SIPL Signal and Image Processing Lab.

THE ANDREW & ERNA VITERBI FACULTY OF ELECTRICAL ENGINEERING

Technion Israel Institute of Technology

Blood Pressure Estimation from PPG Signals

Using Convolutional Neural Networks and Siamese Network

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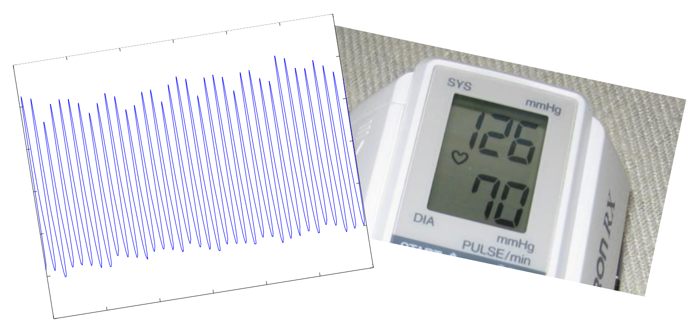
ICASSP2020 Barcelona



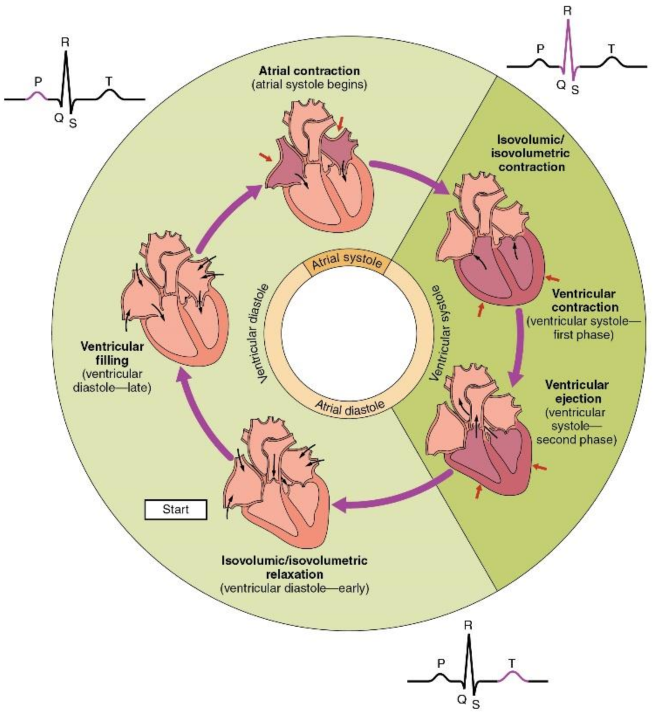
Abstract

- We present two techniques for estimating blood pressure from PPG signals using a Convolutional Neural Network:
  - **First technique:** calibration-free
  - **Second technique:** with respect to the patient's ground truth BP values at calibration time
    - Using Siamese Network
    - More accurate but not always practical
- Accuracy is comparable to the accuracy of many home BP measuring devices

Blood Pressure

- An important parameter of the human body
- Its continuous monitoring allows early detection of medical issues

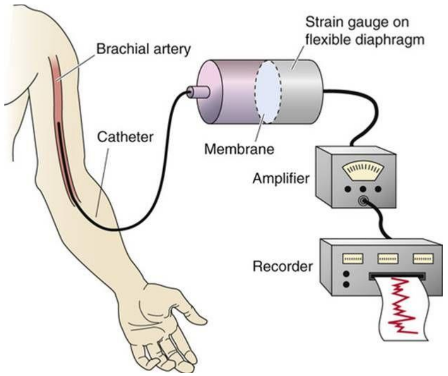
- Normal resting values:
  - Systolic: 120 mmHg
  - Diastolic: 80 mmHg



Courtesy of OpenStax College, Wikimedia

Continuous BP Monitoring

- Invasive
  - A clinical standard (e.g. in ICU)
  - Adverse effects associated with an increased morbidity



