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DR.BEAT: Initial Functional Testing of a BCG Wearable Prototype for Recording Ballistocardiographic Signals

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Abstract. DR.BEAT ("**D**igital **R**esearch on **B**allistocardiography for **E**xtraterrestrial **A**nd **T**errestrial use") develops a miniaturized sensor system with signal processing to interpret ballistocardiographic signals and implements an application oriented user interface. Presented is a breadboard prototype's functional tests with regard to data completeness and plausibility. The analysis confirmed a reliability of 99.99995% over the tests and the signals displayed the expected heart-specific characteristics. These results support the ethical justifiability of an initial study.

Keywords. Ballistocardiography, Seismocardiography, Accelerometer, mHealth

1. Introduction

Ballistocardiography (BCG) non-invasively measures the body's micromovements induced by the blood flow and the heart's movements during the cardiac cycle [1]. The aim of this work is to evaluate a wearable first breadboard prototype through functional testing to ensure its applicability for a first phase of BCG measurements on humans.

2. Methods

The prototype's sensor unit consists of two 3D-accelerometers (Kionix-132) to reduce noise and interference through differential signaling [2]. An OLIMEX SHIELD provides a synchronous reference electrocardiogram (ECG). The sampling rate was lowered from 10 kHz to 1 kHz, found to be sufficient for digitizing BCG features [3].

As a data basis, 14 measurements in unworn and worn state (BCG sensor unit at sternum of a subject) were performed. Signal preprocessing resulted in calibrated data sets for all measurements and filtered data sets for worn condition (BCG: 3. order Butterworth bandpass filter, 10-30 Hz).

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Completeness investigations of unprocessed data included analysis of missing frames, distinguished into unwritten and incomplete frames, to evaluate technical reliability. An unwritten frame was defined as the difference between header values of written frames that exceeded the expected step size of one. An incomplete frame was defined as a deviation in the expected number of twelve bytes per data frame.

To evaluate signal reliability, plausibility tests were performed. Statistical dispersion measures were calculated on the calibrated signal values in unworn state to identify outliers and on the value's differences to identify abrupt signal shifts. In visual inspection of the calibrated and filtered data sets, the entire measurements and one-minute sections were examined by an expert for trends and extreme values.

3. Results

Missing frames occurred during system startup (approx. 700 frames). After startup and during regular measurement, within around 10^7 received frames, five incomplete frames were identified in five measurements. Thus, five milliseconds in a total of 175 minutes were faulty, corresponding to a technical data integrity of 99.99995%.

Plausibility tests showed single outliers in ECG and BCG as well as continuous baseline wander in BCG in one unworn state measurement over 45 minutes. In the filtered signal of measurements in worn state, individual deviations from the expected signal features in ECG and BCG appeared (prob. physiological and/or environmental influences). The majority of measurements did not show abnormalities and filtered data showed expected signal features (cf. [1]), suggesting promising signal quality.

4. Conclusions

The initial breadboard prototype's functional testing showed that data completeness and plausibility are at high level. The results of the functional tests confirm that there are no crucial hardware problems that would preclude initial use in humans. Consequently, the usability of the breadboard prototype for the application in measurements on humans is ensured, which supports the ethical justifiability of the intended study.

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