PREPROCESSING IN MAGNETIC FIELD IMAGING DATA

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Abstract: Magnetic Field Imaging (MFI) is a new method of diagnosis of increasing importance in cardiology. MFI records the magnetic fields (MF) of the electrical activity of the heart using many extremely sensitive sensors and displays them afterwards in a clinically applicable manner. Due to the relatively low signal to noise ratio (SNR) of the magnetic data, the recorded data are often averaged before analysis.
We describe a standardized preprocessing method to be used before averaging MFI data with low SNR. The reported examples are data from 20 subjects out of a normal cohort examined at the Asklepios Klinik St. Georg.

1 INTRODUCTION

Magnetic field imaging (MFI) is a new non-invasive method that combines the recording of external magnetic field (MF) generated by the electrical activity of the heart with its clinically applicable spatio-temporal visualization. Cardiac MFs are very weak in comparison to the earth magnetic field and to electromagnetic disturbances. To reduce the environment noise, magnetic acquisitions are normally carried out in magnetically shielding rooms (MSRs). Unfortunately high performances MSRs are very expensive and cannot be easily integrated in the patient logistic of hospitals; for this reason much effort has been made in order to develop MFI systems usable in clinical environment. To achieve this goal it has been necessary to redistribute the task of noise reduction into the three main components:

- shielding
- design of the sensor system
- data preprocessing

Here, the standardized preprocessing that is used for collecting data routinely under clinical conditions is presented.

2 MATERIALS

Twenty subjects (37 ± 14 years, 6 males, 14 females) with no history of cardiac diseases have been selected from a cohort of healthy controls. Written informed consent has been obtained. The MFI recordings are carried out at the Asklepios Hospital St. Georg in Hamburg (Germany) using an Apollo CXS system (BMDsys Production GmbH, Germany). Apollo CXS is a 55-channels superconducting quantum interference device (SQUID) gradiometer system arranged in a hexagonal matrix, which covers an area of approximately 28 cm. The volunteers lie in a supine position during the recording. The cryostat is placed at approximately 1 cm distance to the anterior chest wall above the heart (Figure 1). The MFI sensor system is operating inside a light magnetically shielded room (Figure 2).
The data are sampled with a rate of 8200 samples per second and stored at a sampling rate of 1025 Hz (the bandwidth is set between 0.016 Hz and 256 Hz). Recording duration is at least 180s.

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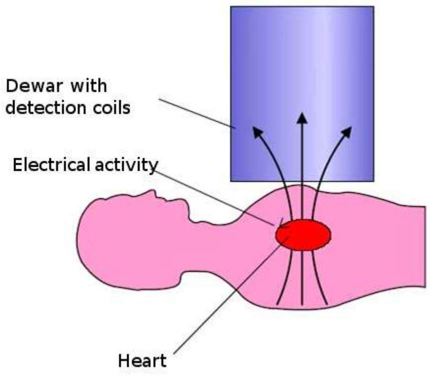

Figure 1: Model of MFI recording.

Figure 2: Biomagnetic system: view from the preparation room into the acquisition room with patient bed and sensor system.

3 METHODS

3.1 Real Time Preprocessing

The first step to be performed is disturbance subtraction. To compensate the noise generated by external interferences, such disturbances are sensed by references sensors and a suitable linear combination of them is calculated for each channel. Then the result of this operation is subtracted from the recording sensors (Vrba, 1996). Successively, the signals are high pass filtered using a RC type filter of the first order with a time constant of 10 s. Before decimation and low pass filtering, a proprietary adaptive comb filter is used to eliminate the power line interference and its harmonics. The comb filter introduces no phase shift. Eventually, the data stream is decimated iteratively in step of two to obtain the storing rate of 1025Hz. In each decimation step an anti-aliasing filter with a relative cut-off frequency of 0.25 is used.

3.2 Segmentation

To perform averaging, the data stream has to be segmented around each QRS complex. At the beginning of the off-line analysis the operator iteratively selects the suitable template parameters (Figure 3). Using the template, the beats are selected according to the maximum coherence matching (MCM) algorithm. Then the beats list is used as input in the categorized cluster analysis (CCA).