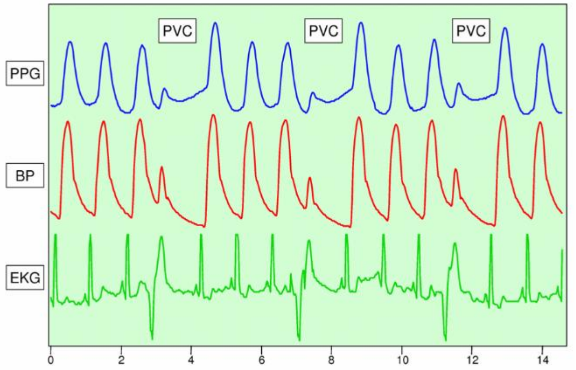
Courtesy of Medical Physiology, 3rd ed. by Boron & Boulpaep, 2016

- Noninvasive
  - Discomfort caused by repeated inflation and deflation
  - Not feasible for long-term monitoring

Courtesy of Администрация Волгоградской области, Wikimedia

Photoplethysmography (PPG)

- An optically obtained signal that can be used to detect blood volume changes
  - Noninvasive
- Contains information on cardiovascular parameters such as BP
  - Has high correlation with BP in both time and frequency domains



Courtesy of Wikipedia

Prior Work

- Most practical approach: Pulse Wave Analysis
  - Use a single PPG sensor

- Many works
  - Extract handcrafted features
  - Use these features along with BP labels to train a regression model
  - Linear regression (Samria et al., 2014), Random forests (Monte-Moreno, 2011), SVM (Zhang & Feng, 2017), ANN (Gaurav et al., 2016)

- Unsatisfactory results

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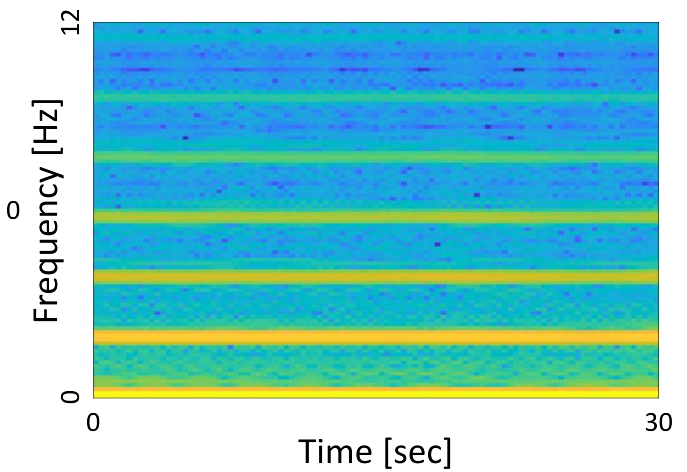
Prior Work

- Several recent works use deep neural networks
  - PPG spectrograms as an input
  - No handcrafted features



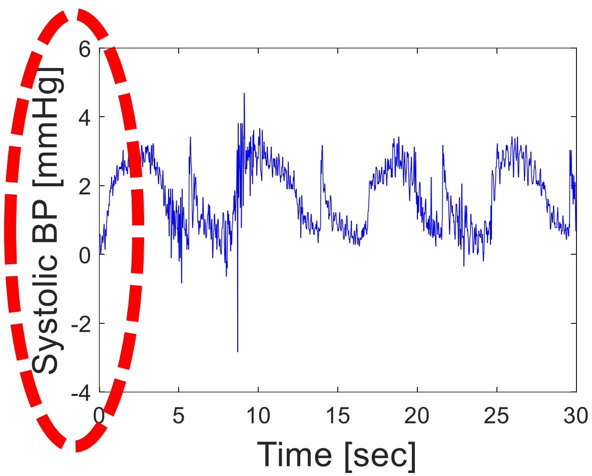
- Sideris, et al., 2016 – trained on a small dataset, difficult to generalize
- Li, et al., 2017 – uses additional calibration data
- Slapničar et al., 2019 – promising but unsatisfactory results

