# Body-Worn Vest for Fully-Passive MagnetoCardioGram (MCG) Monitoring

Keren Zhu, *Student member*, *IEEE*, Asimina Kiourti, *Senior Member, IEEE*

***Abstract* -- Comparing two of the most common practices for human cardiac assessment, magnetocardiography (MCG) and electrocardiography (ECG), significant advantages of MCG can be seen. These include higher sensitivity and accuracy in response to related conditions, detection of more localized signals, and better deep tissue penetration. Here, we propose a new cardiac electromagnetic (EM) field detection system with fully-passive coil sensors for MCG monitoring in the pre-hospital environment. Contrary to conventional MCG detection systems, namely SQUIDs, the proposed system is light weight and inexpensive to operate and does not require any shielding or cryogenic cooling. The MCG detection system contains multiple MCG coil sensors, an ECG sensor, an Analog to Digital Converter (ADC) and a computer for Digital Signal Processing (DSP). The changing magnetic flux of the human heart can be detected by the MCG sensor, in turn helping sense the MCG signal in real time.**

***Index Terms*— Coils, magnetic sensors, magnetocardiography, medical sensing.**

## I. INTRODUCTION

Monitoring human bio-signals, and particularly heart-generated electromagnetic (EM) fields, can be challenging, yet critical for detecting, assessing, grading and diagnosing heart-related conditions. Two of the most commonly technologies used to date for assessing cardiac related conditions are electrocardiography (ECG) and magnetocardiography (MCG). These capture the cardiac electric and magnetic field, respectively [1]. Comparing these two technologies, several studies have shown significant advantages and potential benefits of MCG over ECG for various clinical applications [2]-[4], including: higher sensitivity in response to ischemia [3], higher accuracy in diagnosis of various heart conditions [2], ability to detect more localized signals [2], and higher accuracy in detecting deep EM signals [4].

Unfortunately, MCG signals are extremely weak, making them very hard to capture, i.e., the actual MCG signals will most likely be buried under the noise floor. The widely adopted technology used today for such low-level MCG detection is called Superconducting Quantum Interference Devices (SQUIDs), and was first proposed over 40 years ago [5]. SQUIDs are coils that maintain a superconductive state by being immersed in liquid helium to achieve the required high sensitivity. However, SQUIDs are bulky and expensive, and require extensive shielding and cryogenic cooling. As such, they are limited for use in hospital/medical environments. As an alternative, we propose fully-passive sensors to monitor human MCG in the pre-hospital environment.

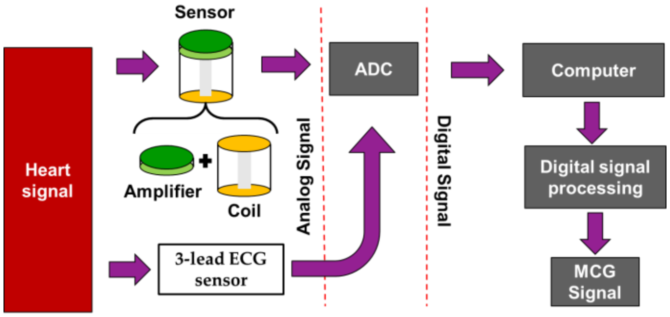

Fig. 1. Overview of the proposed MCG detection system block diagram

## II. SYSTEM DESIGN

The proposed MCG detection system is shown in Fig. 1 and consists of: an MCG coil sensor, an off-the-shelf ECG sensor, an Analog to Digital Converter (ADC), and a computer for Digital Signal Processing (DSP). Our system builds on the work previously done by J. Mooney et al. [6], with smaller MCG coil sensor size and improved signal post-processing.

To obtain the final MCG signal, a three-step procedure is followed. First, the heart signal is captured by the MCG coil sensor and the ECG sensor simultaneously. Next, the captured analog signals go through the ADC and get converted into two corresponding digital signals: raw MCG and raw ECG signals. Finally, the raw signals are routed to a local computer for DSP. Key to this post-processing approach is that the raw MCG signals are synced with the R-peaks of the ECG signal at individual cardiac cycles, in turn creating multiple cycling windows. All windows are then averaged to filter out most of the uncorrelated noise and, eventually, generate the intended MCG signal. Further details regarding the MCG coil sensor design and associated signal post-processing approach are provided below.

### A. *MCG Coil Sensor*

As shown in Fig. 1, the MCG coil sensor consists of an induction coil and an amplifier. The system operates on the principle that the changing magnetic flux of the human heart can be captured by the induction coil, generating, in turn, changing voltage levels across the coil terminals. This can further be amplified to larger signals for easier pick up by the

---

Keren Zhu and Asimina Kiourti are with the Department of Electrical and Computer Engineering at The Ohio State University, Columbus, OH 43210 USA (e-mail: zhu.1266@osu.edu, kiourti.1@osu.edu).

ADC. Due to the fact that the cardiac generated signal is extremely small (smaller than the earth's magnetic field), each induction coil is connected to an amplifier with a gain of 1000.

Our research has explored MCG coil sensors of various sizes, illuminating trade-offs in terms of sensitivity vs. size/weight. We have also explored a single MCG coil sensor as a starting point, followed by an array of coils to help reduce the recording time needed for averaging.

