CPS: Small: Inkjet Printed Flexible Electronic CPS with Context-aware Events of Interest Detection

2024 NSF CYBER-PHYSICAL SYSTEMS PRINCIPAL INVESTIGATORS' MEETING

Team: Bashir I. Morshed[1], Tomoko Fujiwara[2], Frank Andrasik[3], Robert Hewitt[4], Rajesh Kabra[5], Mamunur Rahman[6]

Students: Mst M. R. Momota[1], Tamanna Ferdous[2], Mahfuzur Rahman[1], I Hua Tsai[1]

[1]Computer Science Department, Texas Tech University (TTU); [2]Chemistry Department, University of Memphis (UM); [3]Department of Psychology, UM;

[4]Engineering Technology Department, UM; [5]Cardiology, University of Tennessee Health Science Center (UTHSC); [6]Emergency Department, Baptist Minor Medical Center

CPS Challenges:

- The next generation of CPS incorporating trillions of sensors will need to:
  - utilize resilient and reliable cyber-physical interfacing, while being economically viable
  - process this large data automatically and reliably for real-time event monitoring at smart edge devices that are ever more popular, affordable, and pervasive
- Seamless integration of computation and physical domains along with meaningful interpretation of multimodal and multigrain data of scalable CPS remain major technological barriers.

Proposed Objectives:

- The overriding aim is to develop a novel CPS interface using additive inkjet printing (IJP) to produce low-cost flexible thin-film electronics and new AI algorithms (Fig. 1) for context-aware detection of events with data reliability metrics for closed-loop CPS using real-time machine learning implemented at edge (Fig. 2).
- The project has three objectives:
  1) To create foundational engineering process for CPS interface with thin-film flexible electronic electrodes and sensors fabricated with IJP manufacturing
  2) To develop new algorithms for autonomous processing of sensor data to detect context-aware events of interest and data reliability metric
  3) To deploy CPS practice components for a real-life pilot study to explore detection of cardiac episodes and various closed loop feedback approaches

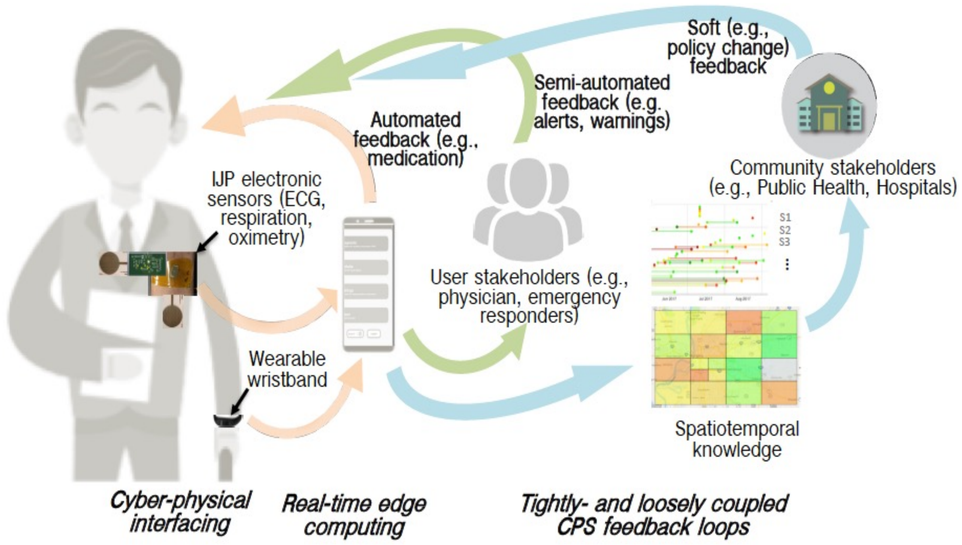


Figure 1: The proposed CPS architecture with practice components.

