Optimizing Source–Detector Distance in Near-Infrared Spectroscopy for Noninvasive Neonatal Blood Pressure Monitoring

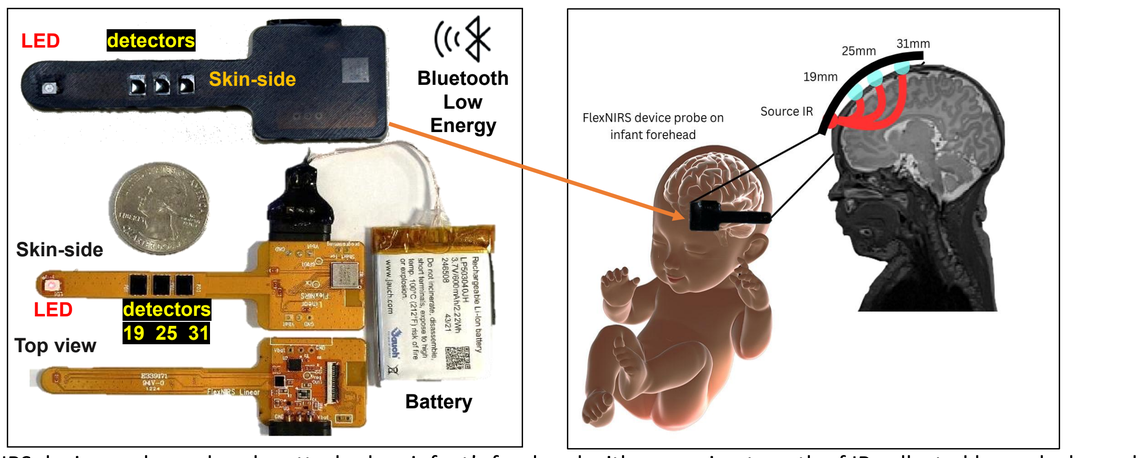
Animesh Giri[1], Ceilidh Smith[1], Julia Davis[1], Tina Steele[1], Myrene Johnson[1], Deborah Cuddyer[1], Marco Renna[2,3], Zachary Starkweather[2], Hoda El-Shibiny[1], Maria Angela Franceschini[2,3], Emily Herzberg[1,2], Mohamed El-Dib[1,2], and John Sunwoo[1,2,3]

1 Division of Newborn Medicine, Department of Pediatrics, Mass General Brigham for Children, Boston, MA, USA; 2 Harvard Medical School, Boston, MA, USA; 3 Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA, USA

Background

- Continuous BP monitoring in neonates is invasive and intermittent.
- **FlexNIRS** is a wearable, wireless LED-based NIRS system that acquires continuous NIRS-PPG signals, which can be used for **BP prediction** via a deep learning model.
- For infants, signals are acquired at **three source–detector separations (SDS): 19, 25, and 31 mm**, probing superficial to deeper tissue layers (Figure 1).
- Optimal SDS selection may enable **probe miniaturization and reduced power consumption** without loss of accuracy.

Figure 1. FlexNIRS on infants



FlexNIRS device probe and probe attached on infant's forehead with approximate path of IR collected by each channel

Objective

- To evaluate whether **superficial vs deeper NIRS-PPG signals** differ in:
  - Signal quality
  - Motion robustness
  - MAP prediction accuracy

Methods

- **Population:** 10 MGB NICU infants with arterial line monitoring, contributing 17 cumulative patient-days of data, with ~3–4 hours of recording per day.
- **Data Acquisition:** Simultaneous FlexNIRS-PPG recordings at 19, 25, and 31 mm source–detector separations, alongside arterial line(A-line) MAP.
- **Preprocessing:** Resampled to 250 Hz; bandpass filtered at 1.5–25 Hz; motion artifact rejection applied.
- **Modeling:** CNN combined with bidirectional LSTM; 20 random trials per SDS per subject to assess robustness.
- **Evaluation:** Metrics defined in Table 1 include signal quality, prediction accuracy, temporal agreement, and model robustness.

