Turtle Shell Publications

Contactless Monitoring of Cardiac Contractions

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The full paper explaining the methodology and algorithm was presented at 2018 IEEE-EMBS Conference on Biomedical Engineering and Sciences in Malaysia. It was published with the proceedings by IEEE (DOI: 10.1109/IECBES.2018.8626652). The full text for the same can be accessed at:
https://ieeexplore.ieee.org/document/8626652

This paper is an extension of the above-mentioned research. The dataset was increased from 13 full night PSG recordings on 8 subjects (106 hours) to 89 full night PSG recordings on 43 subjects (681 hours). It was observed that the results presented were consistent despite increasing the validation dataset by almost 7 times.

In an Intensive Care Unit (ICU), one-to-one nursing care of a patient along with the close monitoring of a patient's vital signs ensures patient safety. ICUs are the only area in the hospital where a patient is under continuous observation by the attending nursing staff. Even a minor deviation that can cause a threat to the patient's life are reported to the attending physician, along with the ICU staff who can intervene immediately at the time of emergency.

Unfortunately, there is no system for continuous monitoring when a patient is shifted outside ICU, after being operated or after undergoing a complicated surgery. They are either shifted to a private room or a general ward due to the high cost of the equipment as well as inconvenience to the patient. As an alternative, nurses manually monitor patients at extended intervals and often miss imminent complications.

Moreover, currently, India faces a shortage of over 2 million nurses [1], putting enormous pressure on the existing nursing staff. Cost-effective continuous monitoring aids in early detection and intervention that can assist the healthcare professionals and infrastructure to alleviate the burden and the cost [2]

Technique for Contactless Heart Monitoring

Ballistocardiography (BCG) is a non-invasive technique of measuring body motion generated by cardiac contractions during each cardiac cycle. It is used as an unobtrusive method to obtain heart rate of a subject and thus can play a significant role in continuous health and vitals monitoring.

BCG sensor, when placed under a subject's chest, captures the ballistic forces resulting from cardiac contraction and expansion, as shown in Figure 1 -- R peak in the ECG sinus corresponds to J peak in the BCG signal.

Fig.1. Representation of ECG sinus rhythm and corresponding BCG waveform

The most crucial step involved is extracting cardiac events from the raw BCG data, which is mostly vibrations captured through electronic data acquisition systems followed by suitable processing in software. While some techniques presented in previous studies simply determine the average heart rate for each 30-second epoch, others identify individual heart beats.

Individual heartbeats vs average heart rate

Heart rate averaged over a time period cannot yield finer granularity cardiac parameters such as heart rate variability and abnormal cardiac contractions or irregular heart beats like arrhythmia -- accurately determining the occurrence of each cardiac contraction is necessary for such applications. The ability to detect each cardiac contraction enables determination of stress, recovery, sleep stages & cycles by using heart rate variability parameters.

Dozee - Contactless Patient Vitals Monitor

Placed under the mattress, Dozee monitors micro-vibrations produced by the body during sleep. Proprietary algorithms convert muscular, respiratory and cardiac movements into useful biomarkers to monitor heart, respiration, stress levels, restlessness, and sleep.

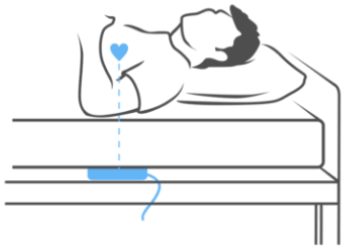

Fig. 2. Dozee in use

Methodology

The raw signal captured through dozee is pre-processed to remove noise and artifacts due to breathing and body movements. J peaks are then identified using proprietary pattern recognition algorithms. The average time difference between two consecutive J peaks for each 30 seconds epoch yields the average heart rate for the period. Figure 3 shows a comparison of BCG data recorded through dozee.

ECG Data Acquisition: The ECG data used for comparison was acquired from full night polysomnography (PSG) recordings conducted at the Human Sleep Research Laboratory of the Department of Neurophysiology at National Institute of Mental Health and Neuro Sciences (NIMHANS), Bangalore, India. All the recordings were done using Nihon Kohden Neurofax EEG-1200 machine [3] (24-bit resolution, 1024 Hz sampling rate and 0.1-250Hz bandpass filter) with ECG recorded by bipolar ECG lead.

Validation Methodology: Dozee was validated for 89 full-night PSG recordings on 43 subjects (for a total of 681 hours). ECG data was extracted from the PSG recordings during which Dozee also recorded BCG data from under the mattress. Data obtained from Dozee was processed to identify J peaks. Furthermore, the detection rates for individual heart beats and 30s epochs were computed -- each 30s epoch for which there is at least 5s of BCG data processed is accounted for. The average heart rate for 30s epochs was also computed. Identified J peaks and the 30s epoch averages are then compared with the same extracted from ECG data.

