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Adjustable cuffless smartphone attachment (ACSA+) for estimation of blood pressure trends: A pilot study

Kseniia Sholokhova

Master's degree student
Taipei Medical University

linkedin.com/in/kseniia-sholokhova-08b7b3267

Blood pressure (BP)

Importance

One of the vital signs and indicator of various cardiovascular diseases

Statistics

- 1 in 3 adults have high BP;
- About 36 million adults with high BP don't control it;
- Contributes to 1000 deaths per day

Gold standards

Although "gold", but either implemented in a surgery room or measurements must be done in a very fixed setting.

The big problem

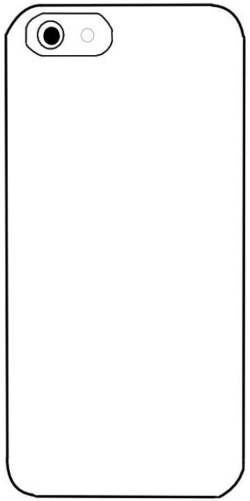
The current methods of measuring BP are inconvenient: bulky, painful, require extra efforts for a daily routine.

https://www.cdc.gov/vitalsigns/hypertension/

Is it possible to make the BP monitoring more convenient or even invisible for users?

This is our research question

Adjustable cuffless smartphone attachment (ACSA+)

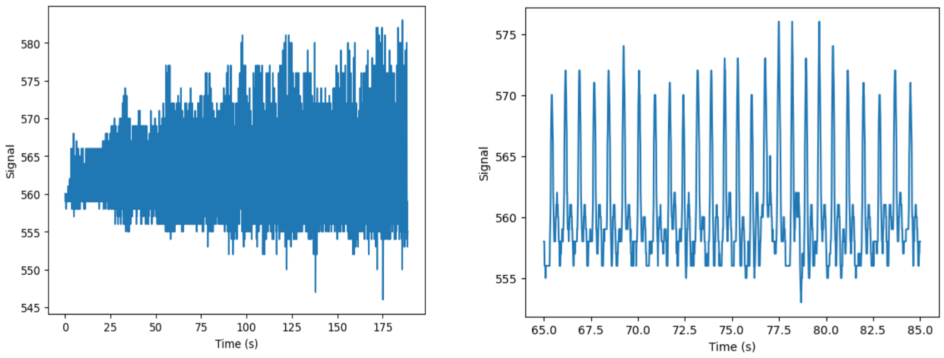


Adjustable cuffless smartphone attachment (ACSA+)

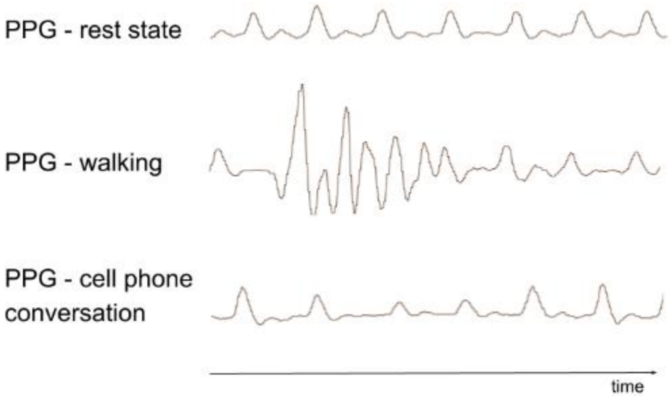
- ✓ Smartphone is our daily possession.
- ✓ Owned by 86.41% of the world's population (Statista, 2023).
- ✓ Mainly used for communication, average adult cell phone owner makes and receives around 5 voice calls a day (Pew Research Center).
- ✓ Therefore, in this study, we created ACSA + to attach to the back of the smartphone. ACSA+ aims to receive the signal from the user and convert it into valuable BP values, while the user is on the phone conversation.

Hardware

PPG-based hardware enabling to capture the signal during conversations.