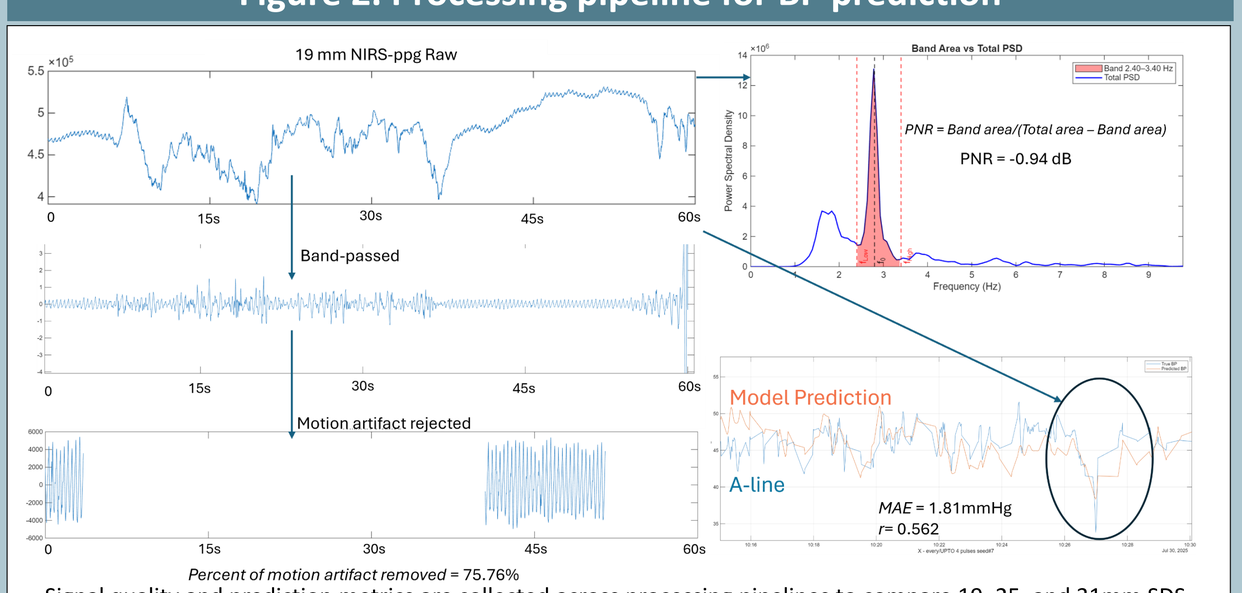
(Figure 2 represents a sample processing pipeline to perform preprocessing, modeling and evaluation.)

Table 1. Signal Quality and Prediction Metrics

Metric	Definition	Purpose
Motion Rejection (%NaNs)	Percentage of samples set to NaN after motion artifact rejection	Data Quality
Pulse-to-Noise Ratio (PNR, dB)	Ratio of pulsatile signal power to noise power	Signal Quality
Mean Absolute Error (MAE, mmHg)	Mean of Absolute Error across true and predicted values	Average magnitude of prediction error
Pearson correlation (r)	Linear correlation between predicted and arterial MAP	Temporal agreement
Coefficient of Determination (R^2, %)	Percentage of variance in arterial MAP explained by prediction	Goodness-of-fit
Model Failure Rate (%)	Percentage of predictions failing *QC thresholds	Model robustness

***QC thresholds:** MAE > Q3 + 1.5×IQR; R^2 < Q1 − 1.5×IQR; |r| < 0.1 (25 mm SDS reference).

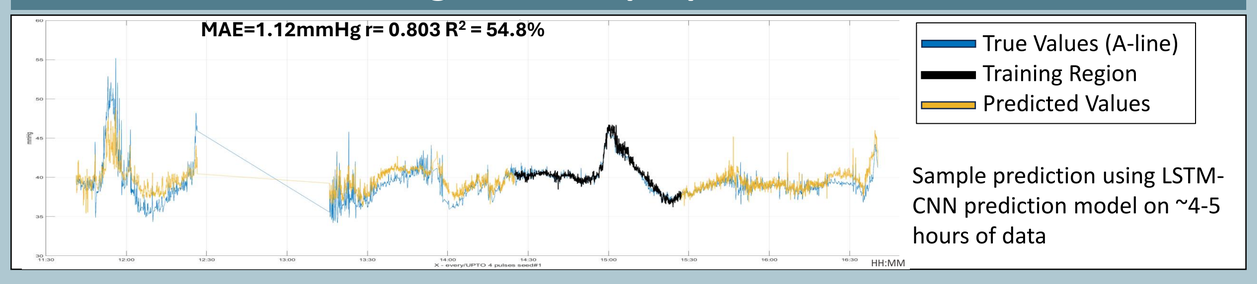
Figure 2. Processing pipeline for BP prediction



