

Smart phone enabled, thin-film epidermal electronic systems for cardiac health monitoring

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Summary:

We present several skin-close, hybrid Epidermal Electronics Systems (EES) for cardiac monitoring. They combine electrodes for electrocardiography (ECG) and piezoelectric thin-film sensors for seismocardiography (SCG). We utilized the near field communication (NFC) functionality of a smart phone to power the systems, to pre-process and classify the data and to transfer it via RFID. Our modular EESs ensure versatility, while providing comfort and high signal quality, enabling accurate and real-time cardiac health monitoring. We demonstrate that the EESs can be used for cardiac diagnosis.

Keywords: Wearable sensors, cardiac monitoring, cardio-pulmonary hypertension, sensor fusion, AI-based data analysis

Introduction

Cardiac monitoring is essential for early detection and management of heart conditions, yet conventional devices are often bulky and uncomfortable, limiting patient compliance. We present advanced, thin-film embedded monitoring systems capable of measuring ECG and SCG simultaneously. The synchronous data acquisition allows for accurate extraction of systolic time intervals (STI), which provide insights into dynamic cardiac function. We tested the systems on a group of patients suffering from pulmonary hypertension and were able to distinguish healthy from diseased patients. Building on these promising results, we developed a next system offering enhanced integration, modularity, and functionality. To enable long-term monitoring away from bed side application, we aim to combine the EES systems with smart textiles as Hybrid E-Tattoos.

Background, Motivation and Objective

The different EESs developed in the clean room of IWE1 at RWTH Aachen university comprise a flexible circuit module based on polyimide (PI) and either a flexible unit based on PI or a stretchable electrode module made from Flexdym™. The circuit module was fabricated using a clean-room microelectronics process, including photolithography, evaporation, and electroplating, ensuring precise patterning and high-quality connections. The stretchable module was produced via a screen-printing process, providing excellent elasticity and adaptability. Both modules

were then interconnected either by direct gluing or by using magnetic snaps, enabling easy assembly and separation.

Results

The classical method to detect the excitation of the heart is ECG, where several electrodes are positioned on the chest of a person on precise locations and different lead signal shapes are combined to analyze the condition of the heart. In many wearable solutions, only the first lead signals are measured (left to right arm), a functionality which is for instance also integrated into modern smart watches.

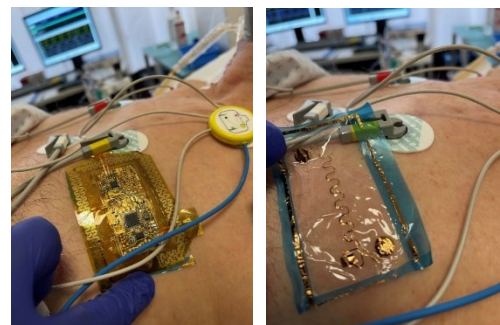


Figure 1: A modular EES generated with a stretchable thin film material and a flexible, reusable part is used in the intensive care unit in the clinic of Giessen University on the chest of a test person.

An older method for cardiac monitoring, which is experiencing a renaissance nowadays, is based on vibration sensing and sub-summed in the term ballistography. A special from of this

method is SCG, where sensitive vibration sensors are positioned at the chest of a test person very closely at similar locations as for classical ECG. In earlier works it was described that in SCG traces the action of cardiac valves such as aortic opening (AO) and aortic closing (AC) can be seen as similar characteristic fiducial points like the QRS complex in ECG. The precise understanding of the signal origins and signal shapes measured from different points at the chest is typically based on signal conditioning, filtering and precise timing analysis [1].

In a first approach for a wearable EES, we integrated a thin-film sensor based on the piezoelectric polymer polyvinylidene fluoride (PVDF) into a polyimide based multilayer system and recorded ECG traces with a second system in a synchronized manner [2].

In the next generation of EES devices, a wearable, flexible, wireless and smartphone-enabled system-in-a-foil with synchronous first-lead ECG and SCG functionality was fabricated using state-of-the-art cleanroom technologies. The timing between the Q peak of ECG and the AO and AC peaks of SCG was automatically analyzed by AI-enabled classification of peaks and extraction of the timing between the STI parameters pre-ejection period (PEP) and left ventricular ejection time (LVET). For this purpose, we developed a machine-learning algorithm and trained it on public ECG data and SCG signals to annotate peaks and analyze their precise timing. The ratio between both peaks is called the Weissler's index, which can be used as prognostic parameter for hypertension. Tests with healthy control persons and patients with cardiopulmonary hypertension showed a promising prognostic performance (Fig. 1) [3].

Next step towards a modular EES

For the next step in the project, the skin-mounted part of the EES was realized in the thermoplastic elastomer styrene-ethylene-butylene-styrene (SEBS), a skin-friendly stretchable material. This stretchable module was produced via a screen-printing process with liquid metal as conductive tracks, providing excellent elasticity and adaptability [4].

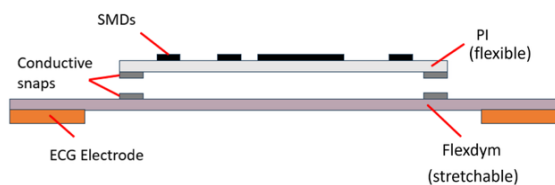


Figure 2: A schematic of the hybrid and modular design concept of the EES. It integrates a reusable circuit module and a disposable on-skin module. Both modules can be combined by magnetic snaps.

Both modules were then interconnected using magnetic snaps, enabling easy assembly and separation (Fig. 2).

In the newer, modular version a MEMS-based 3-axis accelerometer was used to detect the SCG signals while offering additional functions such as body conditions such as lying, walking or running.

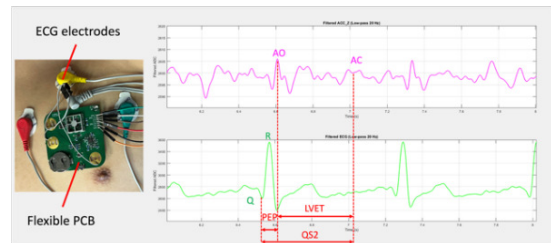


Figure 3: Left: Measurement setup with the prototype PCB. Right: A section of the measured SCG traces (top) and ECG traces (bottom) signals, highlighting key waveform components - AO and AC in SCG, and the QRS complex in ECG.

Conclusion and Outlook

A proof-of-concept EES with a thin-film electronics design was demonstrated through successful prototyping. The next phase in our project will focus on fabricating and assembling both flexible and stretchable modules, further advancing the functionality and integrity of the EES. To enable a better comfort for the persons, we combine the on-skin wearables with smart textiles to enable long-term recording.

References

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