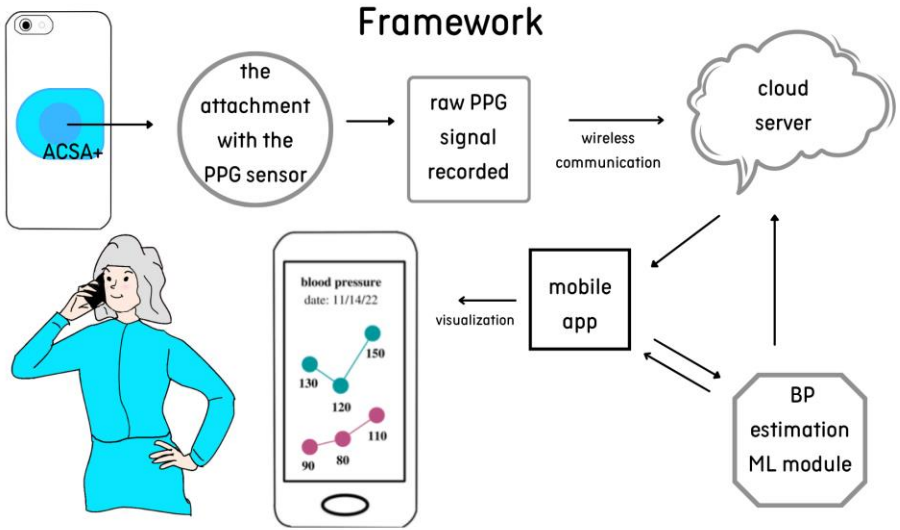


Example of 3 minutes (left) and 20 seconds (right) recording during conversations from ACSA+



Comparison of PPG signals recorded from ACSA+ by performing different activities

Our solution

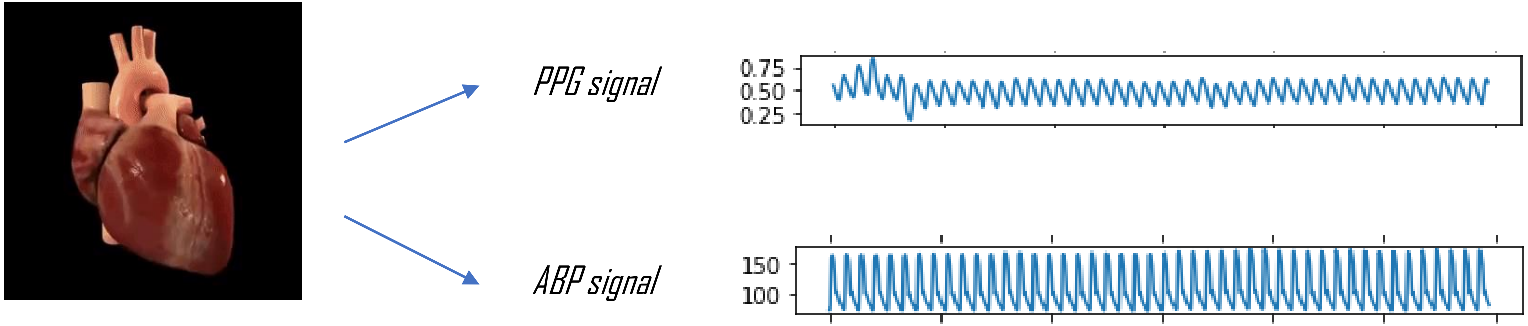


BP estimation machine learning (ML) module

- We used the PPG-based approach for estimation of BP (estimation of BP from the single PPG signal).
- PPG = Simple + Inexpensive + Informative + Promising
- Peripheral volumetric changes and BP are correlated (Langewouters et al., 1986).
- This means that some characteristic PPG features can be used to estimate Systolic BP (SBP) and Diastolic BP (DBP) using ML functions.
- Using only PPG signals, we can extract the features based on the Waveform contour principle: width, height, and other measurements can be used to predict BP values.

Methods - Wave contour feature extraction

The features were extracted based on the waveform contour principle. However, for this method, the wave should have a well-defined contour.



