MR microimaging using a high T_c superconducting bulk magnet with compressed sensing

Daiki Tamada[1,2], Takashi Nakamura[1,2], and Katsumi Kose[1,2]
[1]*Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki, Japan,* [2]*RIKEN, Wako, Saitama, Japan*

INTRODUCTION

A high critical temperature (T_c) superconducting bulk magnet is a promising magnet for magnetic resonance (MR) microimaging since it produces a strong (up to 17 T) and very stable (0.018 μT/hour) magnetic field with a smaller installation space compared to conventional superconducting magnets [1]. However, the room temperature bore diameter is limited because of difficulty to obtain large crystals for the bulk magnet and therefore the major application for the bulk magnet is now limited to MR microimaging of small objects. In such case, a long signal averaging time is required to achieve sufficient signal-to-noise ratio (SNR) for microimaging because SNR of the NMR signal is proportional to the voxel volume. In addition, sample deterioration can be caused during the long scan time when the sample is a biological object. Recently, compressed sensing (CS) MRI which can shorten the imaging time by using udersampled k-space with high image quality has been proposed [2]. In this study, we demonstrated usefulness of compressed sensing in MR microimaging using the high Tc superconducting bulk magnet.

MATERIALS AND METHODS

The MRI system (Fig. 1(a)) we used consists of a superconducting bulk magnet (B_0 = 4.74 T), a 3-axis gradient coil set (Fig. 1(b)), a solenoid RF coil with 4 mm diameter and 4 mm length (Fig.1(c)), and an MRI console.

The bulk magnet comprised six annular bulk superconductors (60 mm OD, 28 mm ID, 20 mm high) made of c-axis oriented single-domain EuBa2Cu3Oy crystals (T_c = 93 K). The bulk magnet was cooled using a pulse tube refrigerator. The magnet was energized by a field cooling method using a vertical wide bore (89 mm) superconducting NMR magnet operated at 4.74 T. The diameter of the room temperature bore of the bulk magnet was 23 mm.

MR images of a biological sample (Phytolacca americana shown in Fig 1(e)) were acquired using fully sampled (2 NEX , scan time = 3.6 hour) and randomly undersampled (10 NEX , reduction factor = 5, scan time = 3.6 hour, Fig.1(d)) 3D spine echo sequences (FOV = (12.8 mm)^3, image matrix = 256^3, voxel size = (50μm)^3, TR/TE = 100/10 ms).

The undersampled image was reconstructed by solving the following optimization problem using the fast composite splitting algorithm [3]:

$x = \arg\min_x \{\frac{1}{2}\|Rx-b\|^2 + \alpha\|x\|_{TV} + \beta\|\Phi x\|_1\}$, where x is a MR image, α and β are constant parameters, b is the undersampled k-space data, R is a partial Fourier transform, and Φ is a wavelet transform. As shown in Fig. 1(d), the k-space data was acquired using a Cartesian trajectory and undersampled in the phase-encode direction to avoid artifacts caused by susceptibility or magnetic field inhomogeneity.

RESULTS AND DISCUSSIONS

Figure 1(f) is an MR image reconstructed from the fully sampled k-space data (2 NEX). As clearly shown in the figure, the SNR (= 5.2) of the MR image was not sufficient. Figures 1(g, and h) are MR images reconstructed from the undersampled k-space data (10 NEX) with (g) zero-filling (ZF), and (h) CS, respectively. The MR image reconstructed using ZF exhibits artifacts and blur due to the undersampling although it has higher SNR (= 9.9). On the other hand, artifacts and blur were removed with high SNR (=25.3) by using the CS reconstruction as clearly shown in Fig. 1(h). These results clearly demonstrate that the SNR per unit time in microimaging was improved significantly by using CS. In conclusion, our approach is useful for MR microimaging using the high T_c superconducting bulk magnet.

REFERENCES

[1] K. Ogawa, et al., "Development of a magnetic resonance microscope using a high T_c bulk superconducting magnet," Applied Physics Letters, 98, 23, p.234101, 2011. [2] M. Lustig, et al., "Sparse MRI: The Application of Compressed Sensing for Rapid. MR Imaging," Magnetic Resonance in Medicine, 58, 6, p.1182-1195, 2007. [3] J. Huang, et al., "Efficient MR image reconstruction for compressed MR imaging," Medical Image Analysis, 15, 5, p. 670-679, 2011.

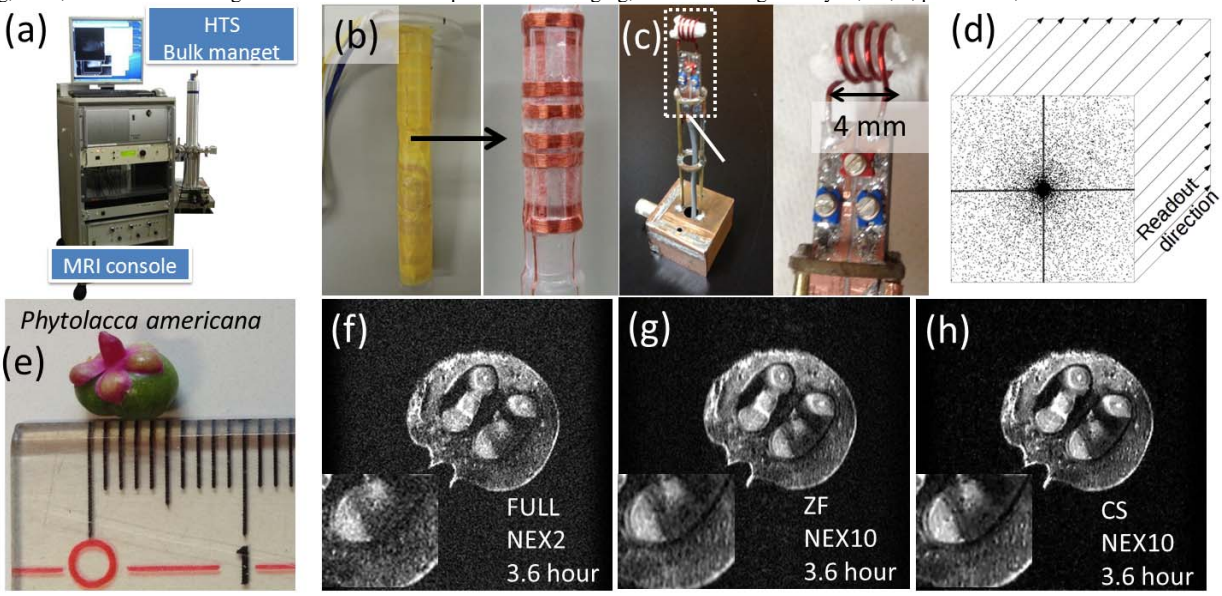

Fig. 1. (a) The MR microscope using the HTS superconducting bulk magnet. (b) A 3-axis gradient coil set. (c) A solenoid RF coil. (d) An undersampled Cartesian trajectory used in this study. (e) Phytolacca americana measured using our MRI system. (f-h) MR images reconstructed from (f) fully sampled k-space data and undersampled k-space data with (g) ZF and (h) CS.