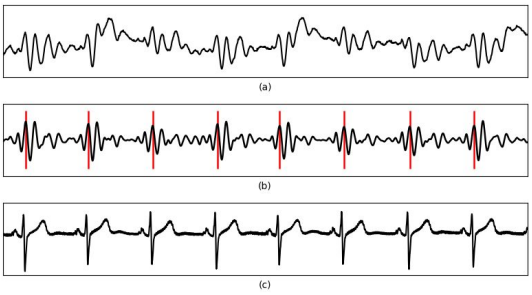

Fig. 3. (a) Raw BCG signal, (b) Processed BCG signal with identified J peaks, (c) ECG waveform

Results

With this, the detection rate for 30s epochs for the same dataset was with the proposed algorithm is 98.70% on average, with an average accuracy of 98.01%. Figure 4 depicts the accuracy and detection rate for heart rate (for each 30s epoch) as well as individual heartbeat over each full night polysomnography recording.

Dozee achieved an average accuracy of 96.46% with an average detection rate of 85.53% for individual heart beats over the entire dataset. Dozee identifies J peaks for every pre-processed signal that is at least 5s in length, and computes average epoch heart rate for every 30s epoch for which we have at least 5s of data.

These results were computed over a cumulative duration of 681 hours on 43 subjects during 89 full night PSG recordings.

Conclusion

Contactless monitoring of cardiac contractions is proposed through vibro-acoustic sensors. This proposition is supported by the high accuracy and detection rate presented in the paper.

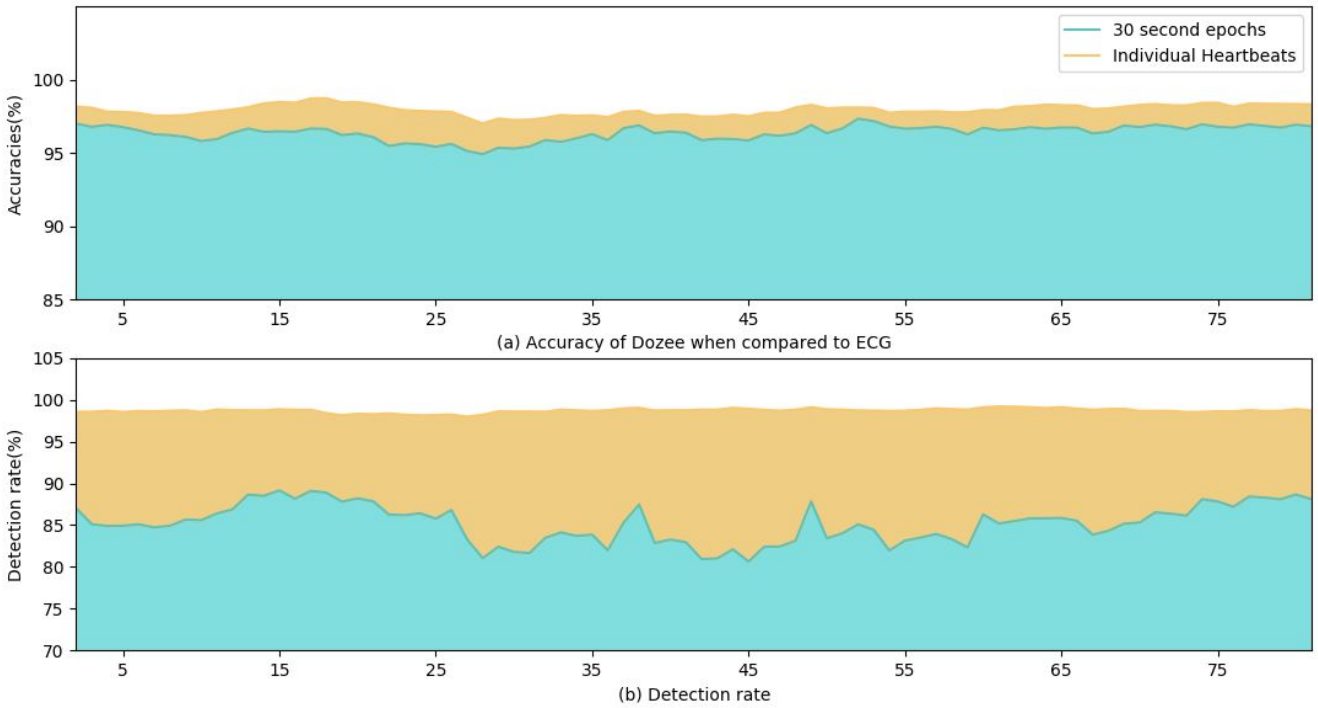

Fig. 4. (a) Accuracy of Heartbeat detection for Dozee when compared to ECG (b) Detection rate for Dozee

References

[1] Wanted: 2.4 million nurses, and that's just in India (http://www.who.int/bulletin/volumes/88/5/10-020510/en/)

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[3] Neurofax EEG-1200, NIHON KOHDEN, https://us.nihonkohden.com/media/1060/eeg-1200-brochure_nmlb-028-g-co-0163.pdf

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