Dataset

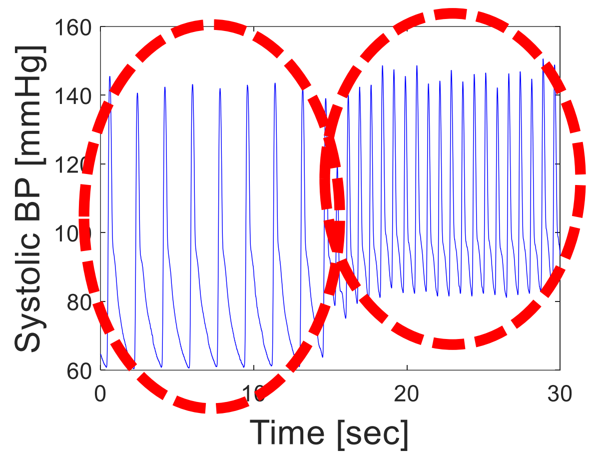
- MIMIC-II database (Saeed et al., 2011)
  - PPG and correspondent arterial BP signals
  - Thousands of patients who stayed within critical care units
- We divided the data into 30-second windows
  - ~2.7 million windows from 1,459 patients
  - ~2.5 years of recordings

Dataset Noise

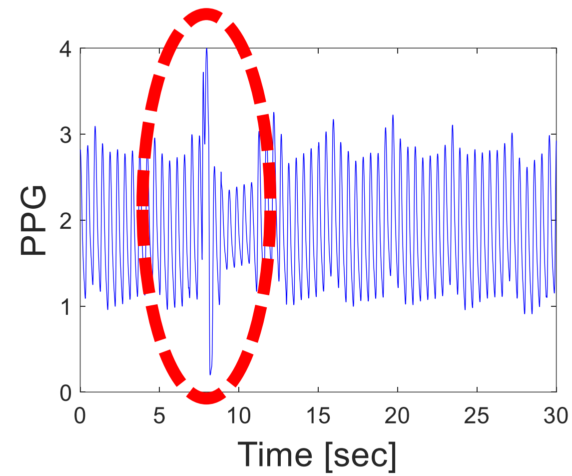
- Signals in this dataset often contain significant artifacts



