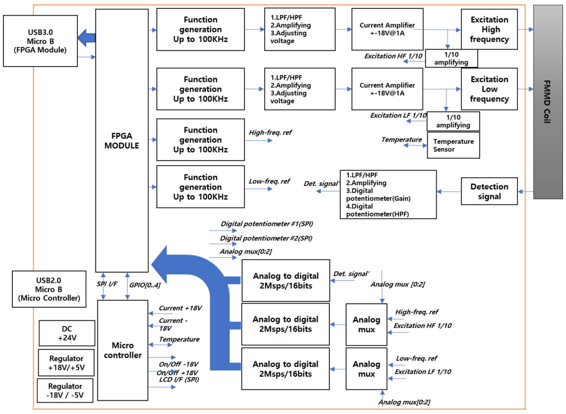

Figure 2: FMMD controller block diagram

translation stage moves by a unit distance, using the 2D image reconstruction the R-T stage is repeated. 2D images are collected and made into a 2D image volume, and 3D imaging is performed.

The detection of the 40mm FMMD coil has a differential coil structure, so it attenuates the excitation signal, but it is impossible to partially remove the strong excitation signal. In order to attenuate to a level that the ADC of the FMMD controller can handle, the signal strength is attenuated using an opamp circuit using a digital electrometer. (digital adjustable register, AD5292). The digital potential meter is controlled by SPI, and the SPI control signal is generated by the FPGA. Control parameter is transmitted/received using USB3.0 I/F in x86 PC-based FMMD controller GUI software. Fig.2 shows overall struct of FMMD controller.

The detection coil signal with the voltage level adjusted is passed through the second stage amplification circuit and a high pass filter (HPF) in the middle. Using a variable amplification circuit using a digital potential meter, the amplification level can be adjusted up to 1024 times by software. Noise is removed through the HFP between the variable amplifiers, and the filter is also variable. The detection coil signal with the voltage level adjusted is passed through the second stage amplification circuit and a high pass filter in the middle. Using a variable amplification circuit using a digital potential meter, the amplification level can be adjusted up to 1024 times by software. Noise is removed through the HFP between

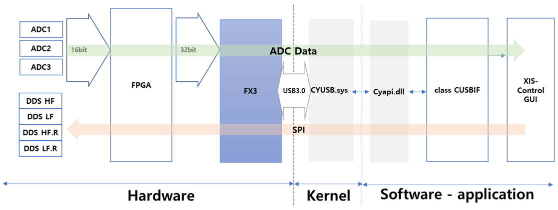

Figure 3: FMMD controller data flow

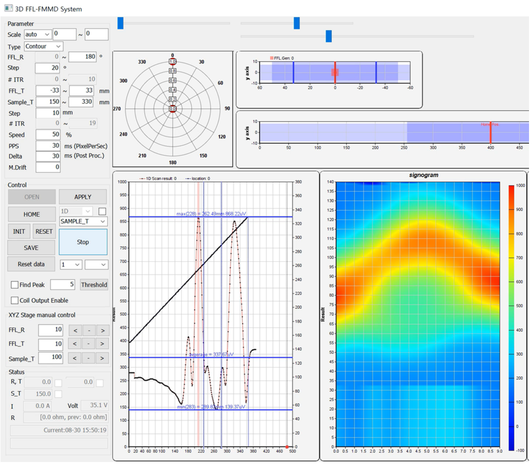

Figure 4: FMMD controller software

the variable amplifiers, and the filter is also variable. It is configured to properly handle changes in the applied frequency by using a variable HFP.

Fig3. shows the data flow after filtering and amplification, analog signal is converted to digital signal with 16bit 2Msps ADC (LTC2389CLX-16) and data is collected using Xilinx's Artix 7 FPGA[6]. The collected data is transferred to Cypress's FX3 USB3.0 peripheral chip[6] and transferred to the HOST PC in real time through USB3.0 I/F.

The data transferred using USB3.0 IF is saved in real time with a circular queue of C++ based CUSBIF class. The class provides functions to control the controller and receive raw data using cypress API(cyapi.dll). It is implemented to store 30 seconds of raw data using a circular queue. Fig.4 shows the MFC-based FMMD controller software, which receives and stores the data of the FMMD coil, can display the raw data as a graph directly on the screen, or perform FFT to obtain the FMMD coil harmonic peak and visualize it.

To perform MPI, it is necessary to synchronize the movement of the mechanical stage and the data of the FMMD coil. Stage control unit and FMMD coil data processing unit are implemented based on thread. Software synchronization was performed using threads. The stage control unit stores location information and time information, and the FMMD coil data unit stores detection signals and time information, which are used for syn-

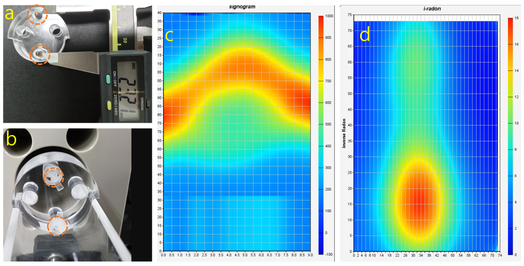

Figure 5: Imaging results using the proposed MPI equipment (a. Sample holder, b. MPI equipment mounted on the sample transfer unit, c. sinogram, d. 2D imaging result)

chronization.

Synchronized detection coil data is reconstructed according to the R-T stage position to generate a sinogram. X-axis means angle information of R-stage, and Y-axis means data information of FMMD coil stored while T-stage moves at each R-stage position.

To reconstruct a 3D image, a 2D image volume is generated by repeatedly generating sinograms by moving the sample a unit distance. Inverse radon transform is used for 2D image transformation from sinogram, and max intensity projection is used for 3D image reconstruction from 2D image volume. For each image processing, Mathwork's image processing toolbox was used.

III. Results and discussion

As shown in Fig. 5, to acquire images with MPI equipment, 50nm 50µl and 20µl of Chemicell's fluidMag-ARA are put in a PCR tube, and then inserted into the sample holder made of acrylic at the top and bottom, and the sample holder is installed in the sample transfer unit. The sample transfer unit moves the acrylic sample holder to the FFL position, rotates the FFL by 20 degrees mechanically, and repeats the linear movement at each rotation angle. When moving linearly, high-frequency and low-frequency excitation signals are applied to the FMMD coil. The anglog signal received from the detection unit of the FMMD coil is transmitted to the host PC using the ADC of the FMMD controller, and the sinogram is created in software as shown in Fig. 5.c and restored to a 2D image through image processing. Synchronization of mechanical movement and FMMD coil signal is processed using the position data of the stage controller. Although the stage controller's position value is received in real time, data drift occurs due to the limitations of the stage controller data processing speed and the serial data communication interface (RS232) from the stage controller to the PC. To solve this problem, noise and blur can be reduced by performing precise synchronization using an external trigger signal between the linear movement of the T-stage and the data of the FMMD coil.

IV. Conclusions

We developed the MPI system for mechanical FFL movement using FMMD controller and software. Since the FMMD controller processes signal amplification, attenuation, filtering and acquisition in one device, the signal processing unit can be minimized. In addition, as the ratio of signal amplification and attenuation and the filtering frequency can be changed in real time, signal processing is possible when changing parameters of the MPI system. All MPI system signals are processed after being transmitted to the host PC software through the USB3.0 I/F of the FMMD controller. Since all signal data is stored in software, additional data analysis and processing is also possible after the MPI system is terminated.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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