Automatic Detection of Atrial Fibrillation using MEMS accelerometer

Tero Koivisto¹, Mikko Pänkäälä¹, Tero Hurnanen¹, Tuija Vasankari², Tuomas Kiviniemi², Antti Saraste², Juhani Airaksinen²

> ¹Technology Research Centrer, University of Turku, Finland ²Heart Center, Turku University Hospital, Finland

Abstract

The aim of the study was to assess the applicability of seismocardiogram (SCG) for the detection of atrial fibrillation (AF) in telemonitoring applications. SCG data used in this study consists of simultaneous SCG and ECG recordings of 12 patients during both AF and sinus rhythm (after cardioversion). An SCG-based AF-detection algorithm was developed and its performance tested with the acquired clinical data. The algorithm is able to distinguish AF positive samples from samples with sinus rhythm with high accuracy.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia in clinical practice affecting about 1.5% to 2% of the general population [1]. AF poses a major diagnostic challenge, as symptoms may be sporadic and absent during medical examinations. Identifying scarcely occurring "silent" AF thus requires long-term continuous monitoring. The ability to detect of cardiac anomalies via a miniaturised, low-cost, personal smart systems has the potential to revolutionise global healthcare services. Via widespread preemptive screening, the focus can shift from expensive and heavy treatment towards low-cost and easy prevention of diseases and effective personalised medication, enabling good health during a greater portion of ones lifetime. This leads to enhanced quality of life and savings for the healthcare sector and the entire society.

For massive screening purposes, cheap, noninvasive, disposable device which frequently monitors the cardiac activity in an unnoticeable manner is a preferred choice. As ECG is the gold standard for diagnosing the cardiac diseases, a lot of research efforts have been targeted in the development of EPMs (ECG Patch Monitors). The main problem with the EPMs is that a reliable analysis requires good electrode-to-patient contact and a minimum electrode distance (5-10 cm) which poses a size limitation and electrodes also irritate the skin in long-term use (see



Figure 1. Minimum distance of electodes required for reliable ECG analysis poses a size limitation for EPMs. MEMS-based approach can be made significantly smaller by integrating everything to a single package.

Fig. 1). In this study, the feasibility of seismocardiography for AF detection is evaluated. A MEMS-based AF detector has the potential to circumvent the problems related to EPMs. A miniature device is achievable by integrating the sensor to a single package with the required components, such as the sensor readout-electronics and DSP [2]. Envisioned System in Package (SiP) would be few millimeters in size, attached with skin-friendly adhesive and could operate for days without battery recharge.

An automatic detetion of AF by analysing the ballistocardiographic signal provided by an accelerometer attached to the bed was proposed in [3], however, to the best of our knowledge until now the detection of AF via an accelerometer attached to the chest has not been reported. Our primary interest is on MEMS only approach, but SCG could also be used to complement the ECG analysis and thus enhance the reliability and performance of EPMs.

2. Methods

2.1. Data Acquisition System

In this study, a measurement system illustrated in Fig. 2 allowing simultaneus SCG and ECG assessment was used.



Figure 2. Measurement setup used in this study allows simultaneus SCG and ECG assessment.



Figure 3. A coordinate system adopted in this study.

A battery powered Freescale FRDM-KL25Z development board controls the signal aquisition and stores the collected data to micro size memory card to be processed and analyzed retrospectively in Matlab. SCG is obtained via a digital output three-axis MEMS accelerometer (Freescale Semiconductor, MMA8451Q) with 14 bits of resolution. ECG acquisition comprises a commercial single-lead heart rate monitor front end (Analog Devices, AD8232), a buildin 16 bit ADC of the MCU and standard electrodes (Ambu, BlueSensor M). Sampling frequency of 800 Hz was used for all channels to ensure sufficient time resolution. A coorninate system shown in Fig. 3 was adopted in this study.

Securing a MEMS accelerometer to the center of the anterior chest with a double side adhesive provides adequate fixing for the sensor. The ECG electrodes were attached to the skin to lower left and lower right rib cage right below the major pectorals so that a standard 12-lead hospital ECG could be recorded normally (see Fig. 2).

2.2. Measurement Scenario

A small group of AF patients and a control group consisting healthy volunteers (20 people with no AF) were investigated. The clinical study was performed in the Heart Center, Turku University Hospital, Finland, with the aforementioned measurement system. The research protocol was approved by the Ethical Committee of the Hospital District of the South-Western Finland. Study included 20 patients with AF who were medically treated or to whom a cardioversion was anticipated. Patients were enrolled from the outpatient clinic, from those referred for cardioversion and from the ward. The main criteria for inclusion were:

- 1) Age \geq 18 years
- 2) History of atrial fibrillation requiring medical therapy or cardioversion
- 3) Patient is willing to comply with specified evaluations

• 4) Patient or legally authorized representative has been informed of the nature of the study, agrees to its provisions and has been provided written informed consent, approved by the appropriate Medical Ethics committee or Institutional Review Board.

and the main exclusion criteria were:

• Age < 18 years

• Any significant medical condition, which in the Investigators opinion may interfere with the patients optimal participation in the study.

