Development of a System Based on Ballistocardiography to Monitor Sleep

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Introduction

Studies have shown that vital signs, such as heart rate, respiration rate, and movement activities during sleep are reliable indicators of neurodegenerative diseases [1]. A promising method that can be used to measure these parameters during sleep is Ballistocardiography (BCG). Currently, commercially available BCG devices lack transparency in terms of their algorithmic methods, making them usable only to a certain extent in research. Therefore, the aim of this master thesis was to develop a system based on BCG as a proof of concept system that could potentially replace existing commercial BCG devices.

Materials and Methods

The developed prototype consists of piezoelectric sensors, differential amplification, analog filtering, and analog-to-digital conversion components. To obtain vital sign data, we employed algorithms to extract heart rate, respiration rate, and physical movements. Additionally, a study involving ten participants was conducted to assess the prototype's performance (Fig. 1).

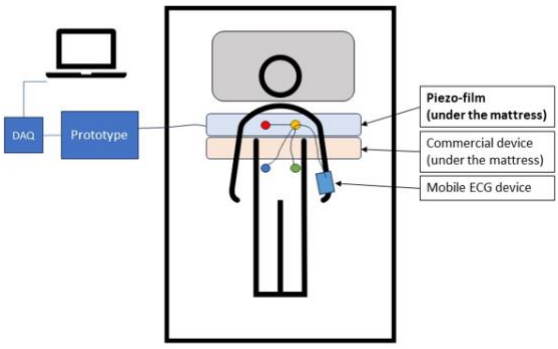

Fig. 1 Study setup: Illustration of a participant laying on the bed with attached electrodes (red, yellow, blue, and green dots) and mobile ECG device on the left wrist. The prototype sensor (light blue) and reference BCG device (light orange) were mounted under the mattress. The prototype sensor was connected to the prototype hardware by wires. The prototype was connected to the NI DAQ card by wires. The NI-DAQ card was connected to the notebook via USB.

Results

The prototype effectively extracted heart rate, respiration rate, and movement activities (Fig. 2). In the assessment of heart rate extraction, the best-case scenario resulted in a mean squared error (MSE) of 1.93 beats per minute (bpm), while the worst-case scenario had an MSE of 194.1 bpm. The evaluation of respiration rate extraction was conducted qualitatively and resulted in 28% categorized as good, 44% as bad, and 28% as undecidable based on morphological matching. Finally, the prototype demonstrated 95% accuracy in detecting executed movements.

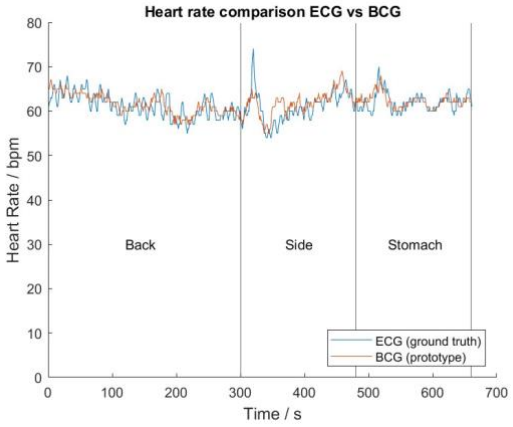

Fig. 2 Comparison of a study participant's heart rate measurements using an electrocardiogram (ECG) shown in blue and the developed prototype in orange, demonstrating one example of heart rate extraction results. The timeline is separated into the corresponding sleeping positions: back, side, and stomach.

Discussion

In this work, we developed a reliable and accurate system that is based on Ballistocardiography to monitor vital signs (i.e., heart rate, respiration rate, and movements) during sleep. Due to its adjustable sampling rates, this prototype could for example be used in studies to reliably measure movements in bed related to conditions such as the periodic limb movement disorder.

References

[1] Lampros C. Kourtis, Oliver B. Regele, Justin M.Wright, and Graham B. Jones. Digital biomarkers for alzheimer's disease: the mobile/wearable devices opportunity, 2019.

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