FlexNIRS-PPG-based Noninvasive Blood Pressure Monitoring with Deep Learning in Neonates

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Background

- **Continuous blood pressure (BP) monitoring is essential** for hyper/hypo-tension diagnosis & management, especially in neonatal intensive care unit (NICU) patients.
- We still require **invasive arterial-line catheter** methods for accurate, continuous BP, but posing risks of:

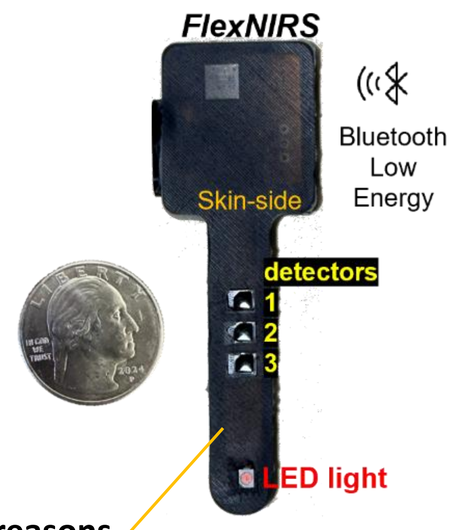
- Hemorrhage	*- Loss of circulation*
- Infection	*- Clot*

- **We present a novel deep learning-based approach for continuous blood pressure prediction using forehead, near-infrared spectroscopy photoplethysmography** (NIRS-PPG):
  - ❑ Data was acquired with our custom-built *FlexNIRS* wearable device and,
  - ❑ Our deep model consists of long, short-term memory and convolutional neural network (LSTM-CNN) architecture, for which
    - ❑ We do not require domain-specific knowledge and hand-crafted feature extraction.

Methods

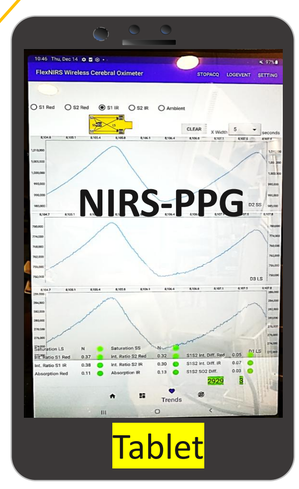
FlexNIRS [Wu et al., 2022]

- 2 wavelengths (760, 850 nm) and 3 photo detectors (19, 25, and 31 mm)
- 320 Hz sampling rate
- 3-axis accelerometer
- Bluetooth Low Energy (BLE 5)
- Medical-grade silicon enclosure
- < $50 parts cost

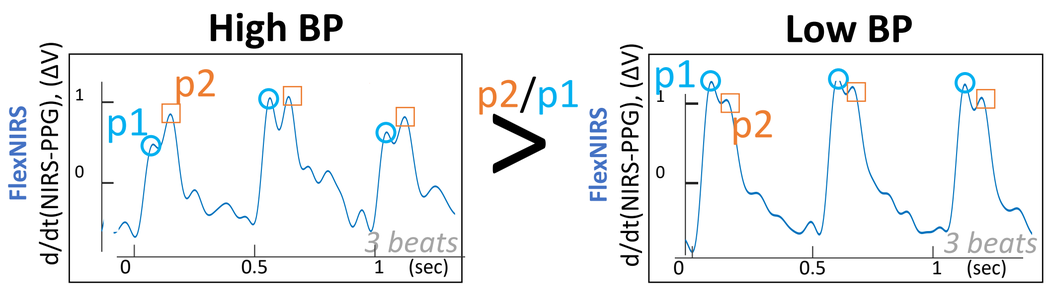


Neonates Enrolled: ≥24 weeks GA and <44 weeks postmenstrual age (PMA) undergoing A-line BP monitoring for clinical reasons





BP-Related Physiologic Markers in d/dt(NIRS-PPG) [Einalou et al., 2025]