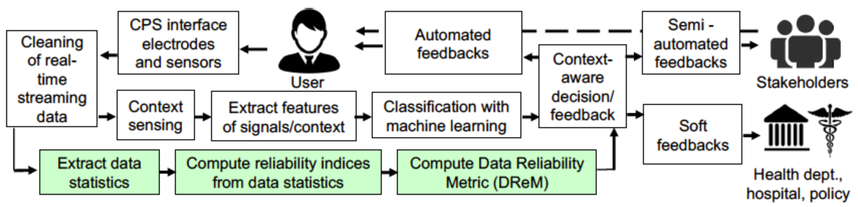
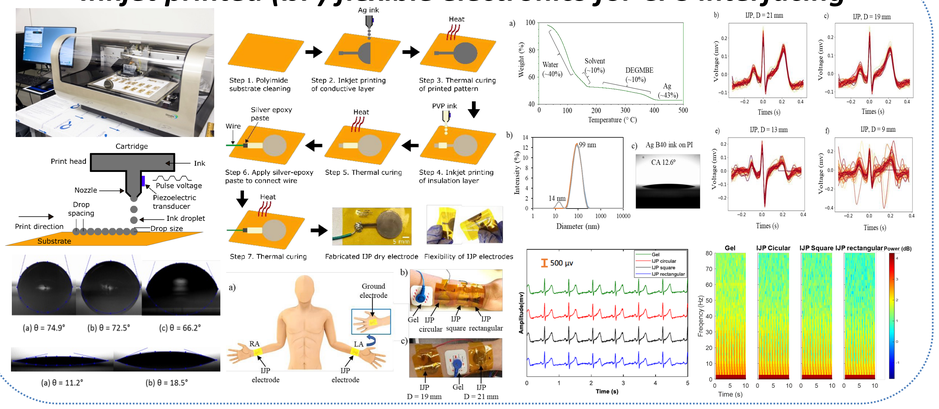


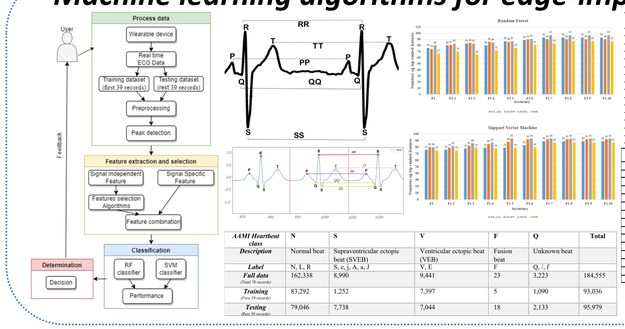
Figure 2: Proposed context-aware event detection with DReM

Summary of progress and key results:

Inkjet printed (IJP) flexible electronics for CPS interfacing



Machine learning algorithms for edge-implementation



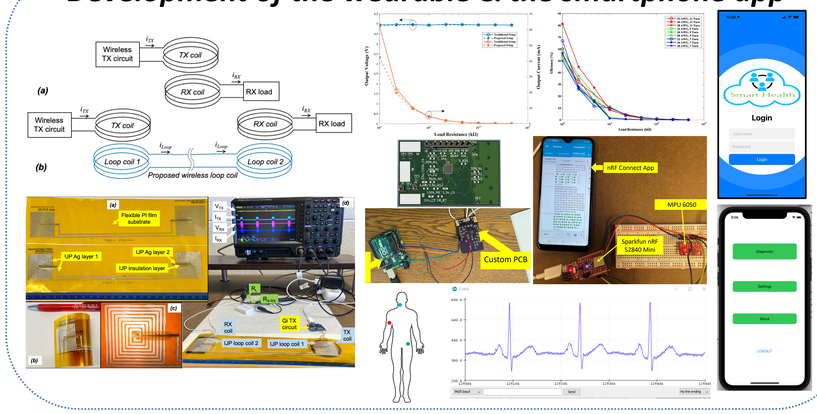
Pati ent	SVM (%)	KNN (%)	Ensemble Tree (%)	Neural Network (%)	Decision Tree (%)	Naïve Bayes (%)	Logistic Regression (%)
1	99.1	93.6	99.1	99.9	99.5	98.6	99.6
2	98.1	99.0	94.5	96.3	93.7	91.7	98.7
3	95.0	95.7	94.7	96.6	94.6	96.8	93.8
4	94.7	97.3	95.8	94.1	99.8	98.4	94.2
5	99.0	99.3	94.2	96.8	95.8	98.7	95.2
6	94.3	99.9	95.7	95.7	99.9	96.2	95.0
7	97.3	97.5	97.7	99.0	94.5	93.7	99.6
8	95.7	94.5	99.5	94.7	98.7	95.7	97.1
9	99.2	98.7	96.9	95.7	97.7	93.6	95.7
10	96.9	97.1	99.8	94.5	99.1	96.9	99.8
11	99.2	99.1	93.6	97.2	97.1	94.6	97.9
12	95.0	97.3	97.7	95.7	94.7	94.7	99.0
13	94.5	96.5	94.1	97.2	95.9	99.5	97.1
14	96.6	99.9	94.5	99.6	97.7	99.9	94.7
15	95.7	98.7	95.6	99.8	98.7	94.1	95.7

Pati ent	Sensitivity (%)	Specificity (%)	Accuracy (%)	Precision (%)	F1 Score (%)
1	94.1	99.8	97.88	99.6	96.97
2	95.2	97.5	96.23	98.7	97.26
3	93.7	98.7	95.78	99.5	98.37
4	94.5	99.2	98.42	96.9	94.65
5	96.2	96.8	97.37	97.3	94.91
6	94.6	99.7	95.07	99.8	98.57
7	94.9	97.9	97.12	97.7	99.64
8	95.3	99.0	96.25	98.2	97.93
9	94.1	96.6	97.98	94.5	95.75
10	93.0	95.7	98.57	95.6	93.70
11	96.7	97.8	96.50	96.4	97.67
12	97.8	94.5	96.34	97.3	96.24
13	95.0	93.9	98.21	94.7	96.64
14	94.2	97.0	97.69	95.8	94.71
15	94.6	99.8	96.98	99.0	96.88

Patient	Sensitivity (%)	Specificity (%)	Accuracy (%)	Precision (%)	F1 Score (%)
All	98.2	99.1	98.64	99.3	99.42

AAMI Heartbeat class	N	S	V	F	Q	Total
Description	Normal beat	Supraventricular ectopic beat (SVEB)	Ventricular ectopic beat (VEB)	Fusion beat	Unknown beat	
Label	N, L, R	S, e, j, A, a, J	V, E	F	Q, / , f	
Full data (Total 70 records)	162,338	8,990	9,441	23	3,223	184,555
Training (First 39 records)	83,292	1,252	7,397	5	1,090	93,036
Testing (Rest 39 records)	79,046	7,738	7,044	18	2,133	95,979

Development of the wearable & the smartphone app



Innovation, Significance, and Impact:

- Flexible IJP thin-film multilayer sensors for CPS interfaces.
- Real-time algorithm for **D**ata **Re**liability **M**etric (DReM) computed from the statistics of streaming data itself.
- Context aware episode detection with machine learning.
- Impacts will extend beyond wearables and medical devices to a host of systems that involve closed-loop feedbacks with sensors and automated data processing.

Broadening Participation in Computing (BPC):

- Developed ten 2-hr synchronous-asynchronous modules for a 2-week-long Virtual Code Camp (VCC)
- This free-to-enroll program was offered in June 2022 to a cohort of 22 high school students from Texas & Tennessee

Award ID#: **CNS-2105766** **Project Duration: Jan. 2020 - Dec. 2024**

Project portal: http://myweb.ttu.edu/bmorshed/NSF_CPS.html