Chapter 5

A Low-cost, Portable, and AI-powered Device for Cardiac Investigation

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Abstract

With cardiovascular diseases ranking as a significant cause of mortality worldwide, timely diagnosis and effective monitoring are essential. In recent decades, interest in non-invasive cardiovascular monitoring technologies has increased significantly, driving research toward the development of advanced tools that can enhance the diagnosis and clinical management of cardiac disorders. Electrocardiography (ECG) is the gold-standard technique for analysing the heart's electrical activity and is widely used to detect rhythm and conduction abnormalities. However, an ECG alone is not always sufficient to identify all pathologies. Disorders related to valvular function, such as heart murmurs, require an acoustic investigation. In this context, phonocardiography (PCG) is a valuable complementary tool, commonly referred to as an electronic stethoscope, that enables the recording and analysis of heart sounds produced during the cardiac cycle.

We have designed and manufactured a low-cost, modular prototype for the early detection and home monitoring of cardiac disorders (MotemaSens). This paper presents preliminary results, with clinical validation ongoing. The device is capable of simultaneously collecting heart sounds (similar to a digital stethoscope) and ECG (up to 12 leads), supported by AI for rapid data interpretation. Furthermore, the device collects the electromyogram (EMG) and has spare channels for additional sensors, such as temperature or pulse oximetry, and is ISO 13485 certified. Our AI algorithm won first prize in the PhysioNet Challenge 2022. The low cost and portability (6 x 6 cm) of MotemaSens make it suitable for both high- and low-income settings, addressing the lack of appropriate technical platforms in low- and middle-income countries (LMICs).

Keywords: *Multimodal and multifunctional, Low-cost device, LMICS, Electrocardiogram, Electromyogram*

Introduction

According to the World Health Organisation (WHO), cardiovascular diseases (CVDs) are the leading cause of death, with a mortality rate of 32% of all global deaths[1], making CVD a significant global public

[1]WHO. "Cardiovascular Diseases (CVDs)." July 31, 2025. https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)

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health crisis. CVD is an umbrella term for all heart and blood vessel diseases. It commonly refers to coronary heart disease and stroke. However, other heart conditions can affect heart valves, muscles, or rhythm. Valvular heart disease (VHD) occurs when heart valves do not function correctly, resulting in either valvular stenosis (narrowing) or valvular insufficiency (leaking), which significantly contributes to the loss of physical function, quality of life, and longevity. Due to an ageing population, around 1.5 million people in the United Kingdom (UK) aged 65 or over are thought to have VHD, including aortic stenosis and mitral regurgitation. Estimates suggest that this will double by the year 2046 and rise to 3.3 million in 2056[2]. Timely treatment is essential because the risk of dying from valve disease is proportional to the severity and symptoms of heart failure[3]. Timely treatment can be achieved by regular screening, monitoring and intervention. Low- and middle-income countries (LMICs) contribute a greater share to the global burden of CVDs, with these conditions being responsible for 80% of all cardiovascular deaths worldwide[4]. Whilst effective measures are being put in place in high-income countries, resulting in a decline in the rate of CVD, CVD mortality is on a steady rise in LMICs, with rates of up to 300–600 deaths attributed to CVD per 100,000 population and is projected to increase, causing preventable loss of lives[5]. The poor have the worst outcomes from non-communicable diseases, including CVD, mainly because of their inability to access or afford preventative services and ongoing treatments. This calls for a more integrated approach for the detection, prevention, and management of CVDs in LMICs.

The underdevelopment and technological under-equipment in this medical sector are primarily due to the fact that all equipment has been imported for a long time, resulting in exorbitant costs that are inaccessible to the majority of the population. To contribute to this approach, we have designed and manufactured a low-cost, modular, and multifunctional prototype for the early detection and home monitoring of CVDs (MotemaSens). The device is capable of simultaneously collecting heart sounds (similar to a digital stethoscope) and ECG (up to 12 leads), supported by AI for rapid data interpretation. Furthermore, the device can measure the electromyogram (EMG) and has multiple input channels ready for the addition of other sensors, such as temperature or pulse oximetry, and is ISO 13485 certified. The low cost and portability (6 x 6 cm) of the system make it suitable for both high- and low-income settings, addressing the lack of appropriate technical platforms in LMICs.

