CAREER: Fair, Energy-Efficient and Cognition-Aware Cyber-Physical Systems to Promote Ad-Hoc Worker-System Teaming in Complex Tasks

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Background and Objectives: Workers often need cognition-aware decision support whenever they experience significant mental load during 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 systems would offer personalized interventions even in the absence of explicit interaction and/or prior coordination, via learning worker's needs 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 will pave a path towards achieving this vision by focusing 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.