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A Structured Measurement of Highly Synchronous Real-Time Ballistocardiography Signal Data of Heart Failure Patients

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Abstract. Ballistocardiography (BCG) has gained more attention due to the fundamental goal of medical intervention in diagnostics and follow-up. BCG is particularly suitable for the study of heart failure, which a recent study has shown. The results of this working group shall be validated and reproduced with another study trial. Therefore, acceleration sensor prototypes will be placed on various parts of the patient's body and be connected to a computer unit, which allows a high data quality and high signal resolution. A temporal shift of only 20 ns ensures real-time measurement of BCG parameters. The reference measurement will be done with a 12-channel ECG. The study will include patients with heart failure. All conducted tests take place as part of the diagnostic-therapeutic routine. The only change in the procedure concerns the additional equipment with the measuring sensors. The results will be the validation of the data from the other working group, as well as the information about the choice of sensors and clock frequency, the measuring points and the needed features for early detection of heart failure in BCG signals.

Keywords. Ballistocardiography, Seismocardiography, Heart Failure

1. Introduction

In recent years, the ballistocardiography has gained more attention [1–10], with the fundamental goal of medical intervention, for example, the diagnosis or follow-up.

However, ballistocardiography or seismocardiography [4,5] is particularly suitable for the study of heart failure (HF), as new studies confirm [10].

With the prospective study described here, the previous explorative results of the scientific society are to be reproduced, and this validates their validity.

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The determination of the course of development of heart disease or long-term measurements of cardiac parameters are currently still difficult to implement and can only be determined with the help of medical visits or measurements of only 24 hours. However, there are diseases that have a much slower course or can appear at irregular intervals and are therefore unnoticed or measured within 24 hours.

Ballistocardiography should be a simple and inexpensive solution, but at the same time efficient and highly specialized [4,5,9,11,12]. Thus, it is possible to determine the blood pressure with the aid of the measured pulse transit time (time difference of the same signal between various measurement points on the subject's body), without the patient being awakened by inflating a cuff around the arm at night or interfering with his activities during the day, thereby distorting the result [13]. Since such a system is very small and has a battery with several days of running time, measurements of more than 24 hours (as a single measurement) can be made to reduce the disease deterioration of e.g. Cardiac insufficiency or high blood pressure (even over a longer period, for example, over months) [4,5].

At present, there are only a few ballistocardiographic measurements performed in everyday life or with cardiac patients. Data on the signal morphology of cardiac insufficiency have only been collected in an exploratory fashion [1]. With this prospective study planned, we then want to validate these exploratory results. Furthermore, in literature found setups raise further questions, so the technical measurement setup from the point of view of the working group is not optimal (choice of sensor, choice of clock frequency, choice of measurement position).

The overall objective of this prospective study is the validation of the results from the published results [10] for the measurement of ballistocardiographic or rather seismocardiographic signals in cardiac patients and their usability for heart failure diagnostics and/or course analysis, through the use of a highly specialized sensor measurement system consisting of body-worn acceleration sensor.

Secondary goal is to find out what features are needed for early detection of heart disease (e.g., Graph Similarity Score or other correlation) and what the signals of such diseases look like in a ballistocardiographic record.

2. Methods

The BCG sensor system is intended for the measurement. Components include the core unit, the FPGA processor board, and seven suitable triaxial acceleration sensors (Accelerometer). For the reference measurement, a 12-channel ECG is read out via the analog output parallel to the acceleration signals. This is a common method to be able to compare the two signals to each other and to provide information when in the BCG signal the characteristic features should appear.

The measuring system allows a high data quality (low signal-to-noise behavior) and a high signal resolution (2g scaling at 16 bit). In addition, an isochronous readout of the 3x7 acceleration sensor channels at a suitable sample frequency can be realized. The sensor positions are 1x sternum, 2x cardiac apex – medio-clavicular (5. ICR), 1x torso, lateral le., 1x spine (7.-8. th), 1x A. temporalis le., and 1x A. radialis left-hand side. The aim of the used two-digit kilohertz range including oversampling is to ensure data robustness. A temporal shift of only 20 ns ensures real-time measurement of ballistocardiographic parameters.

The measurements are carried out simultaneously with the recordings of the general patient assessment. Participation in the study will not give subjects any further inconvenience with regards to additional assessment procedures (e.g., 6-minute-walking- test) or separate visits to the measurement environment. All conducted tests take place as part of the diagnostic-therapeutic routine. The only change in the procedure concerns the additional equipment with the measuring sensors.

