

A Wearable Patch for Remote Monitoring of Cardiac Electromechanical Function

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Abstract

Electrocardiography (ECG) patches are widely used for the remote monitoring of patients with chronic cardiac conditions. While ECG captures the heart's electrical activity, seismocardiography (SCG) provides insights into its mechanical function. We have developed a wearable system that combines ECG and SCG in a single patch for remote monitoring.

Methods: The system consists of a small, lightweight and wearable sensor embedded in a medical patch positioned on the sternum. The sensor integrates a 3-axis accelerometer for SCG and single-lead ECG.

Results: Device testing confirmed reliable acquisition of 27-second ECG and SCG recordings every 30 minutes over a period of 30 days without requiring a battery recharge or replacement. In a pilot test of the system involving 3 subjects over a 48-hour period, configured for 30-minute recording intervals, a total of 255 recordings were obtained out of the expected 288 (88.5%) recording coverage. In addition, the system was tested over 28 days on one subject resulting in 808 out of 1344 (60.12%) acquired measurements. It is argued why a coverage of 88.69% could be expected.

Conclusion: The system enables long-term, remote, and continuous monitoring of cardiac electromechanical function using a combined ECG and SCG patch.

1. Introduction

Different designs of wearable devices for measuring both ECG and SCG, along with additional modalities like PPG and temperature, have been developed [1-3].

However, to fully utilize the lightweight and wearable technology of the devices, there remains a barrier in enabling extended periods of monitoring time and the ability to monitor remotely to use the devices outside of the laboratory.

In this study we present the eMech Patch. A small wearable sensor device for simultaneous measurements of ECG and SCG over extended periods of time. The eMech Patch enables remote monitoring of cardiac electromechanical function through an online cloud service allowing continued monitoring of patients at risk of heart failure after being discharged from the hospital.

2. Method

To monitor patients at risk of heart failure at a minimum of 30 days after discharge from the hospital, a small, lightweight and wearable device, with low-power consumption and ability to transmit data from remote locations was needed. The patch needs to be comfortable to wear to enable extended monitoring periods and allow the patient to continue their daily life with as little interference as possible.

A. The eMech Patch is designed with the goal in mind of enabling remote monitoring for a minimum of 30 days. It is a custom designed wearable sensor device (figure 1) utilizing ECG and SCG sensors to capture cardiac electromechanical signals.

The device uses standard off-the-shelf components but assembled on a custom printed circuit board assembly (PCBA).

The device uses the MAX30003 (Maxim Integrated) sensor for measuring single-lead ECG. For SCG it uses the ADXL355 (Analog Devices) high-resolution, low noise, MEMS digital accelerometer. The central processor is a nRF52832 (Nordic Semiconductor) which handles communication via Bluetooth Low Energy. The device runs on a standard CR2032 3V battery.

ECG measurement is enabled by a specially designed ECG patch (Linxens Healthcare) which has a socket for mounting the eMech device to and connecting the device to the ECG gel electrodes embedded in the medical patch. SCG measurement is enabled simply by placement of the patch at the subject's sternum.

B. An Android smartphone application handles scheduling of measurements and communication to the eMech sensor and the online cloud. An accompanying smartphone running the app must be kept within Bluetooth reach (~10m) of the eMech Patch, for measurements to be performed, as the eMech sensor itself cannot handle scheduling of measurements and must be instructed.

The app also set the measurement configurations the device use. The device can be configured to use different sampling frequencies separately for each sensor, enabling/disabling high or low pass filtering for the MAX30003, enabling/disabling sensors and setting measurement duration.



Figure 1: Left the ECG patch with the socket for the eMech sensor device connecting to the ECG gel electrodes. Right the eMech Patch sensor device.

The time between measurements is set in the app. Measurements are initially started with a button press, performing the first measurement. The time for the next measurement is then set the defined number of minutes ahead of the time when the current measurement completed.

C. The online cloud service consists of a website, an application programming interface (API) and an SQL database. The API receives data from the smartphone app and stores it in the SQL database. Each smartphone app must register with the cloud service to gain access to the API for database access. A website developed for this project, also allows to keep a live list of active smartphone applications, where it can be observed the most recent time, an app has sent data to the database, thus allowing to monitor if measurements are running as expected for included patients.

Data can also be retrieved from the database, and filtered by specific smartphone ID, eMech Patch ID and time of recording. Access to the website is restricted to only registered users to ensure data security.

D. System is tested for robustness of data acquisition in real life settings, by measuring on three subjects performing daily life tasks over a period of 48 hours. Additionally, the system is tested for long term measurements over a period of 30 days on one subject also in a real-life setting.

The eMech sensor device has initially been tested to be able to perform measurements reliably every 30 minutes for a period of 30 days, but not while mounted on a subject.