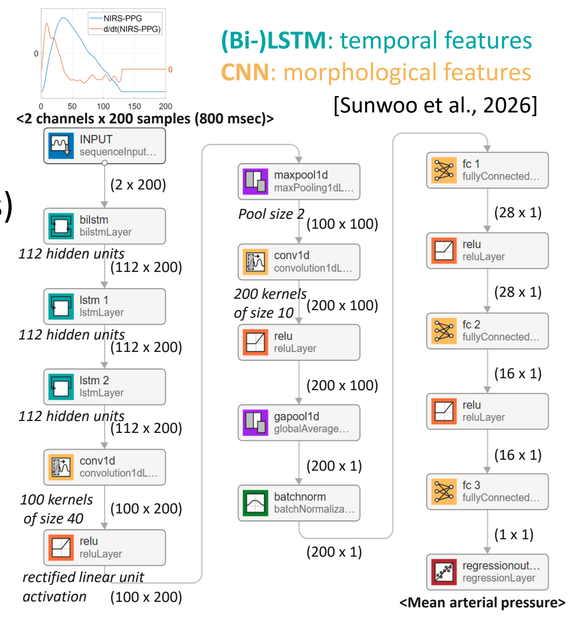
32 weeks gestation preterm infant

Signal Processing and Model Training

- 1.5-25 Hz bandpass filtering
- 4 PPG pulses ensemble averaging
- Individualized, short training period(s) over notable BP changes
- <1 hours of the total 4–8 hours data
- Performance assessment:
- Spearman correlation (r) and mean absolute error (MAE)

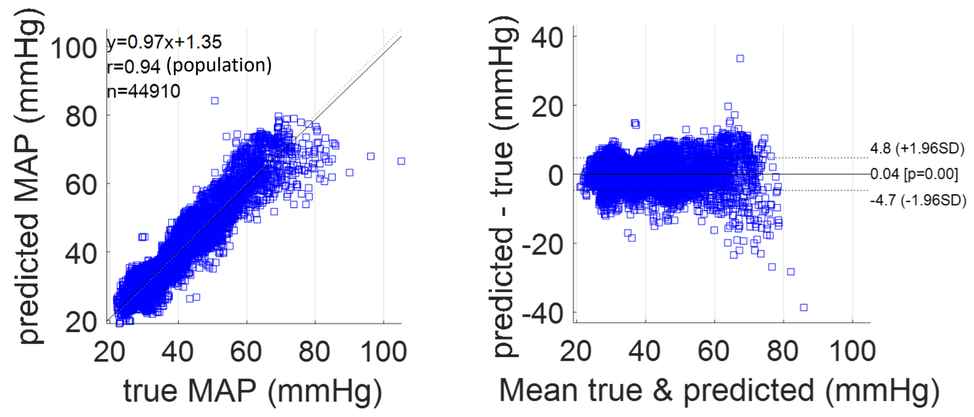
$$\frac{1}{N}\sum_{i=1}^{N}|true - predicted|$$

- MATLAB Deep Learning toolbox with NVIDIA RTX 5000 Ada / A4000 GPUs



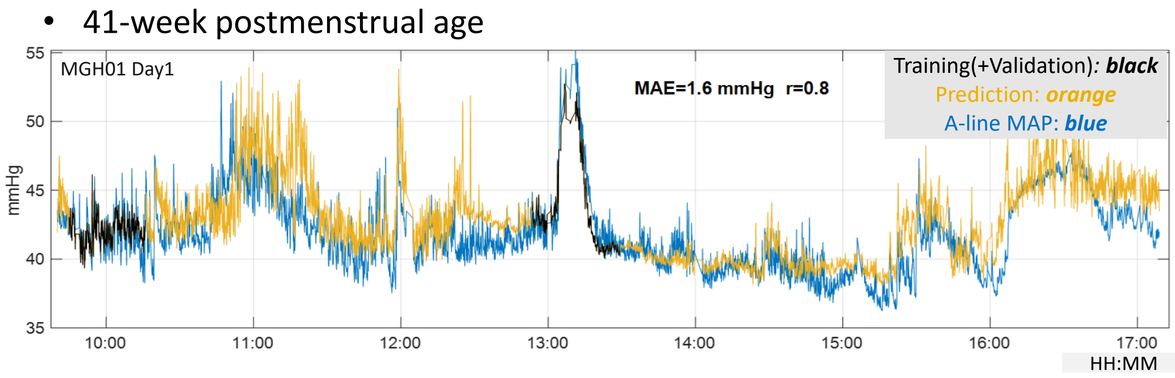
Results

- 16 infants enrolled to date, with ~5 hours of daily recording.
- In 9 subjects (~30.4 weeks PMA; mean arterial pressure ~39.8 mmHg):
  - ❑Average **r** = 0.6 ± 0.1
  - ❑Average **MAE** = 2.0 ± 1.1 mmHg
  - ❑Limit of Agreement (**LoA**) = ± 4.75 mmHg