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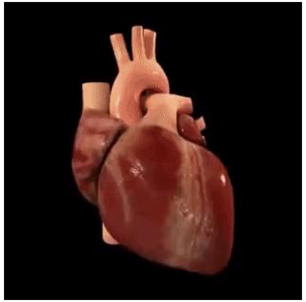
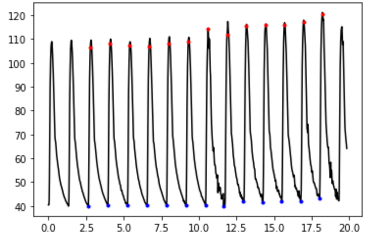


PPG signal

ABP signal

Wave contour analysis regarding the distances of pulsatile component



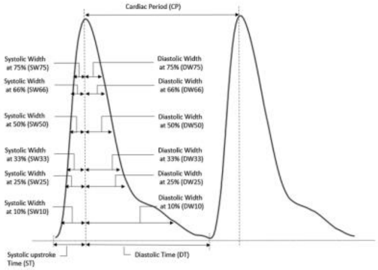


Fig. 5. Selected PPG features extracted from each cycle [8].

Extraction of minimum and maximum of the signal

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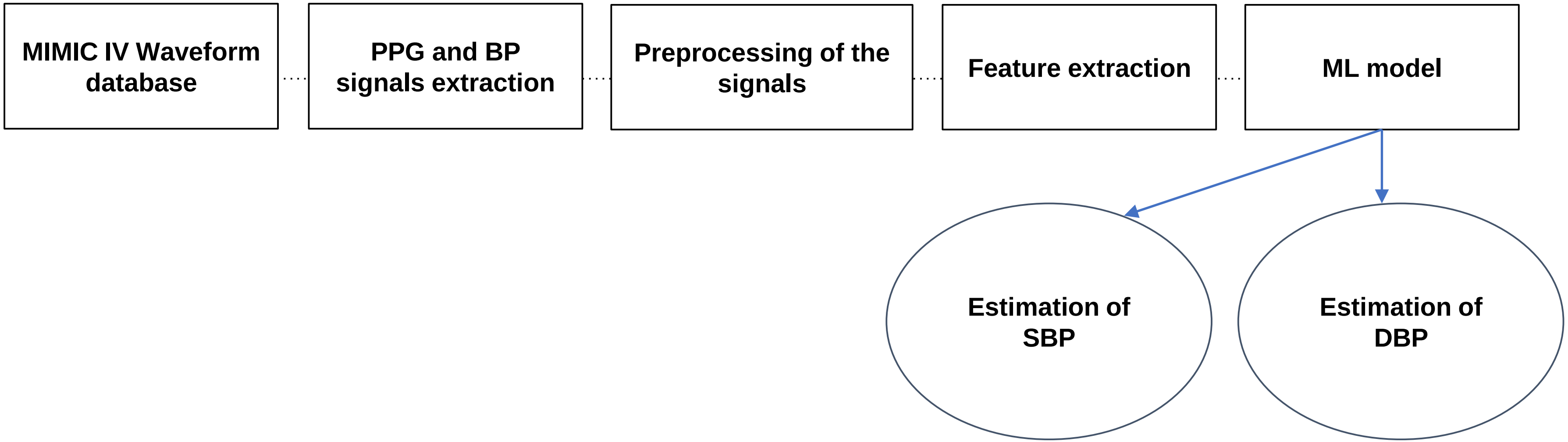
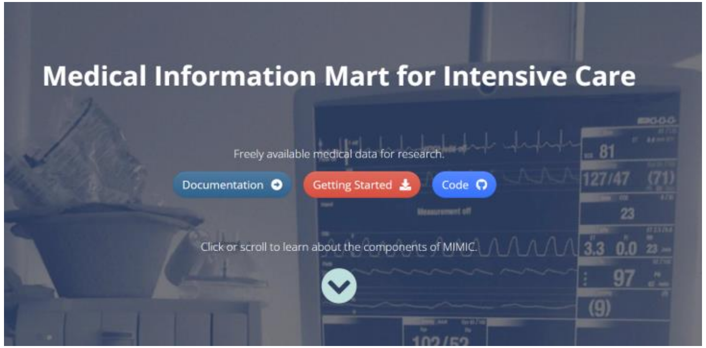
Methods - ML for estimation BP



Database: MIMIC IV waveform database

- MIMIC IV waveform database is the latest version of MIMIC series database containing multiple vital signs collected from ICU patients.
- 198 patients (200 records) are available;
- 57 patients satisfied the condition of the simultaneous presence of ABP and PPG signals and acceptable duration time;
- Only 9 patients had good and acceptable qualities of both signals, resulting in 922 waveforms.
- Upcoming realize is expecting 10000 more records.



