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Neuromorphic AI-Based e-Skin for Emotion-Sensitive Humanoid Robots

Naseer Batt[1], Shubham Gupta[2], Suhaib Ahmed[3]

[1]MAI Monetization Engineering, Microsoft, Redmond, WA 98007, United States of America
[2]Department of Computer Science and Engineering, Model Institute of Engineering and Technology, Jammu 181122, Jammu and Kashmir, India
[3]Centre for Research, Innovation and Entrepreneurship, Model Institute of Engineering and Technology, Jammu 181122, Jammu and Kashmir, India

INTRODUCTION & AIM

Humanoid robots require the ability to perceive emotional cues through touch to achieve natural and socially intelligent interaction. Existing tactile sensors detect only force or pressure, lacking emotional awareness and context interpretation. Neuromorphic computing, especially Spiking Neural Networks (SNNs), provides a biologically inspired pathway for real-time emotion perception with ultra-low power usage. This work introduces a multimodal electronic skin (e-skin) integrating pressure, temperature, and electrostatic sensing with an SNN-based neuromorphic pipeline to enable emotion-sensitive touch processing in humanoid robots.

🩹 Multimodal E-Skin + 🧠 Neuromorphic SNN
= 🤖 Emotion-Aware Humanoid Robots

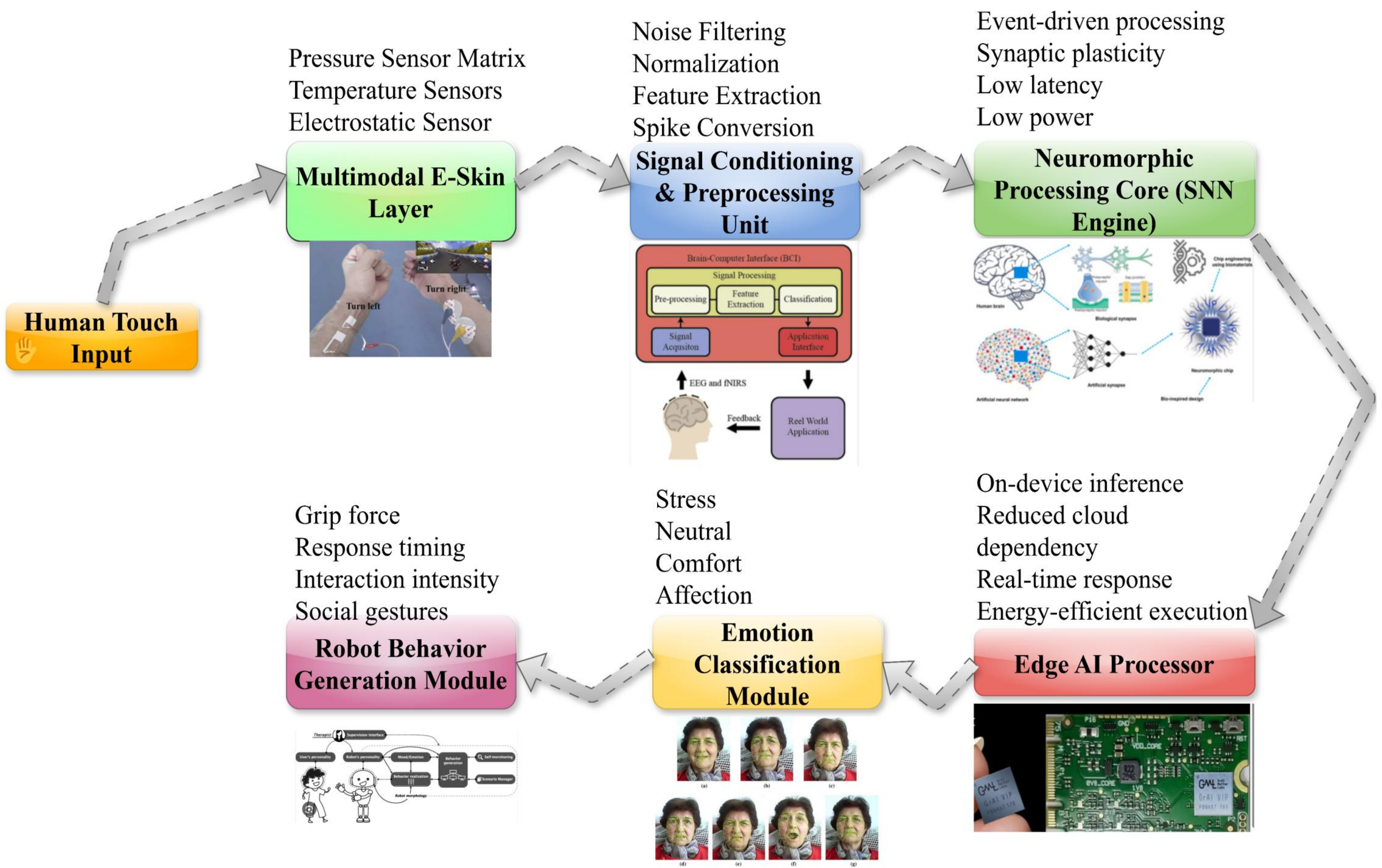
AIM: To design and implement a neuromorphic AI-driven multimodal e-skin that enables humanoid robots to sense, interpret, and respond to human emotional states through touch using real-time, low-power SNN processing.

