CPS: Small: Real-Time Machine Learning-based Control of Human Cyber-Physical Balance Systems

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Motivation

- **Wearable exoskeleton**: Great potentials in rehabilitation and industrial applications but needs intuitive control interfaces.
- **Machine learning technique**s: Enable safe and effective operation of human-exoskeleton systems in highly variable, dynamic environments.
- **Brain-computer interfaces (BCIs)**: Direct link between brain activity and exoskeleton control, leading to a natural and intuitive control interface.
- **Real-time shared control**: A novel control approach that combines EEG or IMU data, leveraging the temporal and spatial dependencies of the human brain and body.

Objectives

- Develop an integrated, multidisciplinary approach to bring the above-mentioned emerging technologies to individuals to enhance the human-exoskeleton interaction experience and improve human safety, health, and productivity.
- Initiate and develop US-India collaborative research on the BCI-enhanced exoskeleton control

Approach

- Develop machine learning-enabled, real-time personalized intention recognition and pose estimation algorithms.
- User-centered, shared exoskeleton control strategies using an EEG/IMU sensor fusion mechanism.

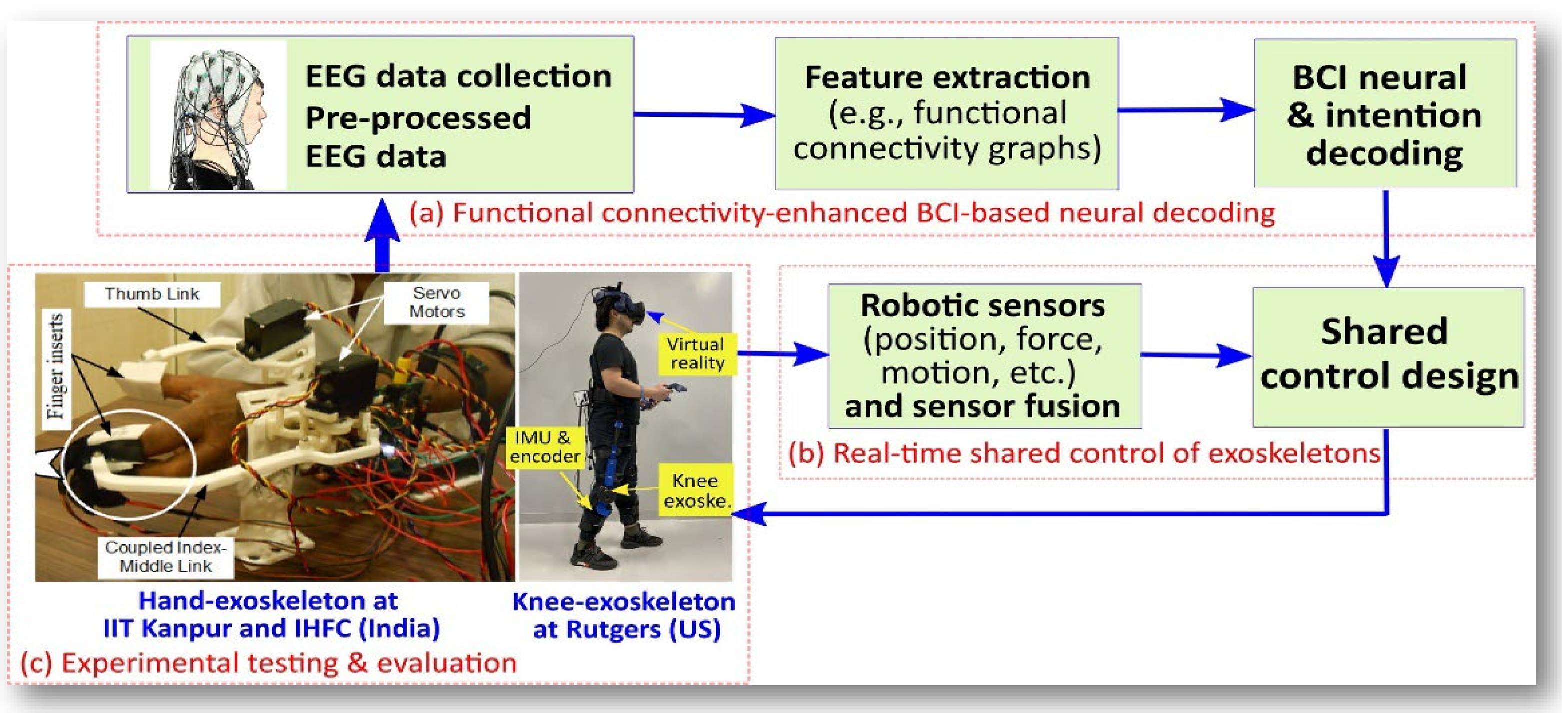


Figure 1: BCI-enhanced, real-time shared control of wearable exoskeletons. (a) Functional connectivity enhanced BCI-based neuronal decoding. (b) Real-time shared control of exoskeletons. (c) Experimental testing and evaluation.