Physiologically improbable BP values



Fluctuations in BP signal within a 30-second window



Noisy PPG and BP signals

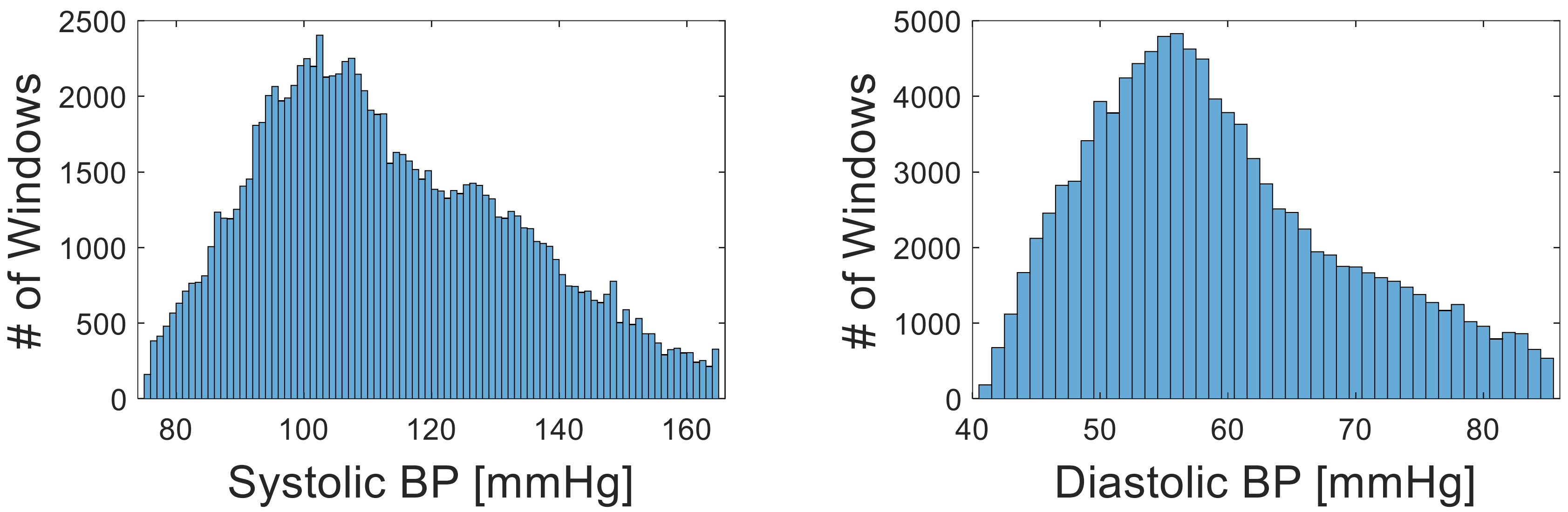
- Strong preprocessing is required

Preprocessing

1. Remove unreliable windows
   – Threshold the energy of the auto-correlation signal
2. Remove unreliable patients and their data
   – Patients which left with less then 100 windows or 5% of their initial data
3. Remove outliers
   – All windows with BP values that vary over ±40 mmHg from the patient's first window

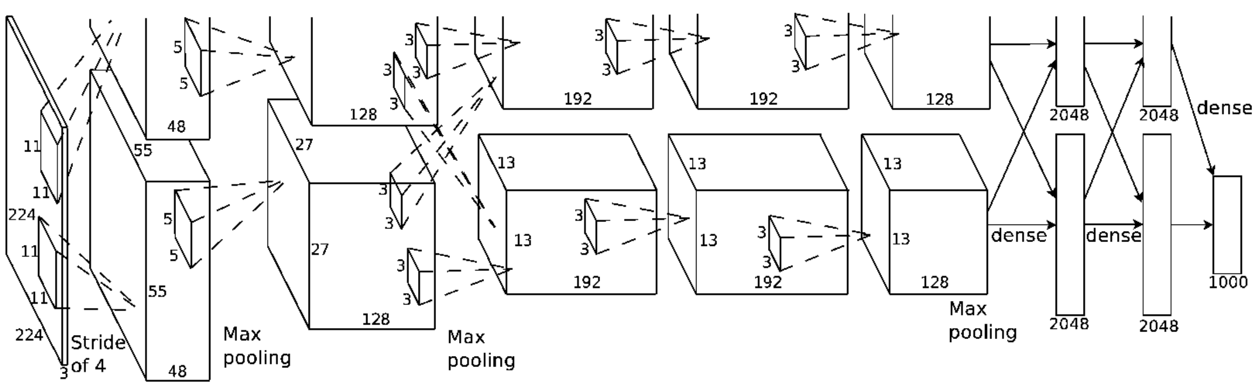
Preprocessed Dataset

- ~10^5 30-second windows from 304 different patients



Calibration-Free BP Estimation

- PPG spectrograms input
- CNN architecture inspired by AlexNet
  - Stronger regularization: added batch normalization layers
  - A regression problem: last fully-connected layer feeds into a linear regression layer
  - L_1-loss: minimizing the MAD of BP estimation accuracy



Courtesy of (Krizhevsky, et al., 2012)

