REAL-TIME ADAPTIVE SUPPRESSION OF MR GRADIENT ARTIFACTS ON ELECTROCARDIOGRAMS USING A NEW 3D HALL PROBE

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INTRODUCTION: Due to heart motion, cardiac MRI is made difficult and image acquisitions have to be synchronized with heart activity to suppress cardiac motion artifacts. Electrocardiogram (ECG) is the most accurate tool for this purpose, and Triggering consists in synchronizing MR sequences on the R-waves. The complex MR environment worsens ECG acquisition conditions because of the static magnetic field (Hall Effect), Radio Frequency (RF) and fast switching magnetic field gradients. Many hardware developments have been achieved so as to limit these undesirable effects [1], but gradient artifacts are still a problem and signal processing is required. Two ways of research have been followed; (a) first way consists in building a MR specific QRS detector [2], which is based on the vectocardiogram (VCG) the 3D representation of heart activity. This method does unfortunately not provide a clear ECG and is unable to process patient with low VCG amplitude. (b) Secondly a real-time gradient artifact suppression method has been designed. This method is based on adaptive signal processing [3] and achieves real-time accurate denoising which enables triggering. This method requires gradient signals information, which is a major drawback as the connection to the MR system is rarely available. In this paper a new real-time gradient artifact correction, which does not require any connection to the MR system, is presented. The magnetic field pulse signals will be provided by a new specifically MR designed 3D Hall probe, integrated on a low cost 0.35µm CMOS technology [4, 5].

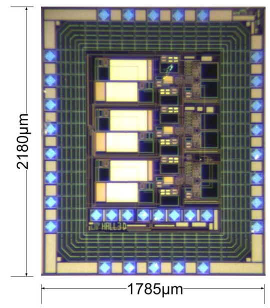

Fig 1: Picture of the 3D Hall Probe chip.

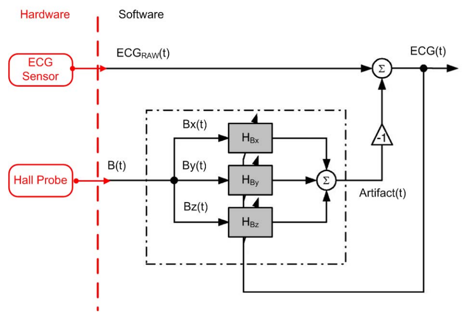

Fig. 2: Flowchart of the artifact reduction method.

MATERIALS AND METHODS: A new monolithic 3D Hall probe was designed and integrated on a low cost 0.35µm CMOS technology [4, 5]. This sensor was specifically dimensioned to measure the varying magnetic fields due to the gradients and its 3D design is of particular interest for accurate measurements, especially in regions where concomitant fields appear. The size and components of the chip (1785 x 2180 µm) ensures patient safety and minimizes RF interferences for both image and magnetic field pulse acquisitions (fig. 1).

The magnetic field pulse signals were modulated, transmitted through optical fibers and finally acquired by the Signal Analyzer and Event Controller (SAEC) homemade dedicated hardware [6]. Corrupted ECG signals were carried by a custom Maglife (Schiller Médical, Wissembourg, France) and recorded by the SAEC.

The gradient artifacts were modeled as the output of a linear time-invariant system composed by three inputs [3]. Each input was filtered by a Finite Impulse Response (FIR) filter. The Hall Probe provided the three required reference signals for the adaptive noise canceller filters, whose parameters were adaptively updated using Least Mean Square (LMS) algorithm (fig. 2).

RESULTS: Acquisitions were performed on a healthy volunteer. Some custom pulse sequences were designed to induce artifacts by producing isolated trapezoidal gradients with user-defined parameters. An example of recording is illustrated on fig. 4. Hall probe signals are highly correlated with gradient amplifier signals. Denoised ECG can then be obtained by applying the presented method and is compared with method described in [3] (fig. 4), the estimated impulse responses are shown on fig. 5. The presented algorithm denoising quality is equivalent to the state of art method.

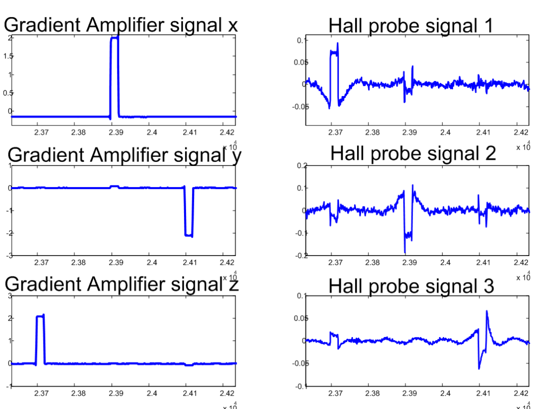

Fig. 3: Comparison of gradient amplifier signals (left) with Hall probe signals (right).

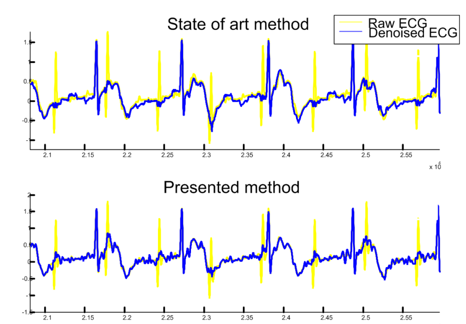

Fig. 4: Comparison of the presented ECG denoising method (bottom) with state of art (top).

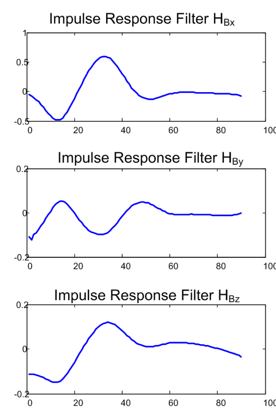

Fig. 5: Impulse response estimated by the presented method.

DISCUSSION: The integration of this new Hall probe shows very promising results. It can provide three uncorrelated magnetic pulse signals required for accurate ECG denoising. The present method is, in such cases, as efficient as the method presented in [4] and do not require any connection to the MR system anymore.

The Hall probe abilities are moreover not constrained to ECG denoising. Since it provides interesting information on local magnetic fields profiles, applications for Peripheral Nerve Stimulation (PNS) studies or coil design are also conceivable.

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