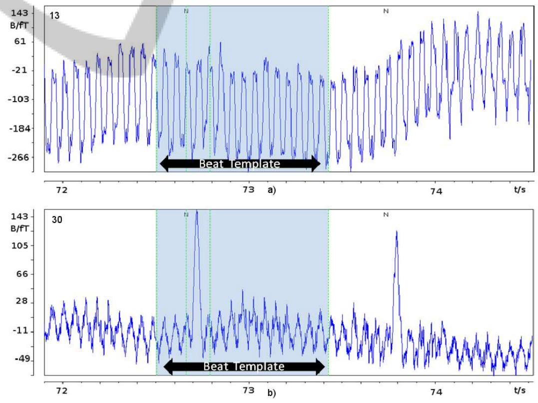

Figure 3: Raw data in two channels: a) The upper panel shows a channel with a transient vibration picked around 14-15 Hz, b) The lower panel shows a channel with very high SNR. The beat with blue background is the beat used for defining the template parameters.

3.3 Categorized Cluster Analysis and Averaging

A modified version of CCA is used in order to find the beats to be used in the averaging algorithm. The problem with the original version of CCA is that in case the noise is homogeneously distributed over time, the number of rejected beats can be very high since the chosen beats are related to only one of the branches

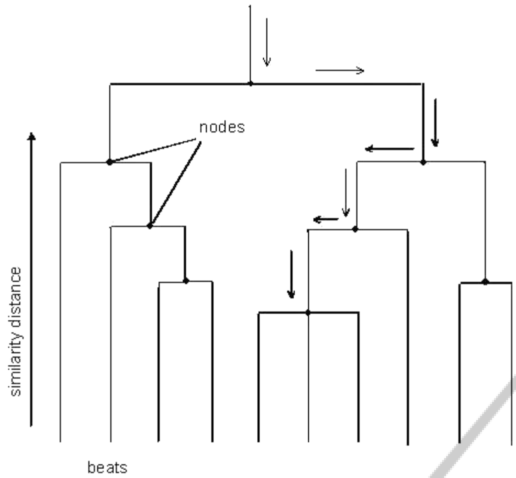

Figure 4: Schematic illustration of a dendrogram which is the graphical representation of the cluster analysis. Following the arrows at each node, the largest group of beats with the smallest similarity distance is found and thus the starting point for function SNR. The horizontal axis represents the observations (beats), the vertical axis gives the distance (or dissimilarity measure).

(Figure 4). For this reason, in order to include more beats to the average procedure, the distance matrix D, used in the cluster analysis, is *weighted* using the average of the most similar beats in the branch taken into consideration. At each step the closest beat is added. In this way a larger number of beats for the average can be reached when compared to the standard CCA. Using these beats the averaging procedure is performed. For further information related to CCA, please refer to (Di Pietro Paolo et al., 2005).

3.4 Transformation to a Standardized Sensor Configuration

A localized source $\vec{j}$ positioned 15 cm below the sensor 0 (center of the sensor system) is used for conversion based on multipole expansion (ME). Parameters till octupole, as proposed by Burghoff et all, (Burghoff et al., 2000) are used in Cartesian space. Using these terms, it is possible to reconstruct a 55-channel averaged signal. A ME is a series expansion that can be used to represent the field produced by a source (in this case heart) in terms of expansion parameters which become small as the distance from the source increases. Katila and Karp (Katila and Karp, 1983) proved the possibility to describe the heart signal by expansion of the magnetic multipoles up to the octupole term. It is interesting to note that the magnetic dipolar term serves as a good approximation in the early ventricular activation (Trontelj et al., 1991).

By adding more terms (quadrupoles and octupole) a very accurate reconstruction of the sources can be obtained. The magnetic multipole expansion as the following form:

$$B(\vec{r}) = -\frac{\mu_0}{4\pi} Re \sum_{n=0}^{\infty}\sum_{m=0}^{\infty} \nabla \left[\frac{1}{r^{n+1}} P_n^m(cos\theta)\, e^{-im\zeta}\right] \quad (1)$$

$$\times \frac{\gamma_{mn}}{n+1}\int \nabla' \left[r'^n P_n^m\left(cos\theta'\right) e^{im\zeta'}\right] x, \vec{r}' \vec{j}\left(r'\right) dv'$$

Here are γ_{mn} the coefficients so that (Katila and Karp, 1983):

$$\gamma_{mn} = [2-\delta(m)]\,\frac{(n-m)!}{(n+m)!}$$

with $P_n^m(cos\theta)$ the associated Legendre functions of first kind. The current density $\vec{j}$ in the expression 1 is the total current density over the volume v' and the expansion is valid for the region lying outside the surface S', i.e. r should exceed the largest value of r'.