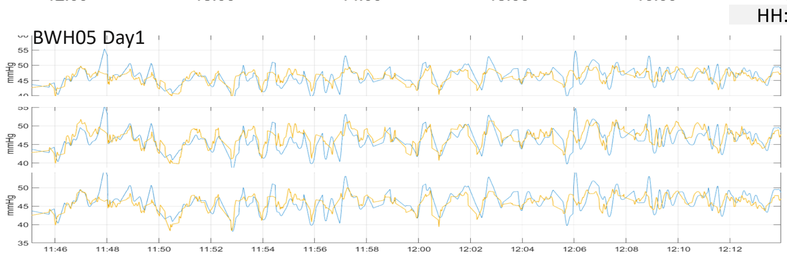


One Patient Example of Model Estimation

- Model trained from scratch: 1-hour training over 8-hour recording
- 19 mm source-detector, 850 nm input
- 41-week postmenstrual age



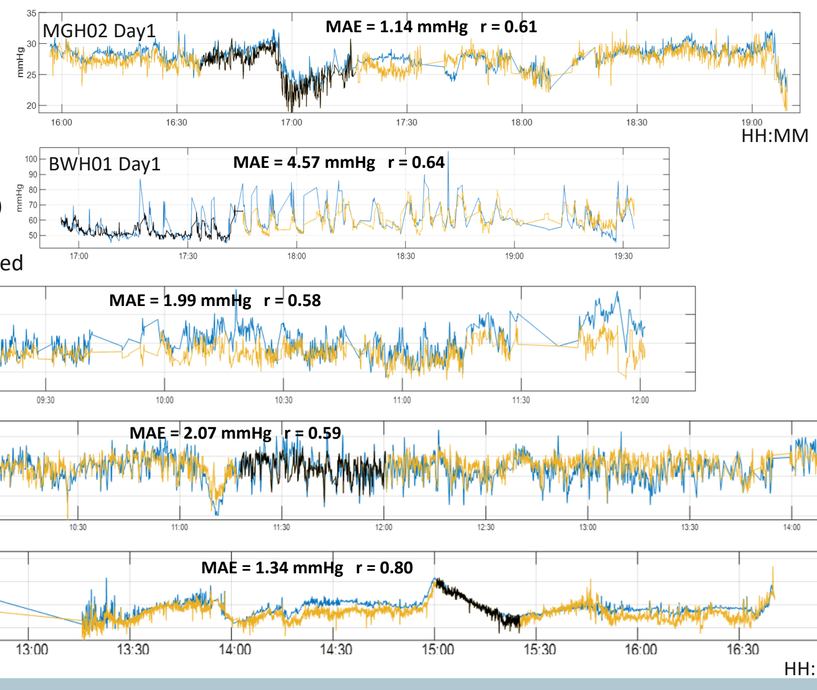
~30 minutes zoom-in example



Other cases

Training(+Validation): ***black***
Prediction: ***orange***
A-line MAP: ***blue***

- <1 hour of training/subject from scratch
- 25 mm source-detector, 850 nm input
- Correlation could be improved



Discussion and Conclusions

***FlexNIRS*-PPG showed feasibility for noninvasive BP monitoring in neonates**

- Active recruitment & model refinement are underway.
- Challenges
  - ❑ Sensor contact and thus signal quality is poor in small preterm infants.
  - ❑ Signal interference from existing, clinically deployed cerebral oximeter.
- Work-In-Progress / Questions
  - ❑ Performance between the source-detector distances?
    - No advantage has been seen (Presentation by Animesh Giri: *Optimizing Source–Detector Distances in Near-Infrared Spectroscopy for Noninvasive Neonatal Blood Pressure Monitoring*).
  - ❑ Cuff-BP measurements (every ~30-60 minutes) instead of A-line data?
- Future directions
  - Attention-based transformers to eliminate PPG input segmentation.
  - Global model makes more sense than individualized models.
  - Real-time, on-board processing and display of blood pressure estimates.

References & Acknowledgement

1. Wu, K. C. et al. *Open-source FlexNIRS: A low-cost, wireless and wearable cerebral health tracker*. Neuroimage 256, 119216 (2022).
2. Einalou, Z. et al. *Noninvasive continuous blood pressure prediction using FlexNIRS and machine learning during carotid endarterectomy*. J Biomed Opt (2025).
3. Sunwoo, J. et al. *Continuous, noninvasive blood pressure estimation using forehead NIRS-PPG and LSTM-CNN deep learning*. Biomed Sig. Proc. Contr. (2026).

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