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[2]Joanna L. D'Arcy et al., "Large-scale Community Echocardiographic Screening Reveals a Major Burden of Undiagnosed Valvular Heart Disease in Older People: The OxVALVE Population Cohort Study," *European Heart Journal* 37, no. 47 (June 26, 2016): 3515–22, https://doi.org/10.1093/eurheartj/ehw229

[3]Rick A. Nishimura et al., "2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease: Executive Summary," *Circulation* 129, no. 23 (March 4, 2014): 2440–92, https://doi.org/10.1161/cir.0000000000000029

[4]Gregory A Roth et al., "Global, Regional, and National Age-sex-specific Mortality for 282 Causes of Death in 195 Countries and Territories, 1980–2017: A Systematic Analysis for the Global Burden of Disease Study 2017," *The Lancet* 392, no. 10159 (November 1, 2018): 1736–88, https://doi.org/10.1016/s0140-6736(18)32203-7

[5]World Health Organization. *Global Status Report on Noncommunicable Diseases 2010*. Geneva: World Health Organization, 2011.

This paper presents the results of verification tests, validation tests, and preliminary data collection of 12-lead ECG signals.

Methods

The device underwent bench tests for signal verification using known input signals across two channels to evaluate gain accuracy, frequency response, linearity, signal-to-noise ratio, and crosstalk. The device has also been validated against a commonly used gold-standard system (referred to as the reference device) for EMG acquisition from the bicep muscles at a moderate force level.

We collected pilot data on 12-lead ECG from six healthy individuals using gel electrodes and dry electrodes. Dry electrodes are reusable, thereby helping to address the challenges associated with the supply chains of disposable gel electrodes in rural areas.

Results and Discussion

Verification tests

The verification tests of the two channels of the device showed the following characteristics:

- Gain accuracy: The two channels displayed similar gain profiles across all voltage inputs (0.1-4.7 V) with a mean absolute difference of - 56 ± 5.3 dB.
- Frequency response: The two channels consistently measured a 130 Hz input as 129.9 Hz across all amplitudes and exhibited a linear behaviour (input vs output) between 0 and 1000 Hz.
- Crosstalk: When connecting one channel at a time, minimal crosstalk was observed with correlation values between 0.009 and 0.3.

Validation tests

Figure **1** shows EMG traces recorded using our device and the gold-standard reference system, respectively. The baseline amplitudes were 1.4 μV and 8.4 μV for MotemaSens and the reference system, respectively. The frequency response obtained from our measurements also aligns with the range reported in the literature, which states that the optimum EMG frequency band lies between 50 and 150 Hz[6].

12-lead ECG data

Figure **2** depicts an example of a 12-lead ECG recording using dry electrodes. The next step is to consult cardiologists to examine the wave morphologies for clinical purposes. We are also working on standardising the ECG results to be shared via WhatsApp or email. ECG traces collected using gel and dry electrodes exhibited similar shapes with correction coefficients ranging from 0.7 to 0.91 and 0.89 to 0.98 for derived and measured channels, respectively.

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[6]Laxmi Shaw and Sangeeta Bhaga. "EMG Signal Analysis for Diagnosis of Neuromuscular Diseases by Using PCA and PNN." International Journal of Engineering Science and Technology 4, no. 10 (Oct 2012): 4453–59.

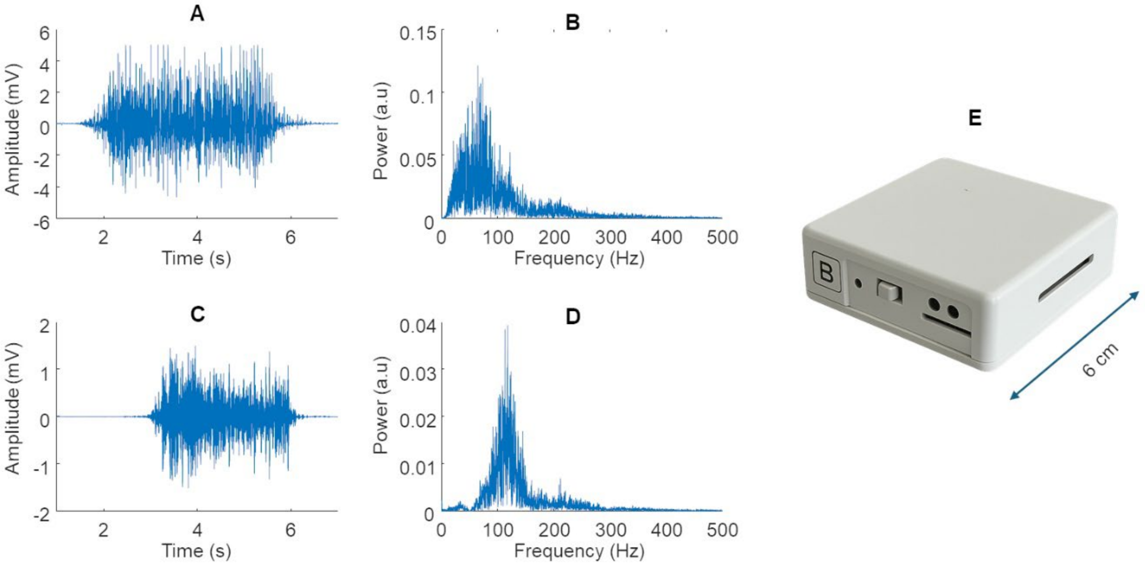

Figure 1: Example of A) EMG signal from the reference gold-standard device with B) associated power spectrum. C) EMG signal from the MotemaSens device with D) associated power spectrum; E) A photo of MotemaSens.

