A 72-channel whole-head system for combined ultra-low-field MRI and magnetoencephalography

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Introduction

In contrast to modern high-field MRI with field strengths of several tesla, ultra-low-field MRI (ULF MRI) uses a B_0 field of μT order [1,2]. To enhance the SNR, the sample is first pre-polarized in a mT-order polarizing field B_p and the resulting signals are measured using extremely sensitive superconducting quantum interference devices (SQUIDs). ULF MRI has several unique characteristics different from conventional MRI, *e.g.*, enhanced T_1 contrast [1], the possibility to image objects in the presence of metal, silent operation, and an open, bore-free geometry of the device. Magnetoencephalography (MEG) employs SQUIDs to measure the weak magnetic fields generated by the human brain [3]. Modified from a whole-head 306-channel MEG system by Elekta Oy (Helsinki, Finland), we present here our 72-channel hybrid device capable of both ULF MRI and MEG [4]. This kind of a combination allows the collection of structural and functional information from the human brain with a single device.

Methods

Our experimental setup in Fig. 1 consists of coils for B_0 (red), B_1 (cyan), three orthogonal gradients (green, yellow, and blue) and a polarizing coil (orange) for B_p. The B_1 and B_p fields are orthogonal to B_0. The Elekta MEG system features an array of 102 triple sensors, each comprising a magnetometer and two orthogonal planar gradiometers in a helmet-shaped configuration (gray and black in Fig. 1); at this stage of the work, 72 channels are used (black). Thus, the signals are measured with 24 SQUID magnetometers (21 mm × 21 mm pick-up loop, noise 4 fT/rHz) and 48 planar SQUID gradiometers (two 10 mm × 27 mm pick-up loops with a 17-mm baseline). The system is placed inside a magnetically shielded room for reduction of environmental magnetic noise.

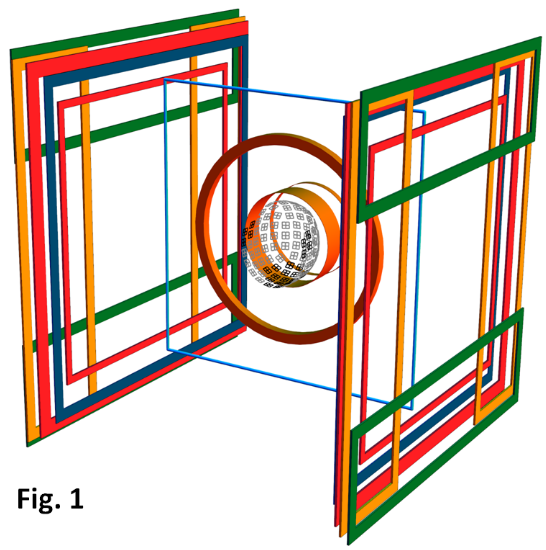

Fig. 1

When the highly sensitive SQUIDs are placed in the polarizing field, vortices are typically induced in their superconducting structures hampering the function of the SQUIDs. To improve the field tolerance of the sensor, our pick-up coils, fabricated using the thin-film technology, employ linewidths below 6 μm, and the SQUID itself is protected by flux dams and placed between two 11 mm × 11 mm niobium shielding plates [5]. Consequently, our sensors spontaneously recover from the polarization without heating.

Our system includes a superconducting coil to efficiently produce a strong polarizing field B_p within the sample. To reduce eddy currents induced by the pulsing of B_p, our B_p coil is connected in series with two shielding coils for zero dipole and quadrupole moments of the coil [6]. However, even modest currents in the coil (> 11 A) induce in its superconducting wires vortices, which produce a field (> 1 μT) that destroys the homogeneity of the B_0 field. Currently, this limits the strength of the B_p field.

Results

Fig. 2 shows 42 ULF-MR single-channel images of a human hand. Using sensitivity profiles acquired in a separate scan, an SNR-optimized pixel-wise linear combination image was formed and is shown in Fig. 2. The image was measured using a 2D spin-echo sequence with an echo time of 80 ms. Prior to collecting each k-space line, the sample was polarized for 800 ms in a 22-mT polarizing field. The imaging time was 40 minutes including 36-fold averaging. The image matrix was 46 × 50 with a pixel size of 4 mm × 3 mm. The B_0 and maximum gradient strengths were 50 μT and 150 μT/m, respectively. Preliminary MEG data indicate that despite the modifications for ULF MRI, the MEG capability of the device has been preserved.

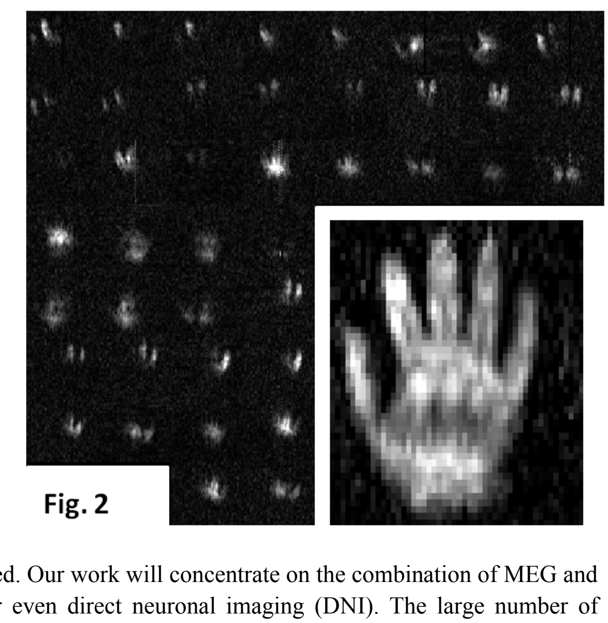

Fig. 2

Discussion

ULF MRI is a new and promising technology, whose potential is still largely unexplored. Our work will concentrate on the combination of MEG and ULF MRI; other potential applications include, *e.g.*, imaging of electric currents or even direct neuronal imaging (DNI). The large number of channels readily available calls for new techniques for combining the multi-dimensional information.

References

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