PROJECT SUMMARY

Overview.

The effectiveness of traditional distributed control algorithms heavily relies on the presence of tractable system models with known parameters, well-connected communication topology between the entities, and clearly specified objectives with known priorities. These conventional assumptions are no longer valid in the emerging era of intelligent and autonomous large-scale dynamical systems, such as connected smart farms and smart buildings. The most promising direction is a data-driven machine learning-based approach that learns through interactions with the system and leverages the domain knowledge. Although bandit learning and reinforcement learning (RL) have emerged as viable approaches for learning-based control, there remains a significant knowledge gap regarding *learning for multi-task control*. The success of multi-task learning has mainly been demonstrated in pre-trained models using supervised learning, with fewer applications in real-world dynamical systems.

Scalability and sample efficiency, communication topology constraints, and conflicting tasks represent three critical challenges that limit the application of multi-task representation learning in control of real-world dynamical systems. This CAREER proposal will develop a unified approach to multi-task representation learning to offer a viable solution to these challenges, enabling privacy-preserved joint learning in dynamic and uncertain environments. The proposed framework and algorithms will be validated using an experimental smart farm testbed at Iowa State in collaboration with the AI Institute for Resilient Agriculture (AIIRA) and numerical experiments on real-world Ag datasets and benchmark robotics environment. Research and education will be closely integrated to train students in the interdisciplinary field of data science and control, addressing the pressing need for rapid and quality workforce development. The education plans involve curriculum development at both graduate and undergraduate levels, undergraduate research experiences, K-12 outreach initiatives, empowering the assisted living community at Ames, IA, and activities to increase and retain diversity, particularly women, in STEM and academia.

Intellectual Merit.

This proposal will provide a fundamental theoretical framework and tractable algorithms with provable guarantees for multi-task representation learning for bandit leaning (BL) and reinforcement learning (RL) algorithms for controlling distributed real-world engineering systems subject to multiple tasks and constraints. The research program comprises three comprehensive thrusts and an evaluation and experimentation plan.

(1) Fast, Federated, and Scalable Multi-Task Representation Learning: This thrust aims to develop a fast, federated, and sample-efficient novel algorithm for multi-task representation learning, specifically bandit learning and reinforcement learning, for related yet different tasks by utilizing the problem structure. (2) Fully Decentralized Multi-Task Representation Learning: This thrust aims to develop a fast, federated, and sample-efficient fully decentralized algorithm for multi-task representation learning when the agents are distributed across a communication network. (3)Multi-Objective and Constrained Distributed Reinforcement Learning: This thrust will develop a novel, safe hierarchical learning and control paradigm to address the conflicting multi-criteria problem and a conservative online RL algorithm to learn optimal policies while incorporating the domain knowledge. To validate the quality, reliability, and effectiveness of the proposed framework and algorithms, we will perform numerical experiments on real-world datasets, benchmark environments, and real-time experiments using industry-grade tools and platforms on the smart farm testbed at ISU. The PI will collaborate with AIIRA to test the algorithms on the existing smart farm testbed at ISU and using the APSIM (Agricultural Production Systems sIMulator) crop simulation model. The algorithms will also be tested on a multi-agent multi-objective MuJoCo environment after enhancing the existing multi-agent MuJoCo environment.

Broader Impacts.

The theoretical and algorithmic outcomes of this project will have a profound impact on the many applications of dynamic learning, in particular smart farming, smart building control, and the automation industry. The project includes an innovative education plan that involves the 'CyMath project,' contributing to workforce development from K-12 students to STEM. Additionally, it incorporates senior design and capstone projects seamlessly integrated with the overall initiative, employing a hands-on learning approach to integrate RL research into the educational curriculum. The PI will mentor students from underrepresented groups and collaborate with the Northcrest assisted living community in Ames, Iowa, to deliver talks on cyber-security and best practices, aiming to empower senior citizens with valuable knowledge and skills in navigating the digital landscape safely.