Percent of motion artifact removed = 75.76%

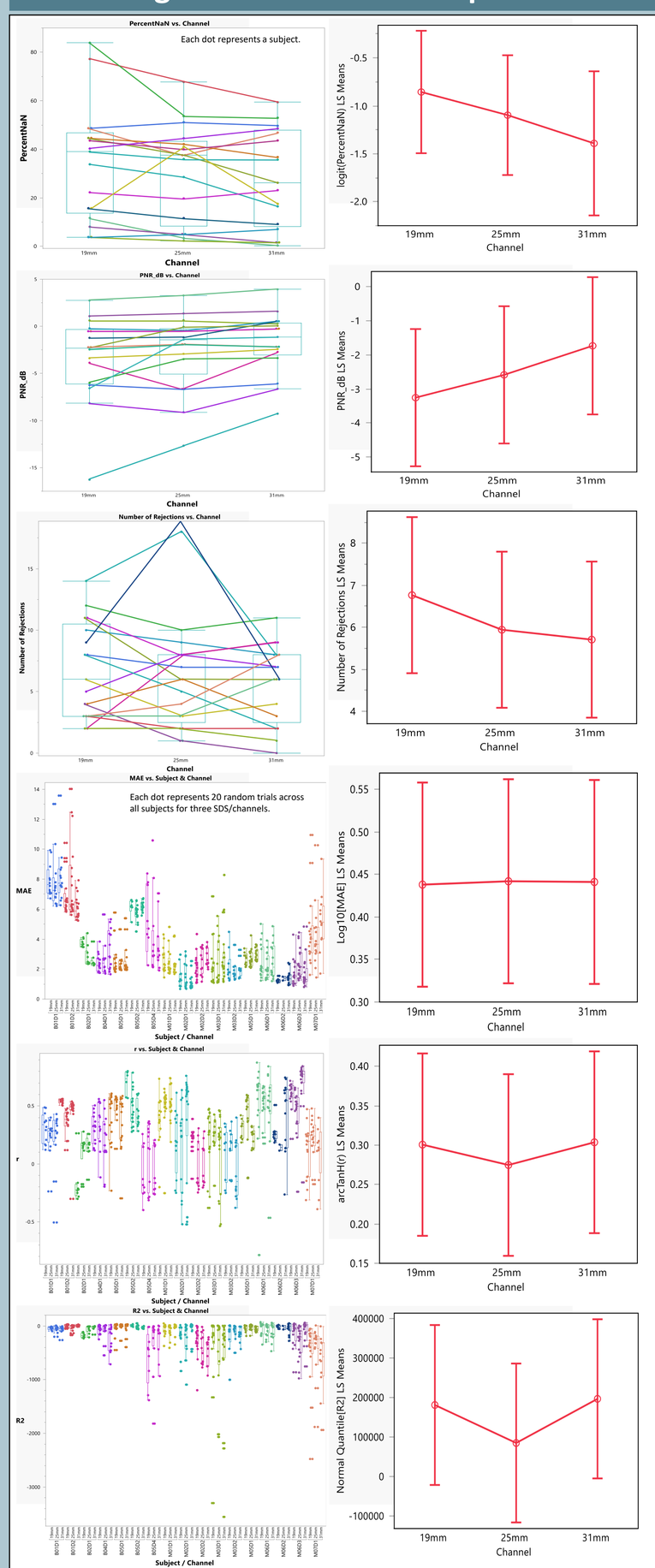
Signal quality and prediction metrics are collected across processing pipelines to compare 19, 25, and 31mm SDS.

Figure 3. Sample prediction



Sample prediction using LSTM-CNN prediction model on ~4-5 hours of data

Figure 4. Statistical comparison across the three channels



Comparison based on PercentNaN(%NaNs)
19mm vs 25mm: p = 0.3243
19mm vs 31mm: p = 0.0077*
25mm vs 31mm: p = 0.1932

Significant difference between 19mm and 31mm channels based on %NaNs (p<0.05)

Comparison based on PNR_dB

19mm vs 25mm: p = 0.3115
19mm vs 31mm: p = 0.0054*
25mm vs 31mm: p = 0.1577

Significant difference between 19mm and 31mm channels based on PNR_dB (p<0.05)

Comparison based on Number of Rejections

19mm vs 25mm: p = 0.7201
19mm vs 31mm: p = 0.5835
25mm vs 31mm: p = 0.9733

No significant difference between any channel pairs

Comparison based on MAE

19mm vs 25mm: p = 0.9613
19mm vs 31mm: p = 0.9750
25mm vs 31mm: p = 0.9982

No significant difference between any channel pairs

Comparison based on r

19mm vs 25mm: p = 0.1212
19mm vs 31mm: p = 0.9791
25mm vs 31mm: p = 0.1654

No significant difference between any channel pairs

Comparison based on R^2

19mm vs 25mm: p = 0.8894
19mm vs 31mm: p = 0.9945
25mm vs 31mm: p = 0.9270

No significant difference between any channel pairs

Each dot represents values for all subjects for the three SDS/channels in plots for %NaNs, PNR_dB, Number of Rejections. Dots in prediction metrics plot represent 20 random trials across all subjects for three SDS/channels.

Results

Statistical analysis across 10 subjects over 17 cumulative patient-days using pairwise comparison Tukey-HSD test showed:

- Statistical difference between 19mm and 31mm SDS for %NaNs and PNR (*p<0.05).
- No statistical difference between 19, 25, and 31mm SDS in MAE, r, R^2, and Model Failure Rate.

Discussion

- Signal quality shows differences between 19 mm and 31 mm SDS, but prediction metrics were similar across all channels.
- Findings suggest that BP estimation may not strongly depend on source–detector separation.
- If these trends hold with larger enrollment, it may be feasible to prioritize shorter SDS for probe design for BP estimation.
- Ongoing data collection will help clarify whether performance is consistent across depths.

References

1. Sunwoo J. et al., *Continuous, noninvasive blood pressure estimation using forehead NIRS-PPG and LSTM-CNN deep learning*, **Biomed. Signal Process. Control**, 113, 108943 (2026).
2. Wu, K. C. et al. *Open-source FlexNIRS: A low-cost, wireless and wearable cerebral health tracker.* Neuroimage 256, 119216 (2022).

This work was supported by National Institutes of Health Grant R21HD117308