

Argos 500: Operation of a Helmet Vector-MEG

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ABSTRACT

We here describe the MEG system recently installed at the University of Ulm; it is specifically designed for clinical application and routine use, to allow investigation of a large number of patients per day. To reach this goal, the system design meets the requirements of reliability, high field sensitivity, minimal set-up time before each measurement and an easy-to-handle user interface. The sensor system consists of a 163 vector-magnetometers array oriented and located in a suitable way to cover the whole head of the patient. Four additional triplets are available as references to arrange software gradiometers. The helmet shaped sensor system is positioned to accommodate the patient in a supine position. Simultaneously to the MEG, there are 64 EEG channels. Other relevant patient information can be recorded up to a total number of 660 acquisition channels. Noise level of a single magnetometer is about $5 \text{ fT}/\sqrt{\text{Hz}}$. Maximum sampling rate is 4200 Hz.

KEY WORDS

Magnetoencephalography, MEG, Wholehead system, Vector magnetometer, Helmet system

INTRODUCTION

After four years of work a magnetoencephalographic system has become operational at the University of Ulm. The sensor design consists of a 163 vector-magnetometers array oriented and located in a suitable way to cover the whole head of the patient. Four additional triplets are available as references to arrange software gradiometers. The helmet shaped sensor system is positioned to accommodate a lying patient in a fashion similar to MRI and CT scanners. Simultaneously to the MEG, 32 EEG channels (expandable to up to 128) and other relevant patient information, up to a total number of 660 acquisition channels, can be recorded. Sampling rate is fixed at 8200 Hz. All basic pre-processing, band-pass filtering, decimation and noise compensation are performed on-line using an array of DSP.

There are several reasons to use vector magnetometers for the MEG. The first is the almost trivial consideration that biomagnetic signals are vector fields and it is worthwhile to collect all components of the signal. The second is the goal to improve precision in determining the site of localised sources or in estimating the distributed sources. The advantage comes because of the field components tangential to the head have a different spatial distribution and, in this way, there is a larger number of channels with good signal to noise ratio. A third very important reason, even if it has not been exploited until now, is that the vector-magnetometer array can be used as a classical array of magnetometers, with a variable geometry. In any measurement site it is possible, on the basis of data from the vector-magnetometer triplet, to calculate the component of the signal normal to the surface of the volume conductor, reducing the effect of the volume currents

The sensor is used in a magnetically shielded room (MSR), consisting of an external 8mm aluminium layer for eddy-current shielding and three layers of 1.57 mm thick soft magnetic material. The interior of the room is seen in Fig. 1. The global system is optimised for clinical use: the system requires only one maintenance session per week. Preliminary measurements on normal subjects are presented.

METHODS

The MEG sensor system consists of a large vertical dewar, held on a fixed basement, with a side helmet-shaped cavity to accommodate the patient's head during the measurement. All sensors (integrated SQUID magnetometers) are arranged in triplets to produce vectormagnetometers. The SQUID system specifications include a square pick-up coil (12 mm in diagonal), integrated Applied Positive Feedback (APF) circuit and feedback coil. The intrinsic noise spectral density ranging between 2 and 5 fT/ $\sqrt{\text{Hz}}$ in the white region, measured in a superconducting shield. This is different in Fig. 2, where the noise is measured during operation and where the total noise, including dewar, and residual environmental noise is shown. During system operation, SQUID operating points are adjusted automatically for stable operation, not for best noise performances. There are 492 basic sensors (166 vectormagnetometers); these cover the helmet-shaped sensing area and detect the magnetic fields of interest. Twelve additional sensors (4 vectormagnetometers), conveniently placed at 4 different locations around the helmet, are dedicated to the detection of the noise field. These two sensors arrays can be combined by software to form synthetic vectorgradiometers.

In addition, the vector-magnetometer array can be used to emulate a non-vectorial array of magnetometers (synthetic magnetometers), with the choice of a variable geometry. In any measurement site it is possible, on the basis of data from the vector magnetometer triplet and of anatomical data from



Figure 1. Argos 500 inside the MSR.

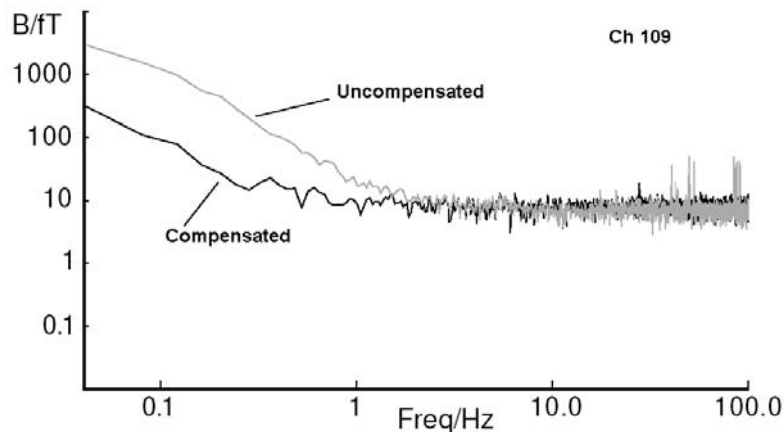


Figure 2. Spectra of the total noise during operation for one sample channel without (gray) and with compensation (black). The white noise level shows just minor changes, whereas the 1/f region is improved by 1 order of magnitude.