🧠 NEUROMORPHIC ADVANTAGES (SNN-BASED)

- ⚡ **Event-Driven Spike Processing**
- 🔋 **Ultra-Low Power (Edge Ready)**
- 🚀 **Real-Time Emotion Interpretation**
- 🤖 **Ideal for Embedded Humanoid Systems**

METHOD

The system integrates a multimodal electronic skin composed of high-resolution pressure sensors, temperature sensors, and electrostatic detectors to capture complex tactile and emotional cues. Sensor outputs undergo noise filtering, normalization, and feature extraction before conversion into spike trains using bio-inspired spike encoding. These spike sequences are processed by a lightweight Spiking Neural Network (SNN) that performs event-driven, low-power computation for real-time emotion recognition.



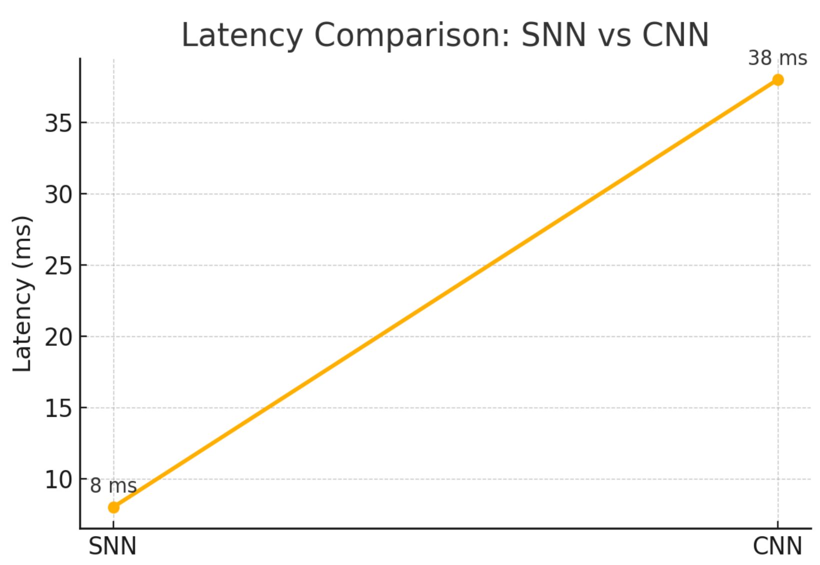
Experimental Setup: The e-skin prototype was mounted on a humanoid robot arm and tested using controlled tactile interactions pressing, holding, stroking, and thermal stimuli, across multiple human subjects.