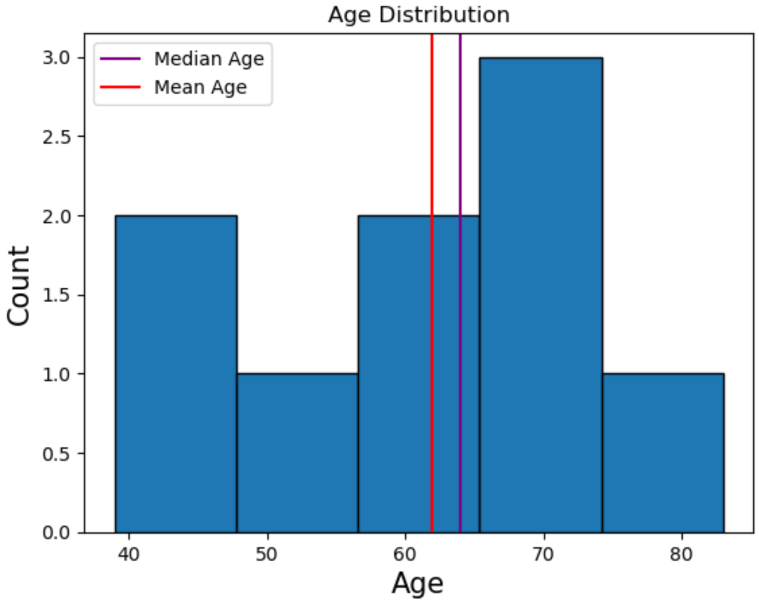
https://mimic.mit.edu/

Database: patients demographics

Connection with MIMIC-IV database, revealed demographic characteristics of participants.

The demographics of qualified patients revealed that 5 (56%) were identified as White, 1 (11%) as Asian, 1 (11%) as Black/African American, 1 (11%) as belonging to another ethnicity, and the ethnicity of 1 (11%) patient was unknown. Among the eligible participants, 6 (67%) were male and 3 (33%) were female.

This figure demonstrates the age distribution of the study participants, with a median age of 64 years old.

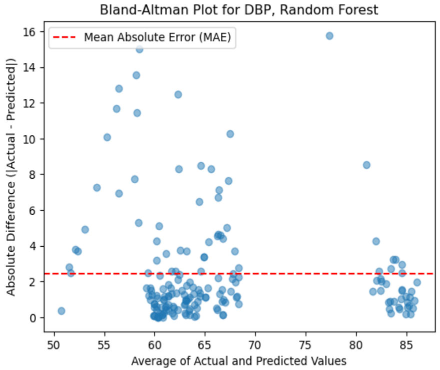


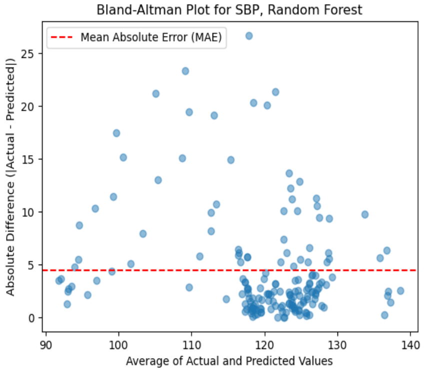
Performance of the models

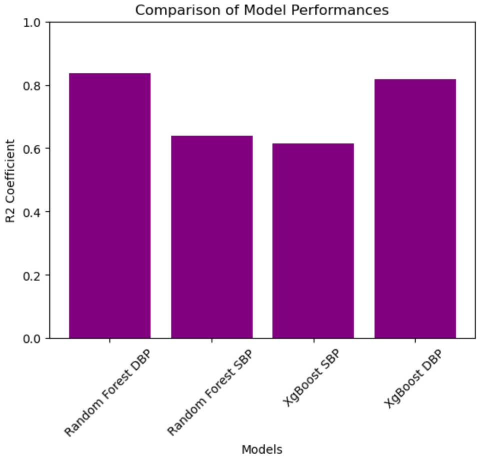
ML model	Prediction task	MAE (mmHg)	SD (mmHg)
Random Forest Regressor	SBP	4.44	± 5.14
	DBP	2.52	± 3.16
XGBoost Regressor	SBP	4.54	± 5.31
	DBP	2.74	± 3.22
AAMI standards	SBP	≤5	≤8
	DBP	≤5	≤8

Performance of two models compared with AAMI standards for cuffless BP estimation. This is MIMIC waveform database training and testing performance. Train and test split (70%:30%), 590 waveforms.

