Turtle Shell Publications

Artificial Intelligence based Contactless Blood Pressure Monitoring using Ballistocardiography Sensors

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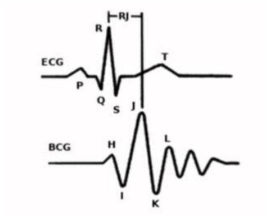
Blood pressure is one of the vital signs, together with respiratory rate, heart rate, oxygen saturation, and body temperature, that healthcare professionals use in evaluating a patient's health. In terms of clinical significance, blood pressure has a vast number of applications eg. cardiovascular disorders, early warning system for identifying patient deterioration (MEWS), screen for sepsis (qSOFA Score) and countless other areas.

Traditionally, blood pressure was measured non-invasively using auscultation with either an aneroid gauge, or a mercury-tube sphygmomanometer. Auscultation is still generally considered to be the gold standard of accuracy for non-invasive blood pressure readings in clinics. [1] However, semi-automated methods have become common, largely due to concerns about potential mercury toxicity [2], although cost, ease of use and applicability to ambulatory blood pressure or home blood pressure measurements have also influenced this trend [3]. Early automated alternatives to mercury-tube sphygmomanometers were often inaccurate, but modern devices validated to international standards achieve an average difference between two standardized reading methods of 5 mm Hg or less, and a standard deviation of less than 8 mm Hg. Most of these semi-automated methods measure blood pressure using oscillometry.

The techniques mentioned above usually require a cuff to be installed on the subjects arm for a reading to be initiated. This step makes it a manual procedure, hence limiting the use to a spot check for at best a few times a day. Another non-invasive method that uses Pulse Plethysmography (PPG) to estimate blood pressure has been used by some devices and studies. PPG incorporated in finger and wrist based devices makes it easy to use on a regular basis continuously. However, studies have shown this technique to be ineffective in measuring BP accurately, particularly Systolic BP [4]. We present a novel approach to measure BP from BCG in a contactless manner with high accuracy and reproducibility.

Ballistocardiography

Ballistocardiography (BCG) is a non-invasive technique of measuring body motion generated by cardiac contractions during each cardiac cycle.



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.

Figure 1 Representation of ECG sinus rhythm and corresponding BCG waveform

Dozee - Contactless Patient Vitals Monitor

Placed under the mattress, Dozee monitors micro-vibrations produced by the body during sleep. These vibrations are converted into meaningful biomarkers. It leverages BCG to enable remote monitoring of vital parameters like respiratory rate, heart rate, heart rate variability, etc. This method extends continuous monitoring out of ICU in a hospital setting and even at home of the subject.

Figure 2 Dozee

Science

Blood pressure is influenced by cardiac output, systemic vascular resistance and arterial stiffness and varies depending on situation, emotional state, activity, and relative health/disease states. In the short term, blood pressure is regulated by baroreceptors which act via the brain to influence the nervous and the endocrine systems. [5]

Methodology

We used multiple features associated with Heart Rate and Heart Rate Variability to train an AI model. The AI model takes changes in the feature from the baseline of a subject and gives the change in systolic and diastolic BP as output.

We used Omron HEM-907 as the gold standard device. The subjects were made to lie down in any comfortable position while Dozee was installed under the mattress as shown in Fig 2. 5 readings were taken at an interval of 5 min each on the HEM-907 machine while Dozee recorded BCG data simultaneously. The subject was then asked to perform any physical activity that caused the heart rate to increase. Post this 5 additional readings were taken in an identical manner to the previous 5 readings.

We then divided the subjects into two categories: training and validation. For both the categories, one of these 10 readings was used to establish the baseline for the subject. The other 9 readings for subjects in the training category were used to train the AI model, while the remaining 9 readings for the subjects in validation category were used to evaluate the method by comparing with the output of the gold standard device. We recruited 423 subjects for the study. Of these, 250 were used for training and the remaining 173 (131 Males & 42 Females) were used for validation. The age of the validation subjects ranged from 18 to 91 (Avg - 39) years.

Results

The following standards are widely used to evaluate a BP measuring system [6]:

- British Hypertension Society (BHS) - Table 1 shows the grading according to BHS depending on the minimum percentages of validation dataset distributed in different tolerances of absolute error from the gold standard.