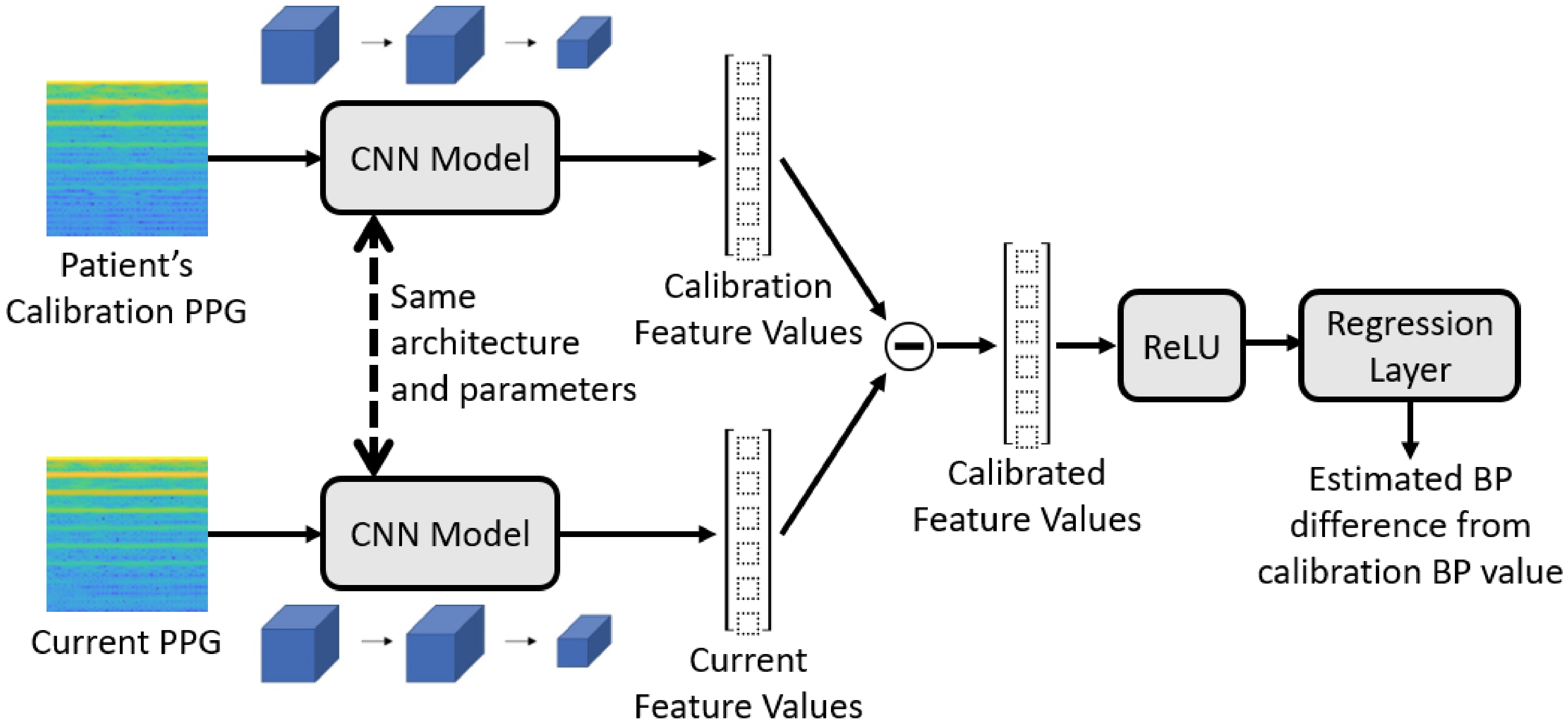
BP Estimation with Calibration

- Per-patient calibration is crucial for accurate BP estimation from PPG
- **Our original contribution:** Calibration using a single, first available 30-second window of PPG signal and its associated BP reading
  - Using a Siamese network architecture

Siamese Network Architecture

- Has been used in other applications
  - Face recognition, signature verification, matching queries with indexed documents and more…
- Contains two identical subnetwork components
  - Use the same architecture and parameters
  - Working in tandem on two different input vectors to compute two output feature vectors
  - Compare the inputs by measuring the distance between the output feature vectors

