Cuff-Less High-Accuracy Calibration-Free Blood Pressure Estimation Using Pulse Transit Time

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Outline

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- Backgrounds
- Methodology
- Results
- Conclusion

Motivation

- **Hypertension** (High Blood Pressure) is the second factor of cardiovascular disease
- 9.4 million death reported because of **hypertension** [1]

Traditional Measurement Method

- Inflatable Cuff
  - Inconvenient
  - Prevents continuous measurements
  - Makes stress and systematic error
  - As shared by many people isn't hygienic

Physical Background [2]

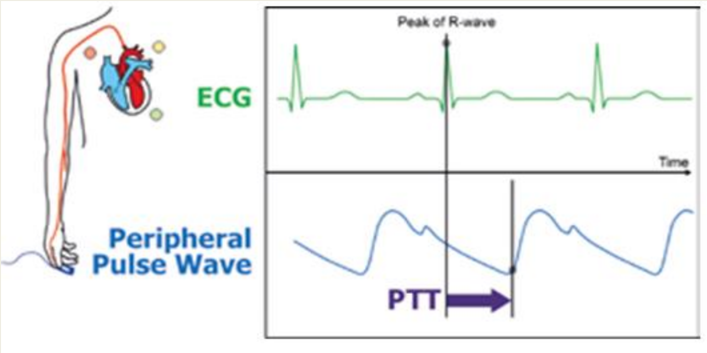
- Vessel like an elastic pipe
- Pulse Wave Velocity (PWV):

$$PWV = \sqrt{\frac{E.t}{2.R.\rho}}$$

  - R: inner radios of vessel
  - ρ: blood density
  - t: vessel thickness
  - E: young's modulus

Physical Background[2]

- $E \propto e^{\alpha P}$
  - α: constant
  - P: blood pressure (BP)



- $PWV = \dfrac{d_{h,p}}{PTT}$
  - $d_{h,p}$: distance from heart to a specific peripheral
  - PTT: Pulse transit time from heart to peripheral

Goal: A Calibration-Free Method

- Challenge: Calibration is needed as its parameters is individual dependent
- Our solution:
  - Extracting features from vital signals
  - Exploiting learning algorithms

Individual Independent

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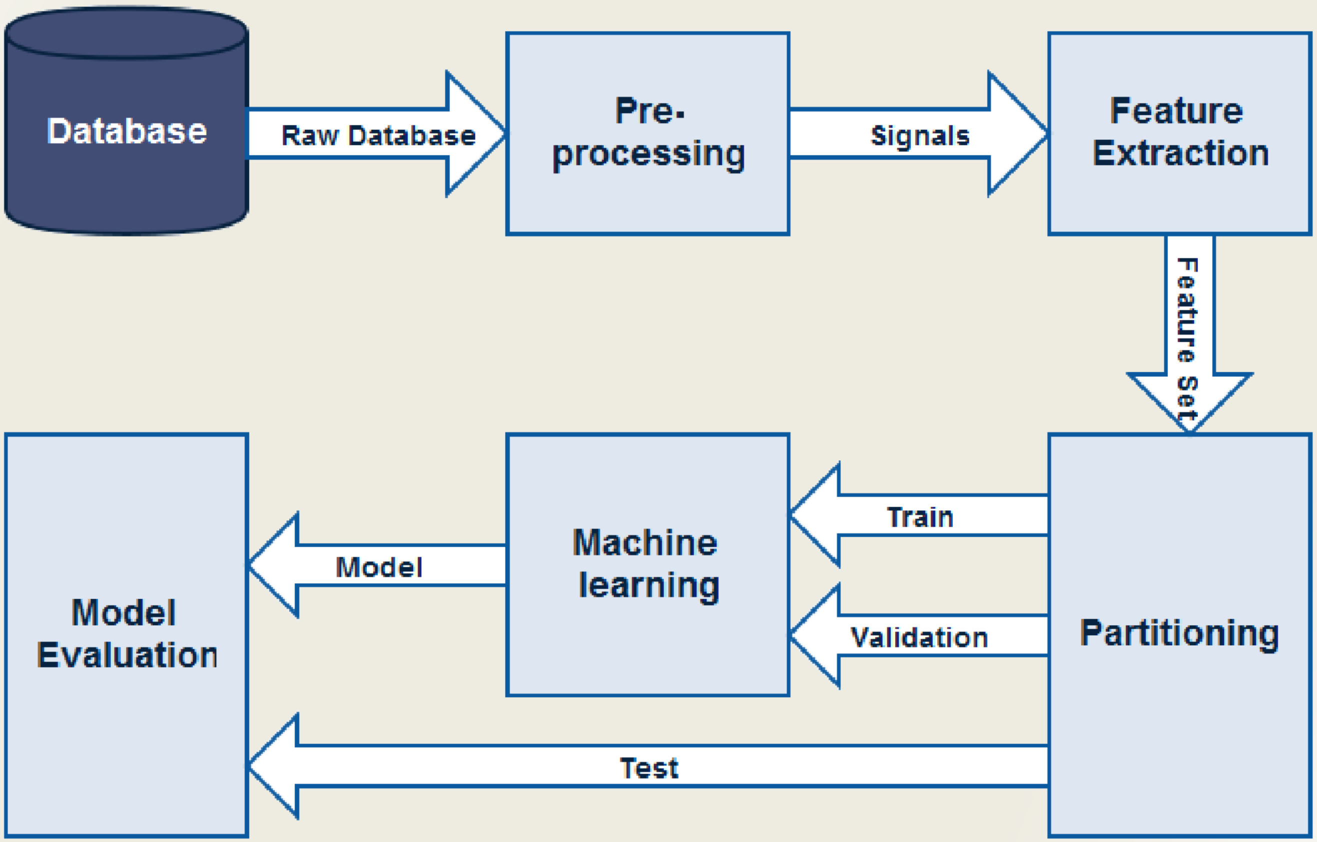
Methodology:



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Methodology

- Database: PhysioNet MIMIC II [3]
  - Thousands vital signals of ICU patient.
  - Sampled at 125 Hz with at least 8 bit accuracy.
- Preprocessing:
  - Step I: Smoothing signals with averaging filter
  - Step II: Removing irregular values (recording error)
  - Step III: Removing unacceptable heart rates
  - Step IV: Removing discontinued signals
  - Step V: Removing highly altered PPG signals

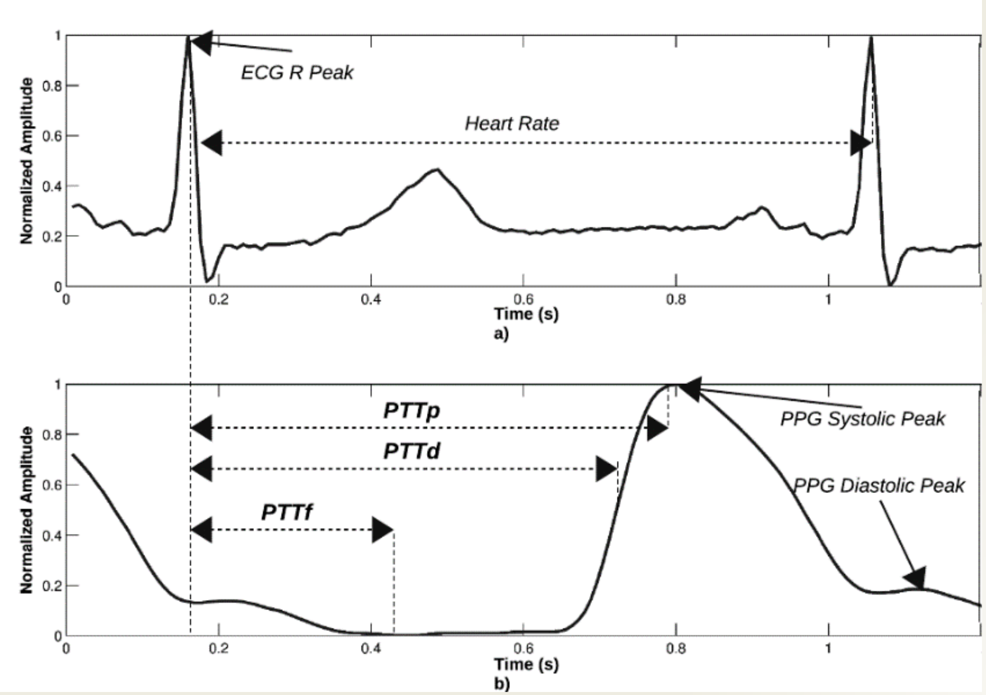
Signals

- Inputs:
  - Electrocardiogram (ECG)
  - Photopletysmograph (PPG)

- Targets:
  - Diastolic blood pressure (DBP)
  - Mean arterial pressure (MAP)
  - Systolic blood pressure (SBP)