Grade	<= 5 mmHg	<= 10 mmHg	<= 15 mmHg
A	60%	85%	95%
B	50%	75%	90%
C	40%	65%	85%

Table 1: BHS Grading Criteria

- Advancement of Medical Instrumentation (AAMI) - the test device must not differ from the mercury standard by a mean difference >5 mm Hg or a standard deviation >8 mmHg
- ISO/ European Society of Hypertension (ESH) /AAMI collaboration - A device is considered acceptable if its estimated probability of a tolerable error (≤10 mm Hg) is at least 85%

	<= 5 mmHg	<= 10 mmHg	<= 15 mmHg
DBP	71%	94%	99%
SBP	52%	80%	94%

Table 2: Proportion of the validation dataset under 5 mmHg, 10 mmHg and 15 mmHg absolute error from the gold standard

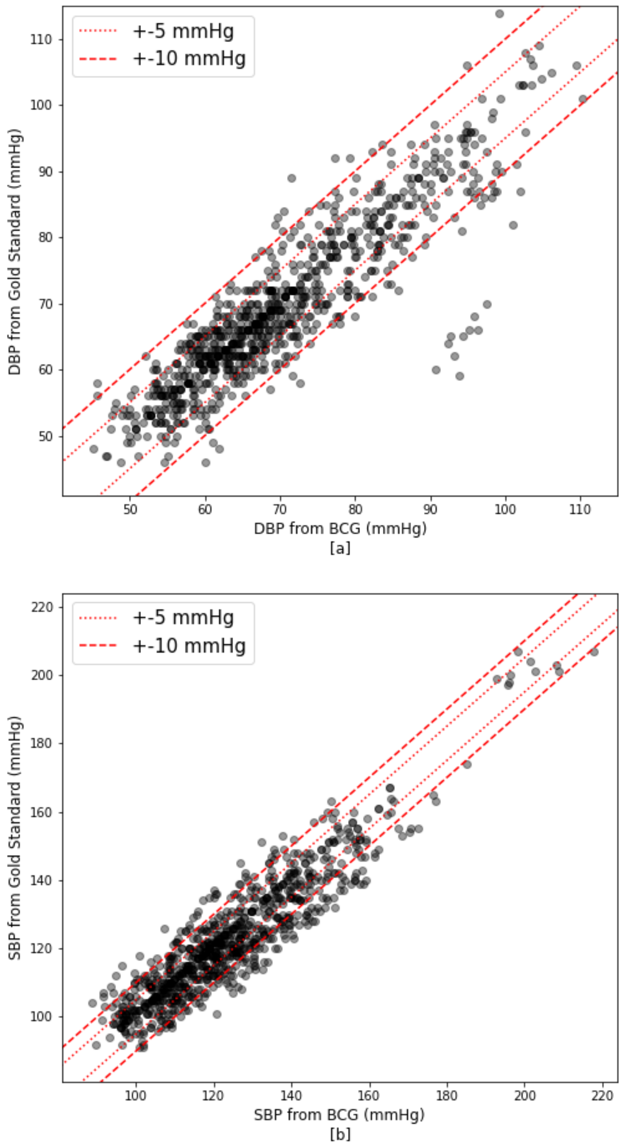


Figure 3 Comparison of BP form gold standard with BP from Dozee

Over 903 recordings on 173 subjects we observed a mean difference of 2.43 mmHg and standard deviation of 5.2 mmHg for DPB and difference of 1.38 mmHg and standard deviation of 7.39 mmHg for SBP. 85% of DBP predictions had error less 6.43 mmHg and 85% of SBP predictions had error less than 9.36 mmHg. This satisfies the BHS, AAMI and ISO/ESH/AAMI collaboration criteria. Based on Table 2, the method presented in this study qualifies for Grade A in DBP and Grade B in SBP. Fig 3 shows the measurements from the gold standard device overlaid with the calculated BP from Dozee. The validation dataset consisted of DBP ranging from 46 mmHg to 114 mmHg and SBP ranging from 91 mmHg to 207 mmHg.

Conclusion

A novel method was proposed in this study to measure Blood Pressure from contactless Ballistocardiography. The method was demonstrated to be accurate and in compliance with standards to evaluate blood pressure measuring devices - BHS, EHS, AAMI and ISO. Ease of use and high accuracy makes this method ideal for use for continuous monitoring in any setting.

Blood pressure is one of the 5 vital signs widely accepted to measure the status and stability of a subject. The traditional methods to capture blood pressure non-invasively require manual intervention and therefore continuous measurement of BP hasn't been feasible uptil now. The method presented in this study enables measurement of BP with high fidelity and continuously without any manual intervention.

In addition to BP, the system described in this study measures respiratory rate and heart rate from the same sensor [7],[8]. Also with an optional accessory oxygen saturation and temperature can also be obtained remotely with the same device. Real time availability of all of these vital parameters remotely has the potential of revolutionizing remote patient monitoring. This system improves the efficiency of the healthcare professionals and enables early intervention thereby saving countless lives.

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