Performance of the models





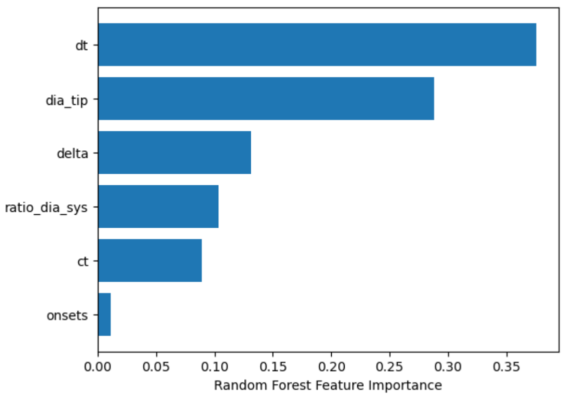


The Bland-Altman plots for MAE and SD helps to evaluate the agreement between PPG-based prediction model and the true SBP and DBP values.

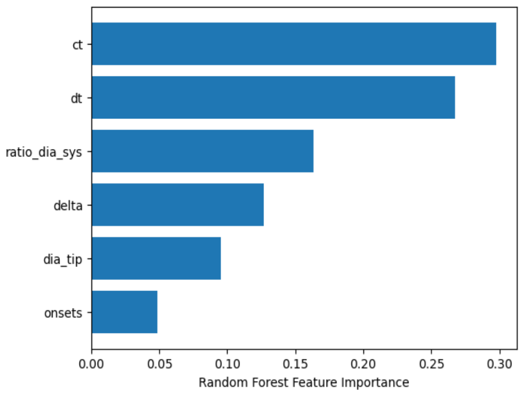
An R-squared coefficient of 0.8 indicates that our prediction model captures a substantial amount of the variation in SBP and DBP values.

Feature importance

DBP



SBP



For predicting DBP, features directly associated with diastolic peak were important.

For predicting SBP, the features related to diastole and systole period were equally important.

Discussion

The Random Forest Regressor demonstrated better performance in estimating SBP (MAE: 4.44 ± 5.14 mmHg) and DBP (MAE: 2.52 ± 3.16 mmHg).

Nevertheless, we met the standards, further enhancements are required to meet the global standards established by the AAMI for cuffless BP estimation.

Incorporating additional features like pulse widths at various amplitudes, as well as considering the first and second derivatives of the signal and time series features could help to improve the model.

Furthermore, the upcoming release of the database, expected to encompass 10,000 new records, presents an opportunity to augment the patient sample size and enhance the model's capacity to generalize to a wider population.

Conclusion

We established the first prototype of ACSA+, both hardware and software, for predicting BP from PPG.

The hardware component demonstrated its ability to record high-quality PPG signals and store them locally. Notably, the hardware excelled in capturing signals even during conversations, which was a key goal in the device's development.

The software component, equipped with a machine learning module for blood pressure estimation, also yielded promising results. The Random Forest Regressor demonstrated better performance in estimating SBP (MAE: 4.44 ± 5.14 mmHg) and DBP (MAE: 2.52 ± 3.16 mmHg).

Conclusion

Comparing ACSA+ with the gold standard of BP monitoring is an essential follow-up work to establish the accuracy and reliability of the device for daily use.

This device is not intended to be a medical device. However, it is intended to be a tracker of blood pressure, revealing the trend line of its stability.

By using this device, people can gain more awareness of their blood pressure levels and follow up with their healthcare provider.

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1960 TMU TAIPEI MEDICAL UNIVERSITY

Thank you for your time and attention!

If you have any questions, I am very happy to address them.