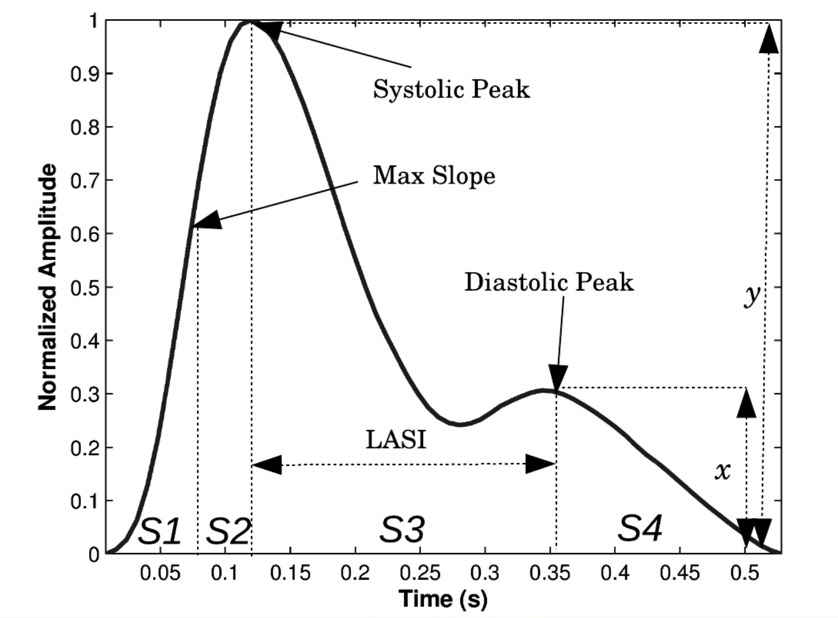
Feature Extraction:

- PTT features:
  - Time between ECG R-peak and PPG (photopletysmograph) points
- Heart rate



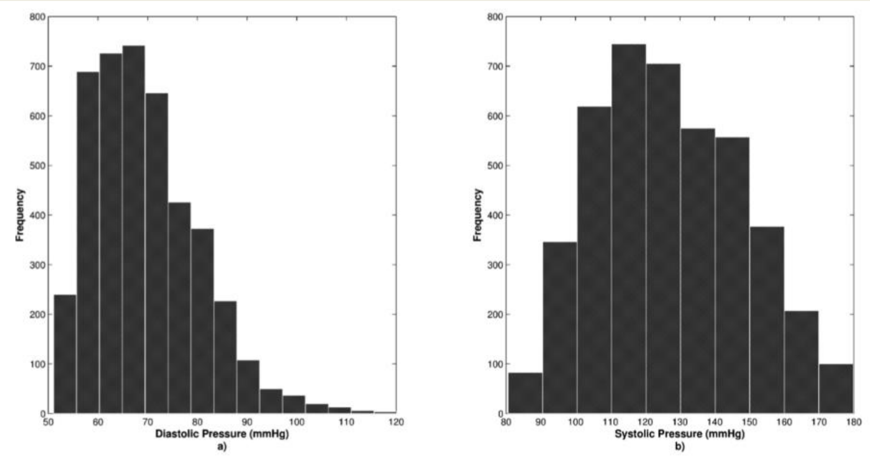
Features Extraction:

- PPG features [4]:
  - AI $= \dfrac{Diastolic\ peak}{Systolic\ peak}$
  - LASI: time between systolic and diastolic peaks
  - Inflection Point Areas: areas under PPG waveform between selected points ($S1, S2, S3, S4$)



Partitioning

- In total 4254 records:
  - 60% as training
  - 20% as validation
  - 20% as test



a) DBP histogram
b) SBP histogram

Machine Learning

- Studied algorithms:
  - Regularized Linear Regression (RLR)
  - Artificial Neural Networks (ANN)
  - Support Vector Machine (SVM)
- Evaluation:
  - Mean Absolute Error (MAE)
  - Standard Deviation (STD)

Results

Algorithm	DP		MAP		SP	
	MAE (mmHg)	STD (mmHg)	MAE (mmHg)	STD (mmHg)	MAE (mmHg)	STD (mmHg)
RLR_{LF}	7.24	9.23	9.34	11.79	14.73	18.47
RLR_{PF}	7.42	10.02	8.50	10.91	14.46	18.17
ANN	6.86	8.96	8.84	11.24	13.78	17.46
SVM	6.34	8.45	7.52	9.54	12.38	16.17