### B. *Digital Signal Processing (DSP)*

As described above, our recording system produces raw MCG and raw ECG signals right before DSP. Depending on the employed number of induction coils, a corresponding number of raw MCG signals is produced (e.g., raw MCG1, raw MCG2 etc.). Our subsequent DSP can be summarized as follows:

- First, raw MCG signals are cut into several viewing windows using the corresponding ECG R peak. Each string of MCG produces N viewing windows: $MCG1_{wdw1}$ … $MCG1_{wdwN}$; $MCG2_{wdw1}$… $MCG2_{wdwN}$, etc.
- Second, all windows within the same string are averaged to produce the resulting averaged MCG signals: $MCG1_{AVE}$, $MCG2_{AVE}$, etc. For example, $MCG1_{AVE}$ can be calculated using equation (1).

$$MCG1AVE = \frac{MCG1_{wdw1}+\cdots+MCG1_{wdwN}}{N} \tag{1}$$

- Third, moving average filters are applied to each of the averaged MCG signals to filter out the main 60 Hz noise. In turn, this step produces the final MCG signal for each MCG string: $MCG1_{final}$, $MCG2_{final}$, etc.
- Fourth, all strings of the final MCG signals are averaged to produce one final MCG signal.

Modifications to the aforementioned DSP method are currently being explored for improves signal to noise ratio.

## III. MAIN RESULTS

Proof-of-concept experiments were carried out to demonstrate the effectiveness of the overall system. The experiment set up is shown in Fig. 2(a). A loop wire powered by a function generator (set to generate a 50 Hz sine wave) was used to emulate human heart. The MCG coil sensor was placed approximately 1 cm away from the emulated heart to pick up the signal. A power supply was used to power the amplifier board for the coil sensor, and a 24-bit ADC was used to record the signals.

Preliminary results show that the proposed system has the ability to detect an emulated 50 Hz signal as low as 2mV peak-to-peak (pk-pk) using only one MCG coil sensor and 5 minutes of recording time. Referring to Fig. 5(b), the blue line is the "fake MCG" signal which is the final DSPed signal picked up by the MCG sensor. The orange line is the "fake ECG" signal, which is a 50Hz, 25mV pk-pk sine wave synced with the 2mV pk-pk signal that is set as input to the emulated heart.

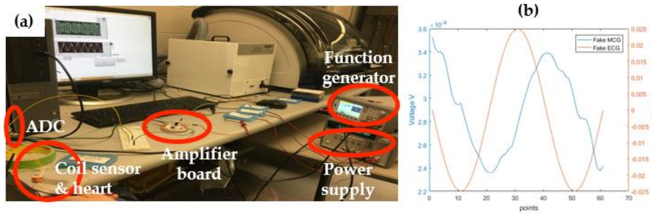

Fig. 2. (a) Proof of concept experimental set up. (b) Experimental result: blue line is the processed final simulated MCG signal, orange line is the original simulated ECG signal.

## IV. CONCLUSION

Preliminary results have shown the ability to successfully detect MCG signals using the proposed coil-based detection system. Ongoing work aims to refine our proof-of-concept system design and experimental set-up. Specifically, we intend to optimize the coil sensor design, optimize the amplifier board design, employ more effective DSP methods, detect real human cardiac signals, and, eventually, translate our coil sensor into a wearable vest.

### A. *Near- and Far- Term Career Plan*

In the short-term, I plan to continue research on this topic and pursue my Ph.D. at Ohio State's ElectroScience Laboratory. In the long-term, I plan to continue working in the RF and EM field in a company after graduation.

### B. *Impact of the MTT-S Scholarship Program*

It has been an honor to receive such a prestigious scholarship through IEEE MTT-S. This award has given me enormous amount of encourage to pursuing this research topic. On top of that, attending the IMS conference gave me the opportunity to meet new people in similar area, attend related technical section to learn more about related topics. The student luncheon introduced me to all kind of activities held by the MTT society and connect myself with students from different universities and research groups. I am really honored to receive this award, and it provide me with plenty resources/opportunities to continue the work I am doing now.

## V. REFERENCES

[1] R. Sameni, "A review of fetal ECG signal processing issues and promising directions," Open Pacing, Electroph. & Therapy J., 2010.

[2] F. E. Smith, P. Langley, P. V. Leeuwen, B. Hailer, L. Trahms, U. Steinhoff, J. P. Bourke, and A. Murray, "Comparison of magnetocardiography and electrocardiography: a study of automatic measurement of dispersion of ventricular repolarization," *EP Europace*, vol. 8, pp. 887–893, Dec. 2006.

[3] E. A. P. Alday, C. Zhang, M. A. Colman, H. Ni, Z. Gan, and H. Zhang, "Comparison of electric- and magnetic- cardiograms produced by myocardial ischemia in models of the human ventricle and torso," in Proc. *2015 Computing in Cardiology Conference (CinC)*, 2015

[4] Y. Wang and L. Guo, "Nanomaterial-enabled neural stimulation," *Frontiers in Neuroscience*, vol. 10, Jul. 2016.

[5] D. Cohen, E. A. Edelsack, and J. E. Zimmerman, "Magnetocardiograms taken inside a shielded room with a superconducting point-contact magnetometer," *Applied Phys. Lett.*, vol. 16, no. 7, pp. 278–280, 1970.

[6] J.W. Mooney, S. Ghasemi-Roudsari, E.R. Banham, C. Symonds, N. Pawlowski and B. Varcoe, "A portable diagnostic device for cardiac magnetic field mapping," *Biomed. Phys. Eng.*, vol. 3, no. 1, 2017.