3. Results and Discussion

The system was configured for doing measurements of 27 seconds duration, using sample frequencies for ECG at 250Hz and SCG at 500Hz. Measurements were set to be performed every 30 minutes.

For the test of data acquisition robustness 288 measurements ($48\text{rec/day} \times 2\text{days} \times 3\text{subjects}$) were expected of which a total of 255 was acquired. This resulted in a measurement coverage of 88,5%.

The long-term measurement period of 30 days resulted in a total of 28 days (from 11/09/2025 to 09/10/2025) of measurements from one subject. Because the system is used in another research study, we had to wait on an available patient to be included and had to stop to hand in before the deadline) We expected 1344 measurements ($48\text{recs/day} \times 28\text{days}$) to be acquired. Unfortunately, from day 3 to day 12 no measurements were obtained as the mobile internet connection on the smartphone running the application was accidentally turned off. This resulted in loss of ~ 434 measurements (9 days, 1 hour, 52 minutes). However, once mobile internet connection was reestablished measurements continued as planned for the rest of the duration.

A total of 808 measurements has successfully been acquired resulting in a coverage of 60.12% of expected measurements.

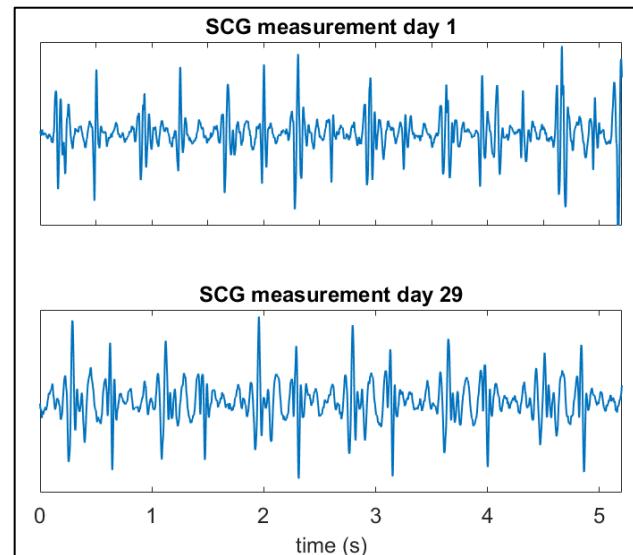


Figure 2: SCG measurements from day 1 and 29.

It should be noted that though 9 days of measurements were missing, 10 days were without internet access. The smartphone application was set up to locally save up to 24

hours of measurements in case of temporary loss of network, and to begin deleting the oldest saved measurement to avoid filling up the smartphones storage when exceeding 24 hours of saved measurements.

However, it had not been anticipated that mobile network would be turned off for such a long time. For future measurements the issue has been fixed by simply increasing the number of measurements the application will save locally.

When network connectivity was reestablished the previous 24 hours of measurements was successfully sent to the online database. If it is assumed that measurements continued accordingly during the time without network and that measurements were acquired with similar coverage as the test on three subjects (88.5%), then only 50 measurements (11.5% of 434) would have been missed, resulting in a total of 1192 measurements (88.69%) measurement coverage for the 28-day monitoring period.

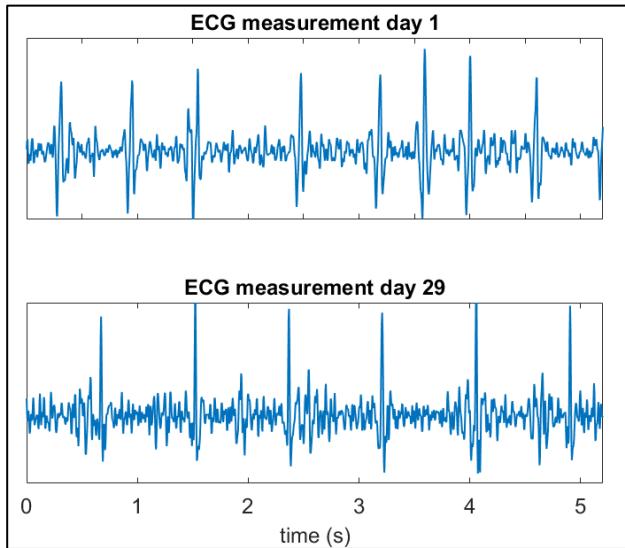


Figure 3: ECG measurements from day 1 and 29.

Figures 2 and 3 show 5 seconds of each SCG and ECG measurements taken from day 1 and day 29 of a measurement period.

As can be seen in figure 2, the ECG signal is noisy, but for the current use-case for the eMech Patch it has easily discernable R-peaks, and the signals show no noticeable changes in quality from day 1 to 29.

The signal-to-noise ratio for both ECG and SCG measurements has not been investigated in this paper but will be addressed in a later study.

Acknowledgments

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References

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