CAREER: Fair, Energy-Efficient and Cognition-Aware Cyber-Physical Systems for Ad-Hoc Human-System Teaming during Complex Tasks

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Background and Objectives: Workers often suffer from bounded rationality and cognitive overload during complex jobs, and need cognition-aware decision support whenever they exhibit attention-switch between sub-tasks. Futuristic worker-assist solutions can be envisioned as perceptive cyber-physical systems, which foster ad-hoc and implicit human-system interaction under stringent time/energy constraints, fatigue, distraction and cognitive overloading. Such a system would offer personalized interventions even in the absence of explicit interaction and/or prior coordination, via making inferences based on multi-modal sensor data regarding both physical environment and worker's cognitive state respectively. PI Nadendla's long-term vision is to promote *ad-hoc human-system teaming via developing trustworthy, energy-efficient and personalized cyber-physical-human systems* which offer fair and personalized decision support for complex tasks via adapting to worker's mental health and cognitive overload under resource constraints. This proposal is an early attempt in achieving this vision, and primarily focuses on three research objectives: (i) Predict worker's cognitive load during multi-robot control using multi-modal bioelectrical data from wearable devices; (ii) Predict attention-switch intent between different subtasks based on multi-modal bioelectrical data; and (iii) Design fair and effective neurofeedback based on worker's cognitive state and attention-switch intent predictions.

Intellectual Merit: Based on the aforementioned three objectives, the research effort in this proposal is organized into three research thrusts. In Thrust 1, novel *neural-correlate based neural networks* (NNs) will be developed using *multi-modal bioelectrical data* (e.g. EEG, ECG and PPV) from wearable devices (e.g. smart headbands and watches) to predict worker's mental health and cognitive overload during multi-robot control missions. Firstly, convolutional NNs will be trained and converted into *spiking NNs* to reduce their energy footprint upon deployment using neuromorphic hardware. PI and his team will also develop novel *few-shot learning* approaches to personalize group-averaged SNN models to individual workers' cognition dynamics. Thrust 2 will also develop convolutional NNs and their corresponding spiking counterparts (similar to Thrust 1) to predict *attention-switch intent*. These attention-switch events are then correlated with moments when the worker experiences cognitive overload, as found in Thrust 1. Finally, Thrust 3 develops unique *audio interventions* (e.g. alerts/recommendations and noise-like stimuli with varying amplitudes) to help mitigate worker's cognitive overload under both normal and attention-switch events via integrating methods developed in Thrusts 1 and 2. Experiments will be designed using small ground robots (e.g. Jetbots) and mini-drones, and wearable devices (e.g. smart watch and Muse/Brainbit headband). In order to ensure that the group-average models are fair, participants will be selected and machine learning models will be trained with *fairness-based regularization* to mitigate discrimination across protected attributes (e.g. race, gender and age).

Education Plan: In addition to mentoring graduate and undergraduate students on proposed research activities, PI Nadendla will also develop a new course called *Ad-Hoc Cyber-Physical-Human Interaction*, and engage both graduate and undergraduate students on simple one-task project involving ad-hoc and intrinsic cyber-physical-human interaction. PI will also organize a two-day CyberMiner summer camp (through Kummer Center for STEM Education at Missouri S&T) to stimulate K-12 students, and a workshop to exchange bold research ideas and opinions across both academic researchers as well as diverse stakeholders from different application domains.

Broader Impacts: If successful, this proposal will radically transform human-system interaction in diverse applications such as driver/pilot-assist systems in semi-autonomous vehicles, multi-robot control (e.g. ground robots and drones) in search-and-rescue operations in disaster management and pest/disease control in agriculture, and production worker support in manufacturing pipelines.