Wearable MagnetoCardioGraphy (MCG) Sensor Using a Single Coil

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***Abstract*—We have previously reported a wearable magnetocardiography (MCG) sensor that utilizes a coil array capable of detecting the weak magnetic fields generated by the heart. In this work, we improve upon our previous design by reducing the number of coils from seven (7) to one (1) while also achieving significantly better detection results. Experimental validation on a human subject shows an increase in heart beat detection accuracy from 28.4% to 96.8%. Key to this improved performance is a new signal processing method that significantly reduces noise. Given the increasing importance of MCG as a reliable and non-contact method of assessing cardiac health and cognitive workload, the proposed sensor is expected to have significant clinical impact.**

***Index Terms*—Coils, heart beats, magnetic field, magnetocardiography, sensor.**

I. Introduction

Magnetocardiography (MCG) is a non-invasive and non-contact method used to sense the weak magnetic fields generated by the heart. Compared to electrocardiography (ECG), MCG offers higher temporal and spatial resolutions in localizing cardiac electrophysiologic phenomena [1]. The first attempt to record the cardiac magnetic field was done in the 1960s by using two large magnetic sensor coils [2]. However, this method was lacking in terms of practical use. Later advancements in technology introduced superconducting quantum interference devices (SQUIDs) capable of achieving very high sensitivity and spatial resolution when it comes to collecting the heart's magnetic fields [3]. However, SQUIDs are known to be very expensive, bulky, and sophisticated to fabricate [4].

In efforts to develop an economical device capable of rapidly assessing chest pain in an emergency room, [5] introduced a portable MCG device. The device utilized 12 coils embedded with a ferrite core to boost the sensitivity. In a step forward, [6] proposed a miniature low-cost MCG sensor that was 4.67 times smaller in diameter than that in [5] and with an air core. This sensor comprised of an array that included seven (7) coils and was capable of sensing the magnetic field of the heart as tested upon human subjects.

In this work, we introduce a new digital signal processing (DSP) method that reduces the number of coils of the device in [6] from seven (7) all the way down to one (1). The new method is experimentally tested on a human subject, showing - alongside its miniaturized footprint and lighter weight - a significant improvement in detecting heart beats within the MCG recording as compared to the full sensor that consists of seven (7) coils.

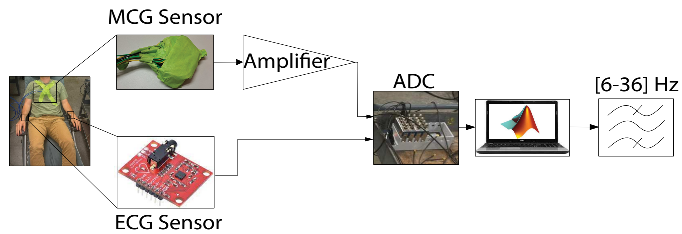

Fig. 1. Experimental setup used to collect MCG and ECG activity on a human subject.

II. Experimental Setup and Digital Signal Processing (DSP) Approach

Fig. 1 shows the experimental setup employed in this study. Heart activity is simultaneously recorded using: (a) the MCG sensor reported in [6] and (b) a 3-lead off-the-shelf ECG sensor. The MCG signal is first amplified and then routed to an Analog-to-Digital Converter (ADC) alongside the ECG signal for further processing in a laptop using MATLAB.

In the DSP process, a variable number of coils is considered for the MCG sensor. The approach entails an intelligent correlation of a single heart beat with the remaining recording to detect the location of each of the heart beats. The ECG data are viewed as the gold-standard that indicates where the actual heart beats are located.

Data is collected on a human subject for a duration of 5 minutes (study approved by The Ohio State University Institutional Review Board).

III. Experimental Results

Fig. 2 reports the MCG signal retrieved using the sensor and DSP method reported in [6]. The simultaneously recorded ECG signal is super-imposed for reference. As seen, multiple fake peaks are introduced by the coils at the location of the true peaks indicated by the ECG signal.

Fig. 3 shows the MCG signal retrieved by using measurements from one (1) coil only and employing the DSP method of Section II. The gold-standard ECG signal is again superimposed. As seen in the zoom-in on an individual heart beat, the new DSP method is capable of removing the false peaks while also minimizing the number of coils used.