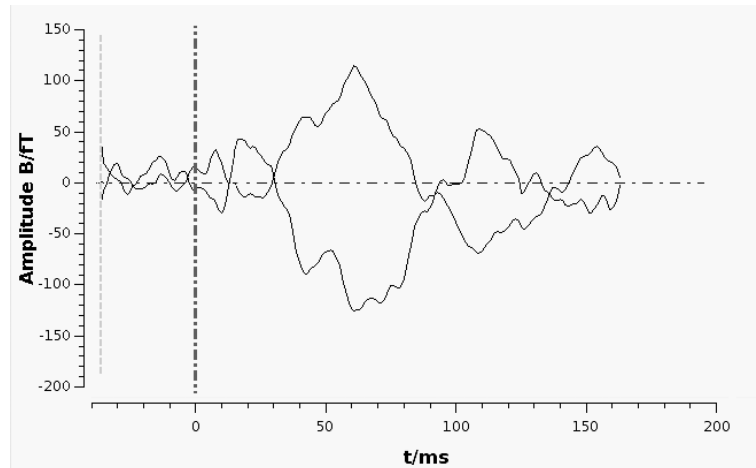
the patient, to calculate the component of the signal normal to the surface of the volume conductor, reducing the effect of the volume currents.

The patient handling set-up is made of non-magnetic material and responds to the same operating criteria of other imaging techniques like CT or MR scanners, with the patient lying on the bed and being slid into the measuring apparatus.

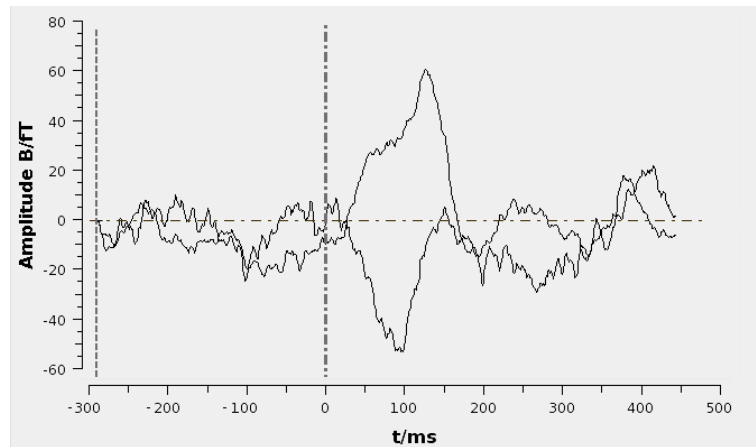
The sensor system is operated inside a magnetically shielded room [Pasquarelli, 2000], with one aluminium layer of eddy current shielding for AC stray fields and three layers of soft high-permeability shielding material for the lower frequency range. The inner room dimensions are 2.9, 2.9, 2.3 m (w, l, h) and require a placement of dewar and patient's bed along the diagonal of the room to ease the access for medical personnel and patients in the case of measurements and also for the technical staff and equipment in the case of maintenance.

All SQUID drive-boards are mounted on top of the cryostat, arranged in 11 groups of 8 boards, each one driving 6 SQUIDs. All operations are remotely programmed by software, through fibre-optics link and dedicated decoder, communicating with a proprietary noiseless protocol.

Up to additional 128 channels are available for EEG and other physiological signals such as respiration, temperature etc., and for triggers and parameters from other devices such as stimulators, timers, supervisor devices .



a



b

Figure 3. (a) Somatosensory evoked field elicited from median nerve stimulation at the wrist (93 averaged events., 3 minutes recording). Two traces with opposite polarity are shown. (b) Motor activity detected after voluntary movements of the index-finger of the right hand (101 averaged events, 3 minutes recording). Two traces with opposite polarity are shown.

All conditioned signals are fed, through adequate EMI filters, to the A/DC unit outside the MSR. The data conversion runs at 8200 Hz per channel and has 20 bits of resolution. The digital outputs of over 600 A/D Converters are collected, formatted in 32-bits words and sent to the acquisition computer by a single chip device working in a star-like architecture. At this point the data stream is fed over an optical gigabit

network link to the on-line DSP processing unit, for compensation (synthetic gradiometers), filtering and decimation to a final sampling rate which can be defined between 62 and 4100 Hz according to the measurements requirements. The last steps in the chain are storage on the data server and archiving on removable media.

In the perspective of clinical routine use of the system, significant efforts were made for the implementation of the acquisition and the post-processing systems, in order to reduce the global measurement time and the analysis time for patient. A side product of the DSP work is a slower data stream for the on-line monitoring of the signals. Here two different continuous displays are available: one low-resolution monitor with several small traces, which can show all signals or just selected groups among several possible choices, and one high-resolution monitor which shows a selection of up to 16 traces with richness of details. This second workstation is at the same time the operator's interface for management and control of the measurements. The processing console provides a flexible and fast tool for data analysis, with both time domain and magnetic source imaging methods.

RESULTS

At first, the system was calibrated to obtain characterization data for both mechanical parameters and sensitivity of all sensors [Pasquarelli, 2004]. After this process, also the compensation matrix was calculated, and the synthetic gradiometers could be built. At this point it was possible to measure the background noise of the system with and without compensation. Sample spectra were shown in Fig 2.

The ultimate check was performed with real measurements of neurological signals, and specifically SEF elicited by median nerve stimulation at the wrist, and voluntary motor activity of the index-finger. In both cases clear signals were detected, as shown in Fig. 3.

Thus, we have described our Argos 500 system, which contains a 163 vector-magnetometers array, which is oriented and located in a suitable way to cover the whole head of the patient. First MEG measurement results have been presented.

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