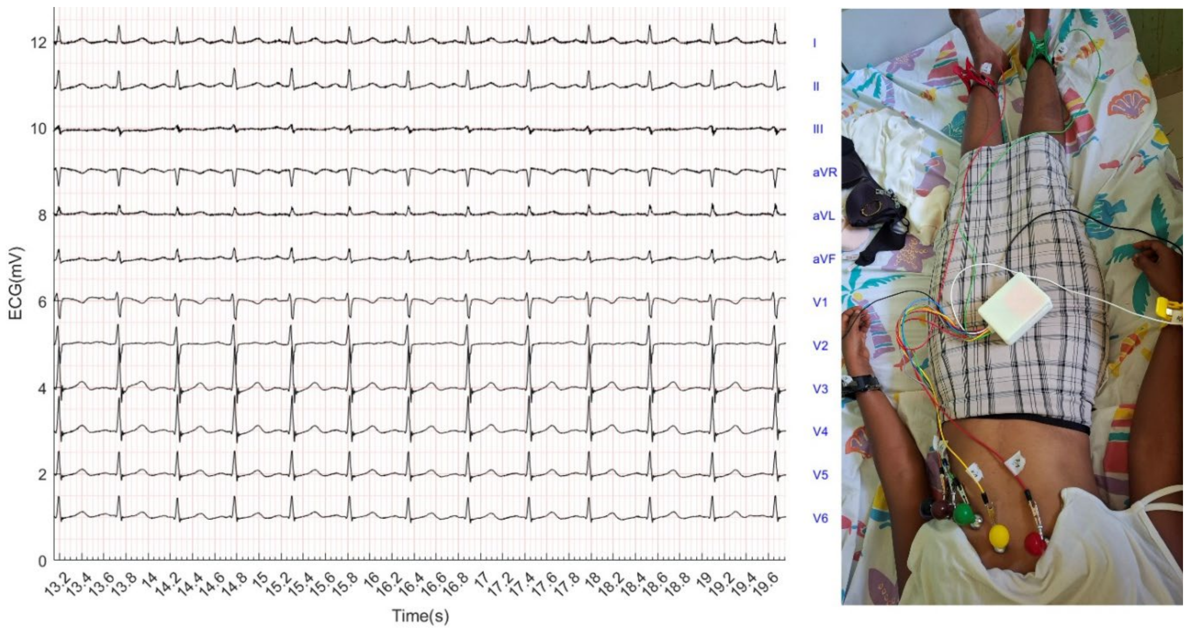

Figure 2: An example of a 12-Lead ECG recording of a female participant (23 years old) using reusable dry electrodes.

Heart sounds measurement

MotemaSens can measure heart sound (using an external electronic stethoscope) and ECG concurrently for improved diagnostics. The traces are superimposed in Figure **3** for visualisation purposes. In the user interface, they are shown on different subplots that are synchronised in time. In this example, the SNRs of heart sound and ECG are 16.8 dB and 27.9 dB, respectively. Our AI algorithm for classifying abnormal murmurs achieved a sensitivity of 90%, winning first prize in the PhysioNet Challenge 2022.

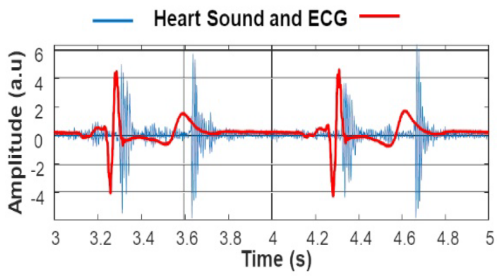

Figure 3: An example of concurrent recording of heart sounds and ECG superimposed for visualisation purposes.

Conclusion

This paper describes a low-cost, portable, and AI-powered device primarily designed for heart investigations, such as ECG and heart sounds. Furthermore, the input amplifier is also configured to accept other biomedical signals, such as EMG. In the future, we will also be able to collect other biosignals. Verification tests demonstrated the device's ability to produce consistent gain values across voltage levels, maintain frequency components without distortion, and achieve high signal-to-noise ratios. With the current tests being conducted in the DRC, we have strong evidence that such a device addresses the challenges associated with the lack of dedicated equipment in LMICs. The device is designed to be built and maintained in low-resource areas.

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