Design of the BCI-Enhanced Exoskeleton Control

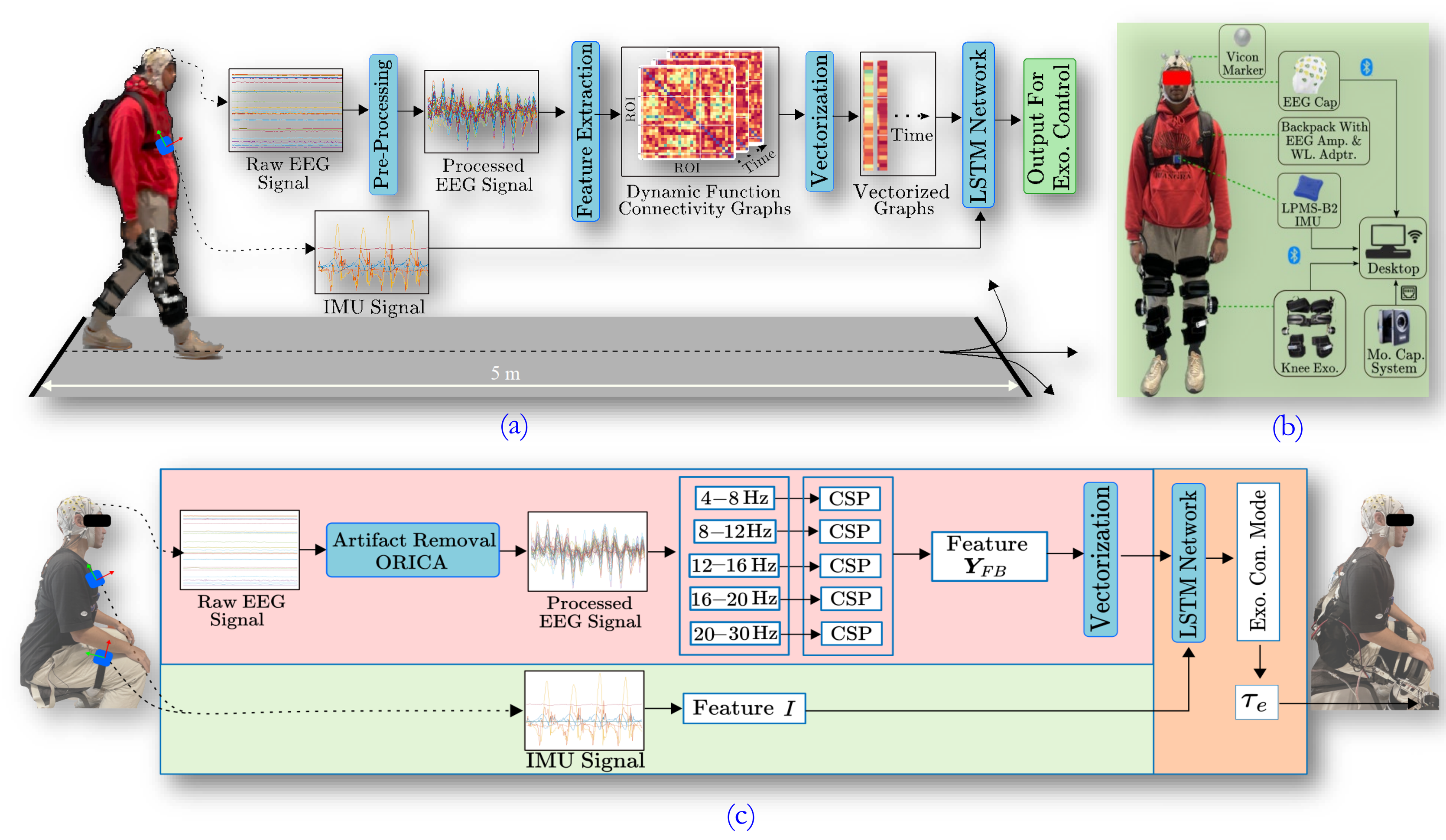


Figure 2: (a) Flowchart of EEG-IMU enabled turning intention detection system. (b) Schematic of the wearable sensing (IMU and EEG) and exoskeleton system, along with interconnection among them. (c) Flowchart of the sit-to-stand intention detection and exoskeleton assistance system with the wearable EEG and IMU sensors.

Results and Evaluation

- Implemented the BCI-enhanced, real-time shared control approach for wearable exoskeletons, using the EEG and IMU data sensor fusion to accurately detect user intention.
- Machine learning-based intention enables effective modeling of spatial and temporal sensor fusion.
- Compared human stability and muscle activations with/without the knee exoskeletons.
- Promising preliminary validation results, great potential for intuitive and effective control of wearable exoskeletons in various applications.