The subject is initially in a stationary position during the measurement (for about one minute). Further, a six minutes gait phase, as is commonly done within the general clinical routine assessment, will follow. After this physical stress on the subjects, there is a five-minute recovery period. Conversations should be avoided during the measurement.

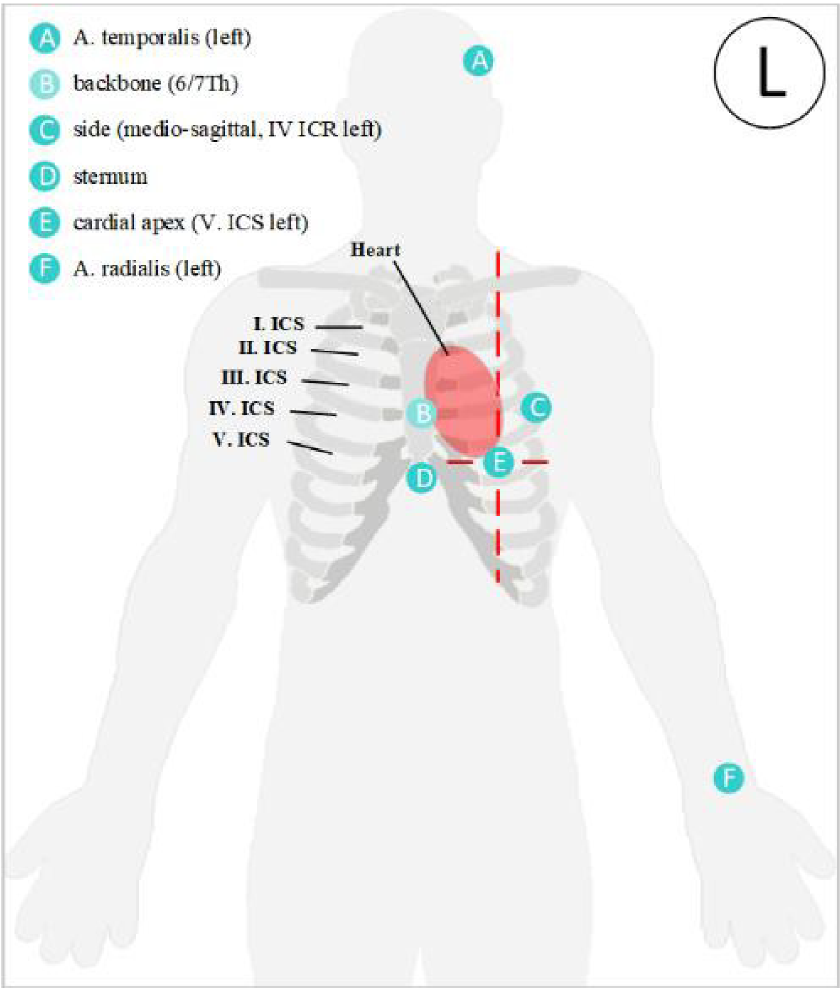

Figure 1. Model of the measure points.

The additional BCG sensor on the apex of the heart serves as a supplement to the first sensor since the electrode of the ECG is also attached to this position. This ensures a good recording of the acceleration at this.

Based on the hypothesis that there will be no subjects within the study population whose BCG/SCG signals differ fundamentally from the known morphology and the assumption that a homogeneous group exists under the given conditions more than 60 percent of the subjects have comparable features in the BCG or SCG signal, a rather small panel of subjects provides sufficient security for verification. In order to test the results of the difference between compensated and decompensated cardiac insufficiency subjects found in the literature see [10], 52 probands are needed with an effect size of 0.35. These subjects should be distributed as equally as possible to the four NYHA classes. In addition, the number of compensated and decompensated subjects should also be equally distributed.

3. Prospective Results

The main results of this study will be the validation of the data and results from the exploratory study with heart failure patients [10]. Hopefully, we are at least able to reproduce these results and give an overview of the performance of ballistocardiographic sensors in the diagnostics of cardiac patients. Moreover, we are confident to collect BCG or SCG signal data in the best quality state, so we can provide them to the scientific community soon as open data like it is requested by FAIR-principle. Those results will provide highly synchronous signal data with the best sample frequency we can reach (about 17 kHz) and the optimal entropy about the heart's movements and functions.

Another result of the performed measurements will be a deeper knowledge of the usability of specific digital triaxle acceleration sensors and other system specifics, like the clock frequency, to gain an optimal measurement result and furthermore, more knowledge about the measurement positions on a patient's body.

In the end, the ideal setup for those measurements is going to be presented. Moreover, the needed features for early detection of heart failure and the characteristics of the disease in BCG data will be shown and also the usability of this type of diagnostic for cardiac patients.

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