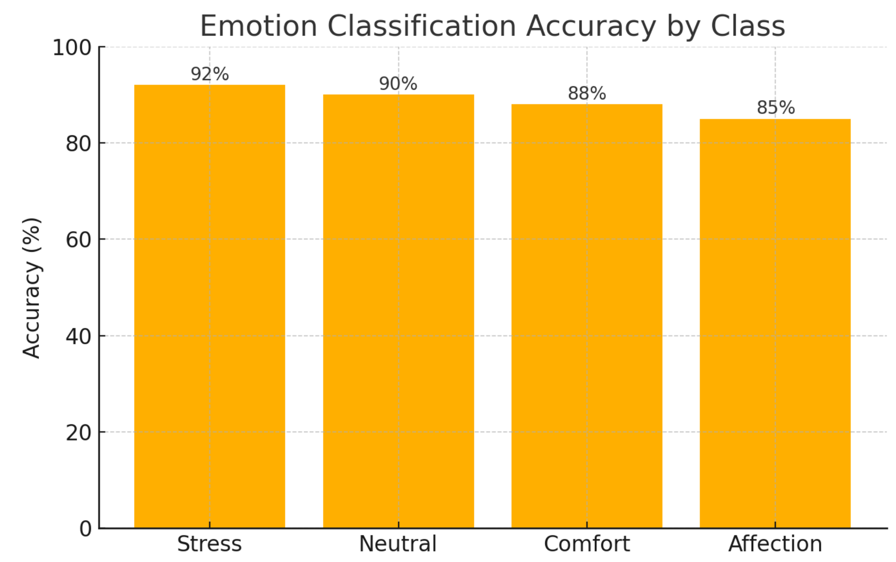
Data Collection: A multimodal tactile dataset was created by recording synchronized pressure, temperature, and electrostatic signals with corresponding emotional labels (stress, neutral, comfort, affection).

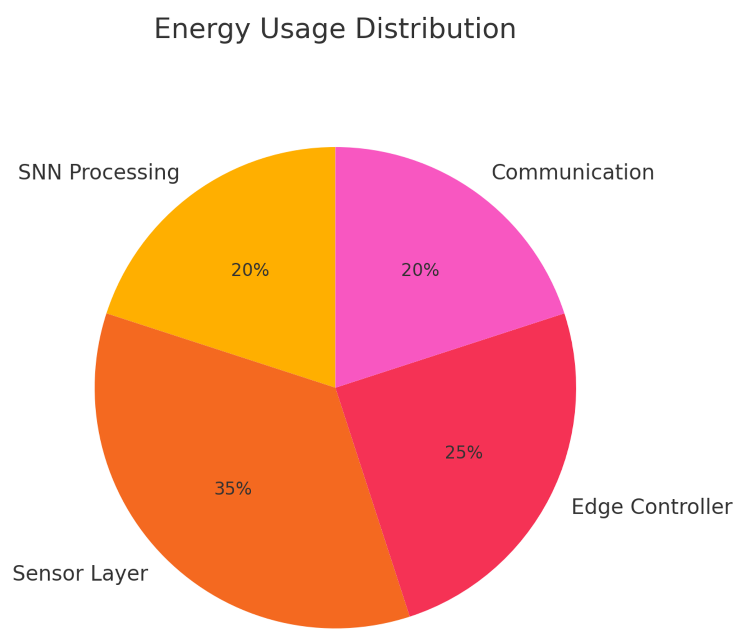
System Integration: All sensing and neuromorphic inference modules were deployed on an edge AI unit, enabling real-time emotion-sensitive behavior on the humanoid robot.

