Cyber-Physical Sensing, Modeling, and Control with Augmented Reality for Smart Manufacturing Workforce Training and Operations Management

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Project Objectives

The aim of this project is to build an integrated set of cyber-physical system methods and tools for sensing, recognizing, characterizing, modeling, and optimizing the learning and operations of manufacturing workers in order to significantly improve worker training performance, behavioral operations management, and front-line worker safety for smart manufacturing.

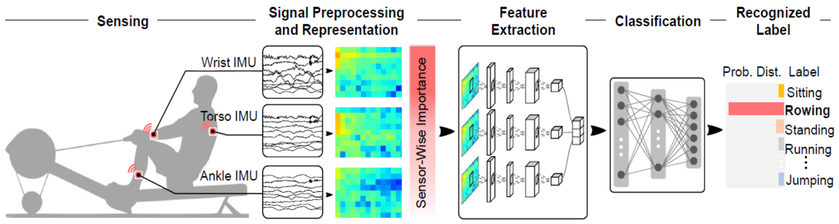
Multi-modal Sensing and Attention-based Sensor Fusion

Scientific Challenges:

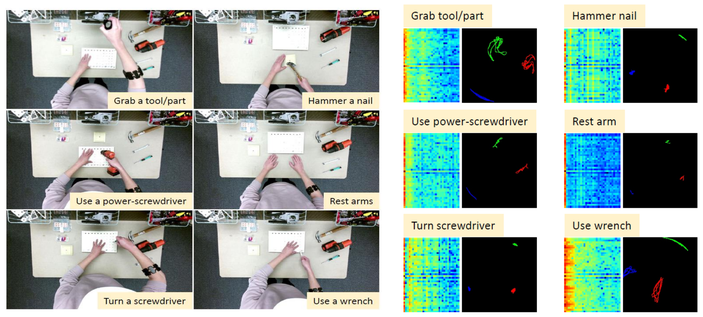
- How to sense and understand low perception of high-complexity human activities using wearable and noncontact sensors?
- How to fuse multi-modal sensing to develop more reliable and robust human-centered action recognition systems?

Our Contributions:

- A novel multi-modal sensing approach is proposed for worker activity recognition by leveraging information from different sensors and in different modalities, for recognition of the worker's activity to enable quantification and assessment of the worker performance.
- A novel attention-based approach is designed to recognize human activity using multiple IMU sensors worn at different body locations.
- A sensor-wise attention module is developed to enable the neural network to emphasize features from specific sensors depending on the signals.



human activity recognition pipeline using IMU signals



Worker activities and IMU image representations

Collaborative Forward and Backward Teacher-Student Learning for Long-Term Future Action Anticipation

Scientific Challenges:

- How to recognize an action that does not occupy the entire region of a single frame or the entire volume of a short video clip, which may lead to misclassification?
- For long-term future action anticipation, how to obtain an efficient and accurate action anticipation network that can anticipate the actions in both the near future and far future?

Our Contributions:

- Knowledge distillation based teacher-student networks are constructed that can anticipate the human actions in both the near future and far future.
- A collaborative forward and backward teacher-student learning framework is built, where the forward and backward learning processes collaborate with each other based on cyclic consistency constraints.
- A new transition loss is introduced for modeling the sequential actions.

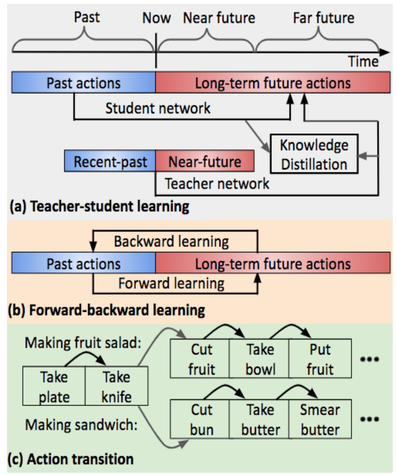
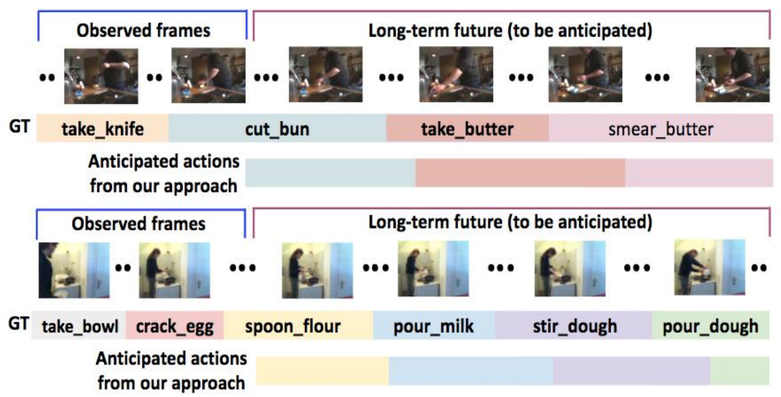


Illustration of our main ideas



Qualitative results of our approach for the future action anticipation: The model observed the first 30% of the video and anticipates the frame-wise actions of the following 50% of that video. (GT: ground truth)

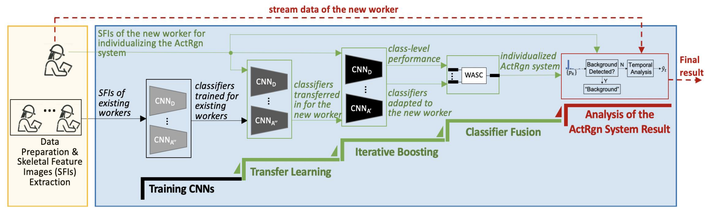
Skeletal Data-Based CNN Classifiers for Action Recognition in Manufacturing Assembly

Scientific Challenges:

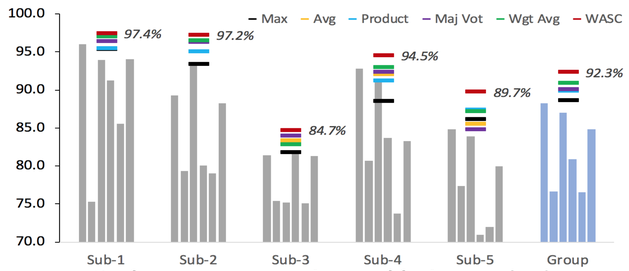
- How to address the negative impact of human heterogeneity (within-subject and between-subject) on the action recognition performance?
- How to fuse multiple classifiers to develop a more reliable and robust action recognition system?

Our Contributions:

- A method is designed to adapt action classifiers to individual workers.
- A fusion method named the Weighted Average of Selected Classifiers is proposed to maximize the performance of an individual worker.
- A data analysis algorithm is designed to improve the accuracy by analyzing untrimmed stream data.



An individualized action recognition system of CNN classifiers



Performance comparisons of fusion methods.

Broader Impacts

- We published 4 papers in scientific journals, 4 papers in conference proceedings, and 1 book chapter in the past year.
- We trained 8 Ph.D. students, of whom one graduated in May 2020. Also, we provided research experiences to 5 undergraduate students, including one female.
- We conducted convergent research involving PIs in multiple disciplines from multiple universities.
- The technologies developed are helpful to training future manufacturing workers and improving their job performance.

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