BP Estimation with Calibration

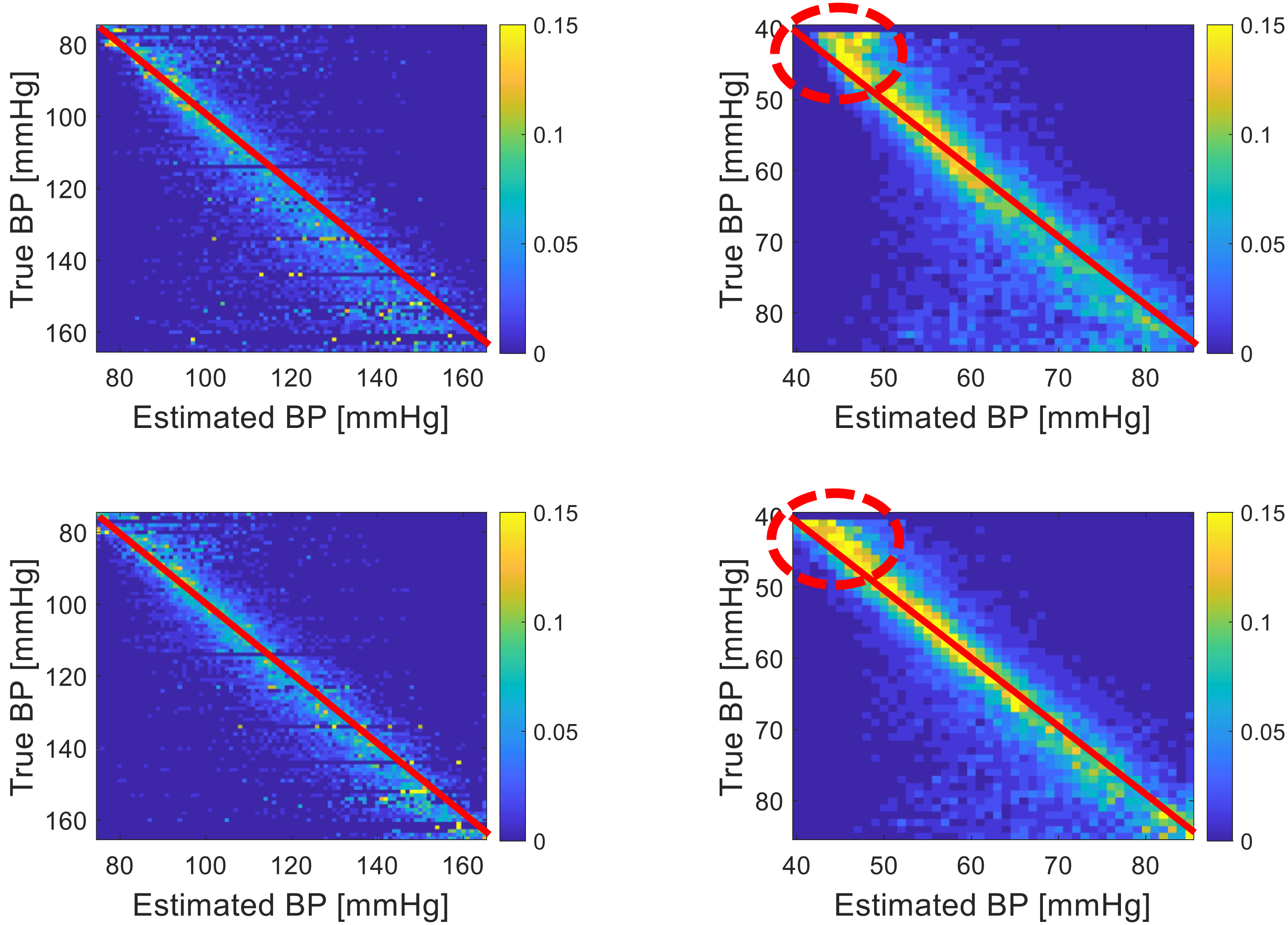


Results

Systolic BP | Diastolic BP

No Calibration

Siamese Network architecture



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Results

	(Šlapničar et al., 2019)	Proposed Calibration-free		Proposed Siamese network	
	MAD [mmHg]	MAD [mmHg]	STD [mmHg]	MAD [mmHg]	STD [mmHg]
Systolic BP	9.43	7.34	8.65	5.95	6.69
Diastolic BP	6.88	3.91	4.48	3.41	3.97

- AAMI recommendation:
  - MAD < 5 mmHg
  - STD < 8 mmHg

Conclusion

- Two techniques for estimating BP from PPG signals using a CNN
- Trained on a large dataset after extensive pre-processing
- **First technique:** calibration-free
  - Meet AAMI requirements for diastolic BP
- **Second technique:** calibration using the patient's single, first available 30-second window
  - Using Siamese Network architecture
  - Meet AAMI requirements for diastolic BP and is very close to meeting them for systolic BP

Conclusion

- Accuracy is comparable to the accuracy of many home BP measuring devices
- Results we obtained are sufficient for many practical medical applications