4 RESULTS

The preprocessing is applied to the 20 acquisitions. The performances of the preprocessing in terms of noise reduction are measured using the Root Mean Square (RMS) before and after the application of CCA and transformation to a standard sensor configuration. The SNR has been applied on the averaged magnetic signals in the segment [T-end, P-onset], since in this region the signal amplitude is usually very low. A summary of the results is shown in table 1. The application of CCA and ME improved the SNR of the averaged magnetic signals in almost all cases up to 90%. Only in one case the preprocessing was not successful. Examples of averaged signals are shown in Figure 5.

5 DISCUSSION AND CONCLUSIONS

The preprocessing of MFI data outlined here is the basis for all specific analysis that can be performed with the MFI software of Apollo CXS (QRS fragmentation analysis, digital subtraction MFI for stress induced ischemia detection etc). It has been shown that combining a carefully designed low cost shielded room (patent DE 10 2007 017 316 B4) with a gradiometric sensor system it is possible to obtain data usable in clinical environment. Furthermore, the use of a dedicated algorithm for the averaging procedure

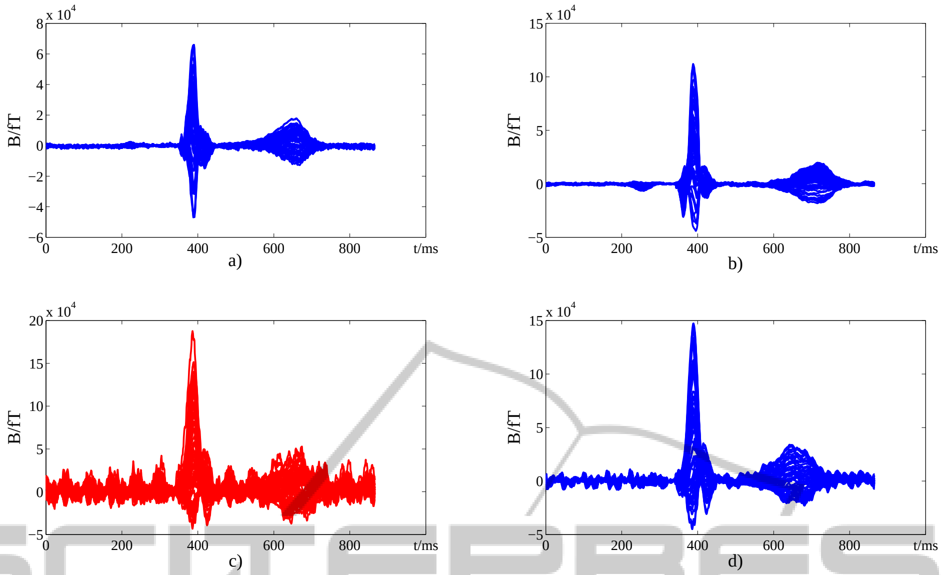

Figure 5: Averaged magnetic signals using Apollo CXS: a), b) averaged magnetic signals after CCA and transformation to standard sensor configuration (Subject 6 and 7, respectively); Subject 10 before (red) c) and after d) (blue) application of CCA and ME.

Table 1: Noise reduction percentage in the 20 subjects after applying CCA and standard sensor configuration transformation

Subjects	Noise Reduction (%) after CCA + ME
1	33,76%
2	61,44%
3	65,05%
4	53,62%
5	-43,00%
6	74,52%
7	60,08%
8	35,49%
9	64,87%
10	68,29%
11	91,99%
12	62,83%
13	15,39%
14	56,98%
15	33,27%
16	14,14%
17	91,48%
18	16,73%
19	40,14%
20	91,28%

and the transformation to standard sensor configuration make it possible to obtain data of quality comparable to those obtained in much more complicated and expensive systems.

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