SVM with RBF kernel for better performance in non linearity in higher BP

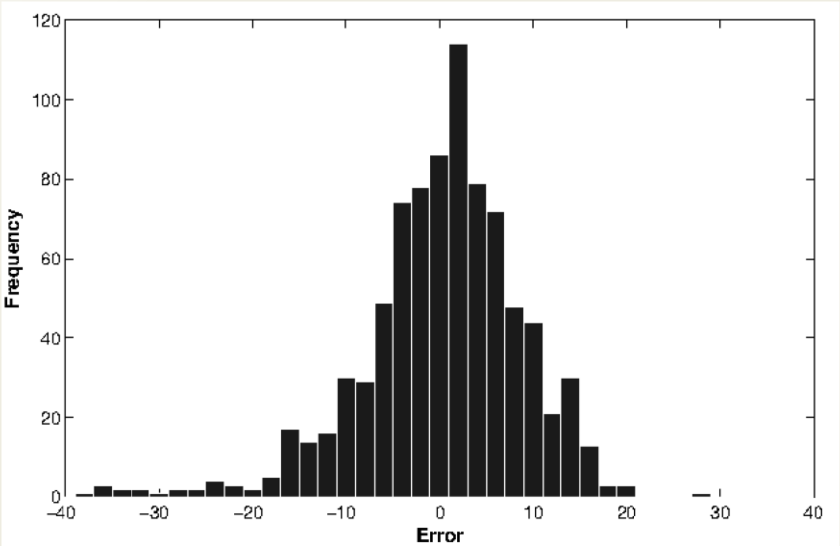
Results (BHS)

- British Hypertension Society (BHS) standard

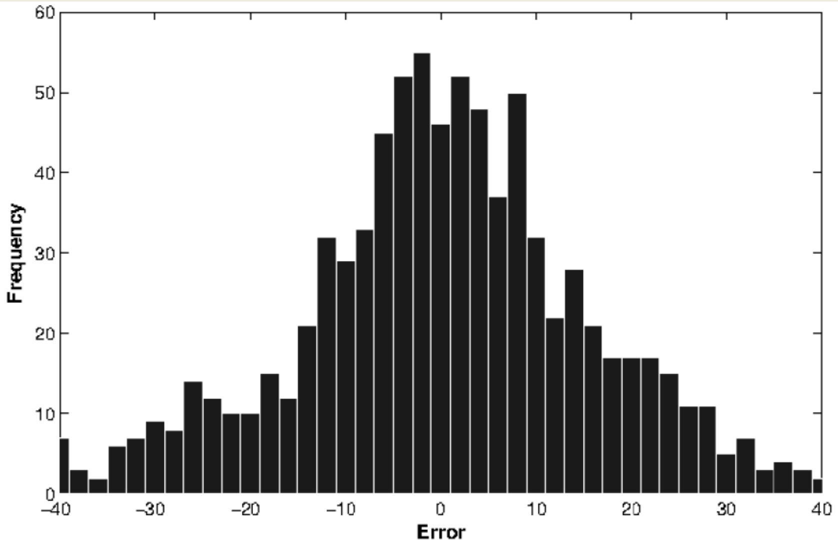
		$\geq 5mmHg$	$\geq 10mmHg$	$\geq 15mmHg$
Our result	Diastolic	51.2%	78.9%	93.6%
	Mean Pressure	44.7%	71.6%	86.7%
	Systolic	28.8%	51.5%	69.5%
BHS	Grade A	60%	85%	95%
	Grade B	50%	75%	90%
	Grade C	40%	65%	85%

Result (histogram)

Histograms of estimation error on 904 subjects:



Diastolic error histogram from SVM



Systolic error histogram from SVM

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Conclusion

- Compared to previous works:
  - Bigger dataset
  - Calibration free
  - Acceptable estimation accuracy
- BP continuous monitoring is reachable with our method
- We established BP estimation model based on physiological parameter and machine learning
- In BHS standard, our system satisfied the grade B in DBP and the grade C in the MAP estimation.

Future work

- Inclusion of additional informative features
  - Age
  - Height
  - Weight
- Implementation of a smart health based on the proposed algorithm

References

[1] World Health Organization, “World Health Statistics 2014”, 2014.

[2] A. Goldberger, L. Amaral, L. Glass, J. Hausdorff, P. Ivanov, R. Mark, J. Mietus, G. Moody, C. Peng and H. Stanley, “Physiobank, physiotoolkit, and physionet components of a new research resource for complex physiologic signals,” Circulation, vol. 101, no. 23, pp. 215–220, 2000.

[3] H. Gesche, D. Grosskurth, G. Kuchler and A. Patzak, “Continuous blood pressure measurement by using the pulse transit time: comparison to a cuff-based method,” European journal of applied physiology, vol. 112, no. 1, pp. 309–315, 2012.

[4] M. Elgendi, “On the analysis of fingertip photoplethysmogram signals,” Current cardiology reviews, vol. 8, no. 1, p. 14, 2012.

Thank you!