IV. Discussion

Results show that the method introduced in [6] results in 202 false heart beats out of the total 282 beats present over the

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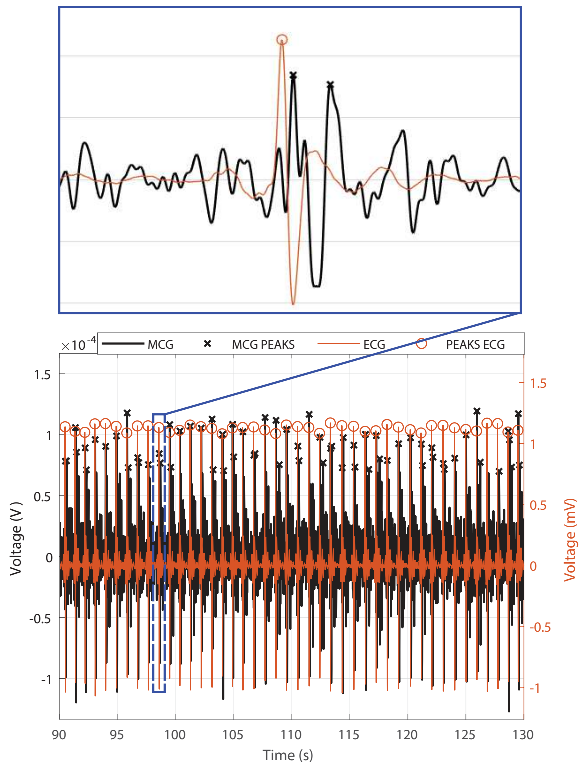

Fig. 2. Comparison of MCG vs. ECG using 7 coils and the DSP method reported in [6].

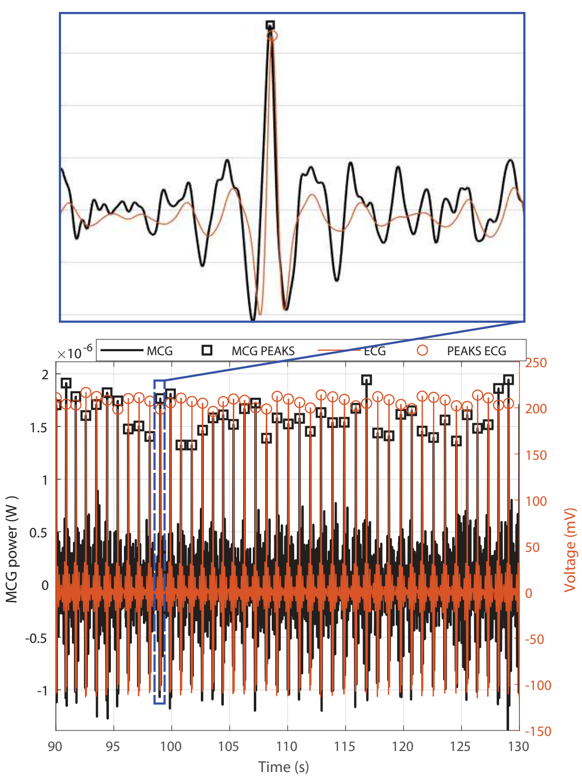

Fig. 3. Comparison of MCG vs. ECG using 1 coil and the new DSP method.

full 5 minutes recording. This implies a 28.4% beat detection accuracy. After applying the new DSP method, the number of false peaks drops to 9 over the full recording, increasing the accuracy to 96.81%.

Being able to eliminate false heart beats from the MCG recording is critical in clinical applications. For example, parameters such as Heart Rate Variability (HRV) that are traditionally acquired via R-peaks and can be obtained using heart beat indices, can be very informative in indicating diverse cardiovascular diseases [7] as well as classifying cognitive workload [8].

V. Conclusion

We introduced a new DSP method capable of reducing the number of coils used by our previously reported MCG sensor from seven (7) to one (1). Besides the footprint miniaturization and weight savings, results also showed an improvement in the accurate detection of heart beats within the MCG recording by more than 3 times. Future work will focus on improving upon the method to make it applicable in real-time and robust against sudden movements from the wearer/patient.

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All studies were conducted under approval by The Ohio State University Institutional Review Board (IRB) (protocol # 2019H0259).

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