SCG was taken while at rest in supine position simultaneously with ECG assessment during AF as well as sinus rhythm after successful cardioversion. The assessment took approximately 30 minutes per patient. Incomplete data due to reasons like patient had atrial flutter instead of AF or the cardioversion was unsuccessful, was discarded during the off-line analysis so that complete data set was eventually obtained from 12 patients. Using this measurement scenario it was possible to investigate the differences in the SCG signal during AF and normal sinus rhythm for each individual patient instead of studying interpersonal differences between AF and normal populations. This is important, because in contrast to ECG there is considerable interpersonal variation in the SCG morphology regarding even sinus rhythm let alone during AF. Data obtained from the control group was mainly used to achieve a better understanding on the differences in the acquired signal quality between healthy people and AF patients.

3. Results

The detection of single heart beats is often the starting point for different analyses, such as HRV, in health and well-being applications. An adaptive heart beat detection presented in [4] is based on SCG and performs very well with healthy people, e.g. sensitivity of 99% and specificity of 99% was achieved. Similarly, often the first step in ECG-based AF detection algorithms is to find R-peaks from the signal. The typical SCG waveforms recorded from one healthy individual in sinus and one AF patient during AF are shown in Fig. 4 and Fig. 5. From these figures, it is seen that finding heart beats reliably from the SCG signal without ECG is difficult even for healthy people, especially for target group, e.g. people over 65 years. In other words, when the signal quality is not high enough



Figure 4. Example of normal rhythm measured from target group. Upper graph z-axis SCG and lower graph ECG.



Figure 5. Atrial fibrillation. Upper graph z-axis SCG and lower graph ECG.

for reliable heart beat detection, an alternative strategy must be developed.

Nevertheless, as accelerometer is prone to motion artefacts by definition, be it SCG data from healthy people or patients with AF, it is crucial to pick only those portions of data for further analysis with no excessive motion artefacts caused by body movements. As shown in Fig. 6 only artefact-free segments are considered for further processing and peak detection procedures. For detecting artefacts, signal energy envelope is calculated from acceleration data with root mean square (RMS) [4]. Length of the RMS window is set to 0.5 s. A detection threshold is chosen to be twice the median value of energy envelope. Parts of the signal, where the energy envelope exceeds this threshold, are considered as motion artefacts.



Figure 6. The measurement set-up to detect atrial fibrillation from the accelerometer signal.

We have investigated and developed different methods and algorithms to detect atrial fibrillation from SCG signal. Fig. 7 shows the results based on combination of two different analyses. As shown in Fig. 7, the algorithm is able to distinguish the AF positive samples (red asterisk) from AF negative samples (blue circles). The analysis length is 62.5 seconds consisting of five individual 12.5 second samples. Fig. 8 shows the derivative of RR interval calculated using our algorithm from one patient during sinus rhythm and atrial fibrillation. Upper graph is sinus rhytm and lower graph atrial fibrillation. As seen for the Fig. 8, there are large differences between these two rhythms. Fig. 9 presents mean and median values of RR interval derivative achieved using this method for all patients; blue asterisk is sinus rythm and red asterisk AF. As seen from the results, it is possible to separate AF positive samples from AF negative samples with 100% accuracy using our algorithm and measured data.

4. Discussion

We envision three alternatives for MEMS accelerometer based AF detection:

• MEMS accelerometer only based AF detection. The main competitive advantage of this approach is the potential size of the equipment. Using commercially available off-the-self components, such as MEMS accelerometer, Bluetooth LE and small batteries, it is possible to build a button sized (diameter circa 1-1.5 cm) wireless AF detection device. In the future, it could be possible to achieve even cubic-millimeter size. This could be called AF smart dust.

• Combined ECG and accelerometer based detection. Using this combination, it is possible to detect cardiac time intervals. Furthermore, the ECG allows accurate R peak



Figure 7. A combination of two different analyses to detect atrial fibrillation. Blue circle AF negative sample and red asterisk AF positive sample.



Figure 8. Derivate of RR interval. Upper graph sinus rhythm and lower graph atrial fibrillation.

detection and therefore reliable segmentation of the SCG signal even during AF. Our results have shown that there is a typical behaviour for SCG signal during AF, at least in our dataset, and this could possibly be used to enchance the realibility in current systems, e.g. for example to separate multifocal atrial extrasystoles from atrial fibrillation during still periods. Moreover, many current ECG devices (on-skin or under-skin) already include accelerometer.

• Smartphone only based AF detection. We have already developed an android app for AF detection using smartphone built-in accelerometer sensor. This solution is software based and it could be deployed on smartphones around the world with minimal costs, in the future.



Figure 9. Median and mean values of derivative of RR interval. Blue asterisk sinus rhythm and red asterisk AF.

5. Conclusion

In this paper, it was shown that it is possible to separate sinus rhythm from atrial fibrillation with high accuracy using only MEMS accelerometer. Given the very small dimensions of modern MEMS accelerometers ($2 \times 2 \text{ mm}$), SCG based measurement may provide totally new venues especially for asymptomatic AF detection.

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Address for correspondence:

Tero Koivisto Technology Research Centre / University of Turku Joukahaisenkatu 1, Turku, Finland tejuko@utu.fi