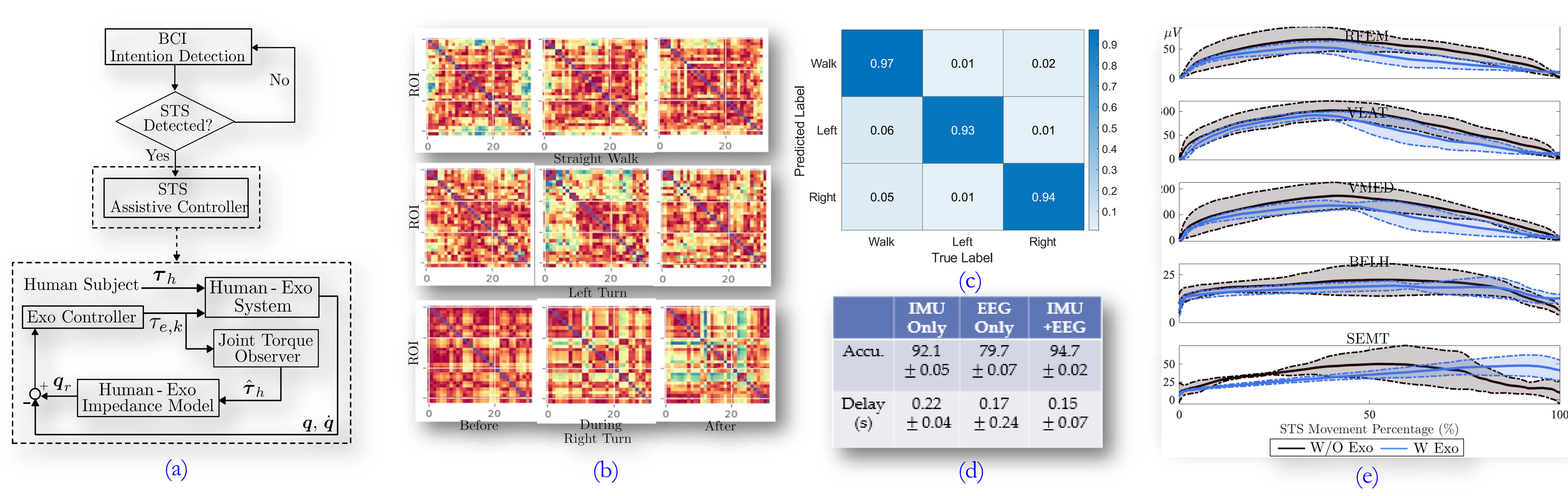


Figure 3: (a) Integrated BCI and exoskeleton control framework. (b) Dynamic functional connectivity diagrams of EEG signals under three different tasks, i.e., straight walk, left and right turns. (c) Learning-based sensor fusion prediction results for different tasks. (d) Prediction accuracy and delay comparison among different testing groups. (e) Lower limb muscle activation comparison during sit-to-stand task with/without exoskeleton assistance.

Research Results and Ongoing Work

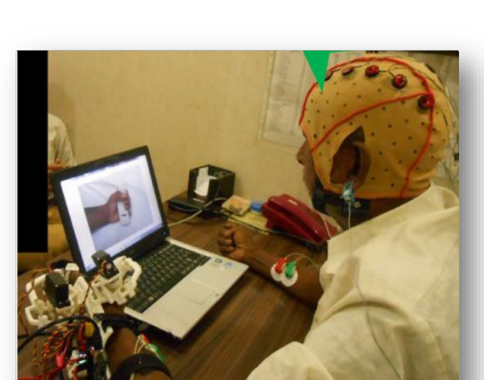
- Built the machine learning-based algorithm for activity detection and pose estimation.
- Developed the user-center exoskeleton controller and conducted extensive experiments.
- Plan to analyze learning algorithms for guaranteed control performance.

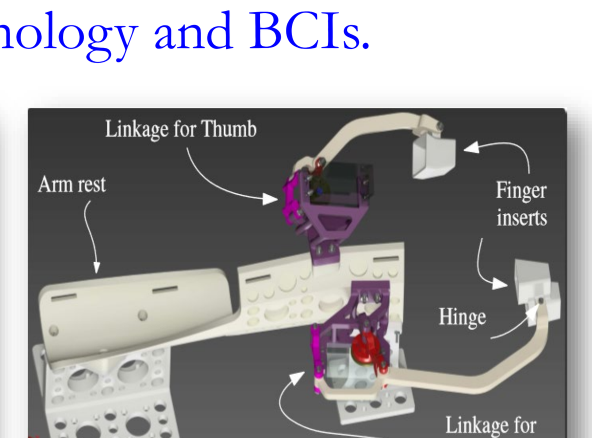
Up-to-Date Educational Activities

- Promoted human-exoskeleton interaction related education and interest at Rutgers.
- Recruited and trained graduate and undergraduate team members at Rutgers.

Research Impacts

- Offer innovative solutions for the elderly and those with disabilities to participate more fully in daily activities and work.
- Reduce healthcare costs with preventive and responsive exoskeleton support.
- Stimulate further research and innovation in wearable technology and BCIs.





Publications

- C. Zhu, S. Maurya, J. Yi, and A. Dutta (2024). Brain computer interface (BCI)-enhanced knee exoskeleton control for assisted sit-to-stand movement. Submitted to *2024 IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics*.
- S. Maurya, C. Zhu,, J. Yi, and A. Dutta (2024). Enhancement of SVM classification accuracy using IMU along with EEG and EMG signals for BCI based control of a robotic hand exoskeleton for stroke patients. Submitted to *2024 IEEE Int. Symp. on Medical Measurements and Applications*.
- F. Han and J. Yi (2024). Gaussian process-enhanced, external and internal convertible (EIC) form-based control of underactuated balance robots. In Proc. *2024 IEEE Int. Conf. on Robotics and Automation*, Yokohama, Japan.
- F. Han and J. Yi (2024). Safe motion control of autonomous vehicle ski-stunt maneuvers. *IEEE/ASME Trans. on Mechatronics*, in press.