Development of a digital MRI console using general purpose digital instruments and board computers

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INTRODUCTION

Various approaches to digital MRI consoles have been reported [1-3]. Many of them have used FPGA and/or other sophisticated hardware units. However, their developments are difficult for most MRI researchers and the cost for them is very expensive. In this study, we have overcome these problems by using general-purpose digital instruments and board computers.

MATERIALS AND METHODS

Figures 1 and 2 show an overview and a block diagram of the MRI console developed in this study. The MRI console consists of (A) a digital oscilloscope (PicoScope 3205B, Pico Technology, St Neots, UK), (B) an arbitrary waveform generator (AWG-100, ELMOS Co. Ltd., Osaka, Japan), (C) three 32-bit board computers (Arduino Due, Smart Project, Torino, Italy), and (D) a note PC (CPU: Intel Core i5, 2.40GHz). The oscilloscope has two-channel ADC inputs with 8-bit resolution, 500 MHz sampling speed, and 32 M points/CH record length. The waveform generator has 14-bit resolution and a 1 M word DAC output with 10 ns sampling speed (maximum). The board computer uses a 32-bit CPU (AT91SAM3X8E), 96 kB SRAM, and two 12-bit DAC outputs. These digital instruments are connected to the PC via the USB 2.0 interface as shown in Fig.2. We used Qt5.2.1(C/C++), Arduino IDE 1.5.7 BETA, and Matlab2011a for software developments.

One of the board computers (master system) controls the timing of the MRI pulse sequence (20 µs time resolution) and outputs trigger signals to other board computers, the waveform generator, and the oscilloscope. The board computers output waveforms of Gx, Gy, and Gz field gradients synchronously via each DA output to the gradient driver. The waveform generator directly generates Larmor frequency (43.85 MHz) RF pulses to the RF transmitter. The detected NMR signal is amplified with a preamplifier and supplied to the oscilloscope through the band-pass filter. To reduce the amount of the sampling data and speed up the data transfer and processing time, the undersampling technique (sampling frequency = 6.9 MHz) is used [4]. To correct the received signal phase, the RF pulse is synchronously sampled using the oscilloscope as shown in Fig.2 (shown by the red arrow). Imaging experiments were performed using a 1.0 T MRI system using a yokeless permanent magnet with a 90 mm gap [5].

RESULTS AND DISCUSSION

Figure 3 shows cross sections of a water phantom with and without phase correction. The unpredictable signal phase caused by three independent time base used in the digital instruments (A, B, and C) was precisely corrected using the phase of the RF pulse simultaneously sampled. Figure 4 shows two horizontal cross sections selected from a 3D image dataset of a chemically fixed mouse acquired with a 3D SE sequence (TR/TE = 400ms/11.9ms, image matrix = 256×128×16). In conclusion, because the total cost of the digital instruments is about $2,000 and the time required for the system development is about one year, our system can be a promising approach to development of a digital MRI console.

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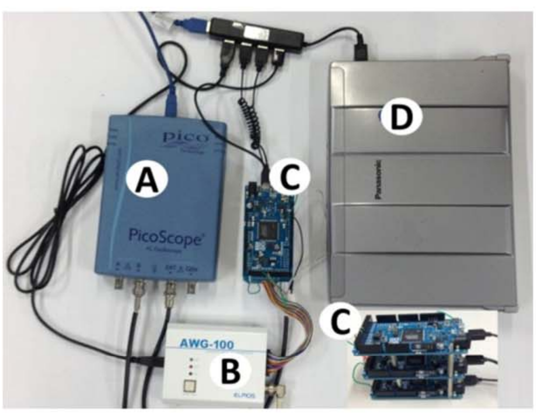

Fig.1. Overview of the MRI console.

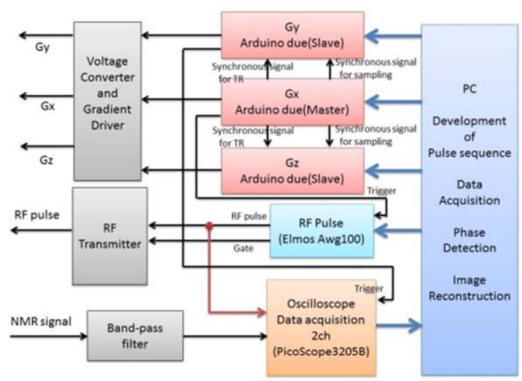

Fig.2. Block diagram of the MRI console.

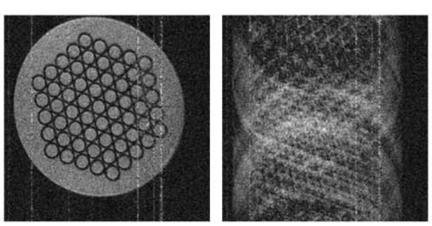

Fig.3 Water phantom. w/wo phase correction.

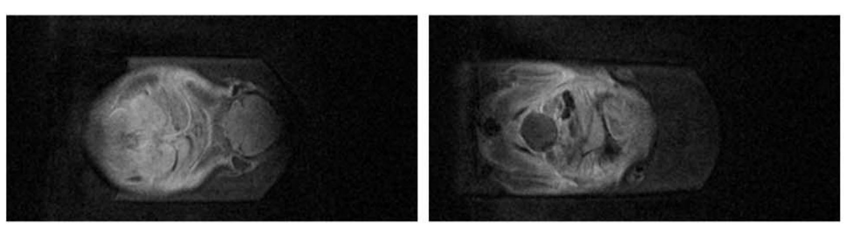

Fig.4. 2D cross sections selected from a 3D image dataset of a chemically fixed mouse.