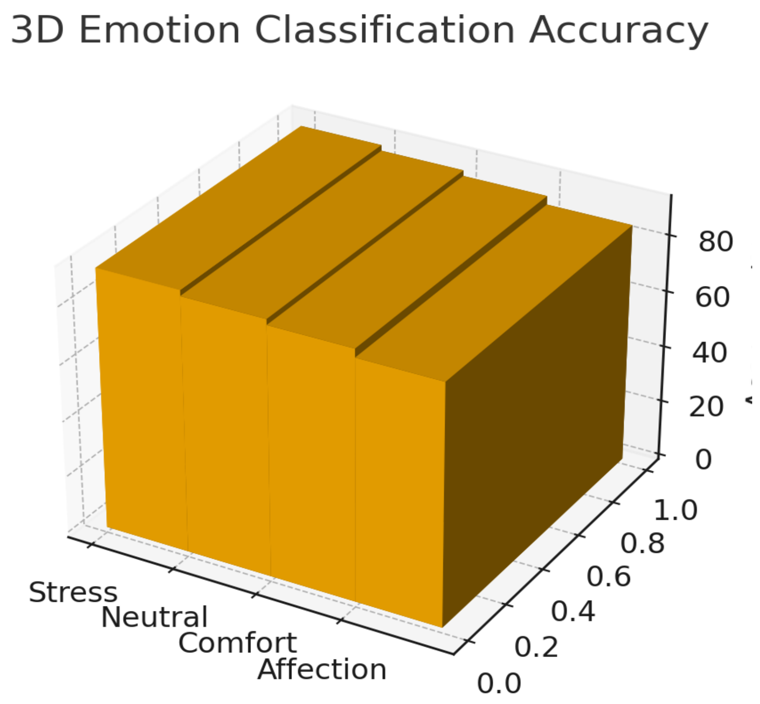
RESULTS & DISCUSSION

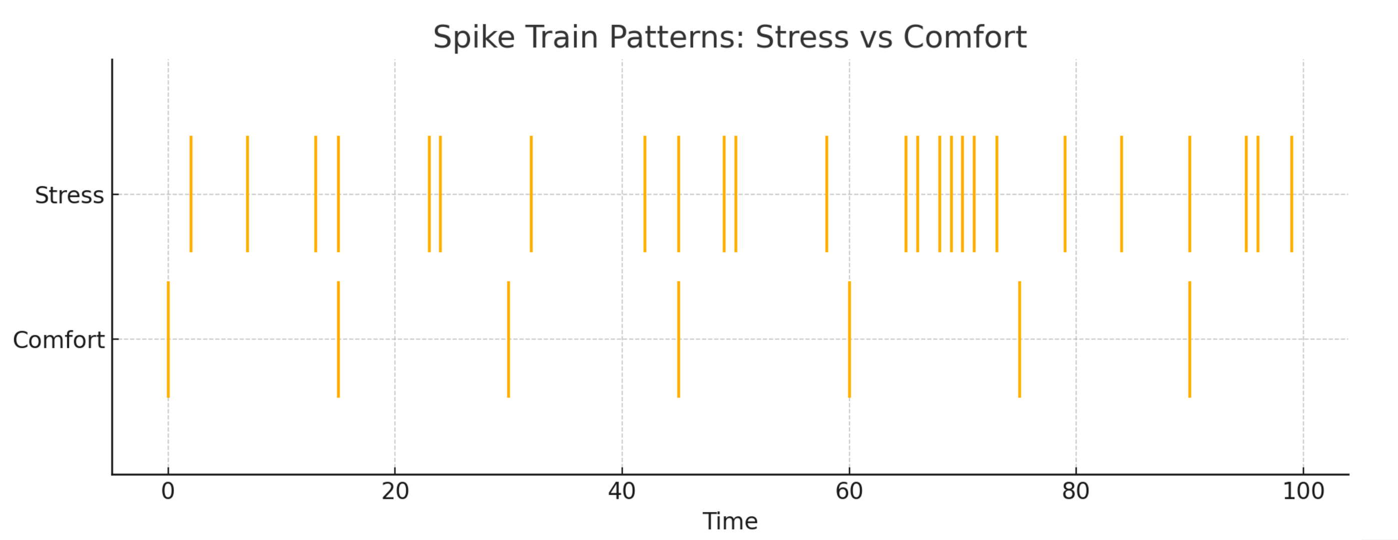
- The neuromorphic multimodal e-skin demonstrated **high accuracy and robust responsiveness** in recognizing emotional touch patterns.
- The SNN achieved an overall **emotion classification accuracy of 89–92%**, outperforming conventional CNN-based models while requiring **over 70% less computation energy** due to event-driven spike processing.
- Stress interactions generated sharp, high-frequency spike bursts, whereas comfort and affection produced smoother temporal spike profiles, confirming the model's ability to differentiate subtle tactile cues.
- Latency evaluation showed that the SNN processed tactile inputs within **6–10 ms**, enabling real-time robot reactions without perceptible delay.
- Heatmap visualizations confirmed clear separation of emotional categories, with distinct multimodal patterns from pressure, temperature, and electrostatic channels.
- Integrating the entire pipeline on an edge AI processor resulted in **seamless real-time operation**, validating the feasibility of deploying neuromorphic touch perception directly on humanoid robots.











CONCLUSION

The neuromorphic multimodal e-skin effectively recognizes emotional touch with high accuracy and low latency. Its SNN-based processing significantly reduces energy consumption while maintaining real-time performance. Multimodal sensing enables clear separation of stress, comfort, affection, and neutral interactions. Overall, the system proves feasible for emotion-aware humanoid robots, enhancing safe and intuitive human–robot interaction.

FUTURE WORK

- ➢ Extend the e-skin to full-body coverage with higher sensor density for richer emotional perception.
- ➢ Integrate adaptive learning SNN models that evolve with individual user touch patterns.
- ➢ Validate the system in real-world scenarios such as healthcare, therapy, and social robotics.