NRI: INT: COLLAB: Manufacturing USA: Intelligent Human-Robot Collaboration for Smart Factory

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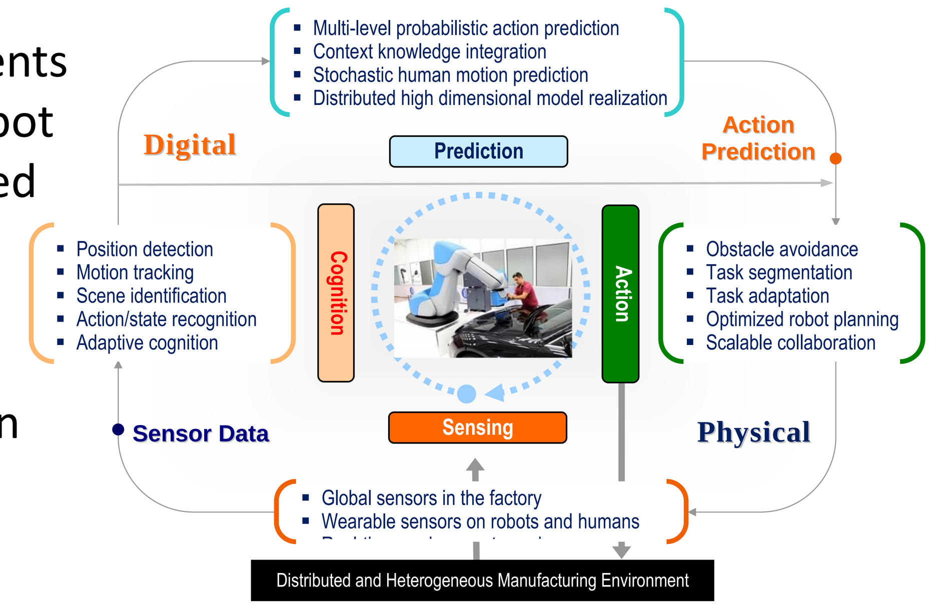
We propose four research components to realize the envisioned human-robot collaboration (HRC) for an automated HRC manufacturing cell, from data acquisition in the physical domain to data manipulation in the digital domain, and back to robot control in the physical domain: sensing, cognition, prediction, and action.



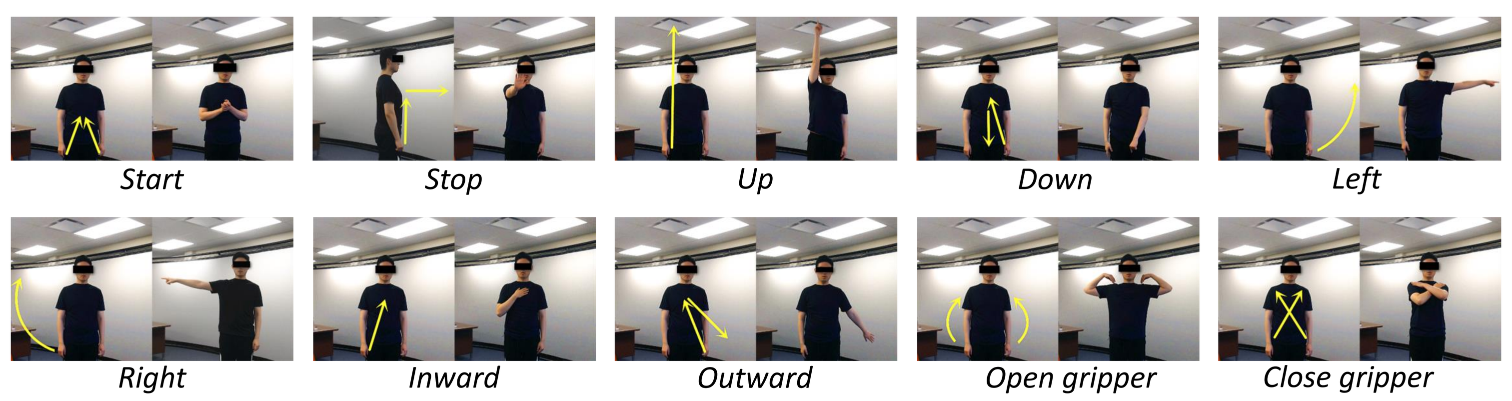
Sensing/ Cognition

Dynamic Gesture Design and Recognition for Human-robot Collaboration Based on Convolutional Neural Networks

Task Objective: Design a dynamic gesture communication system in the human-robot collaboration (HRC). Recognize the gestures based on the Motion History Image (MHI) and the Convolutional Neural Networks (CNN).

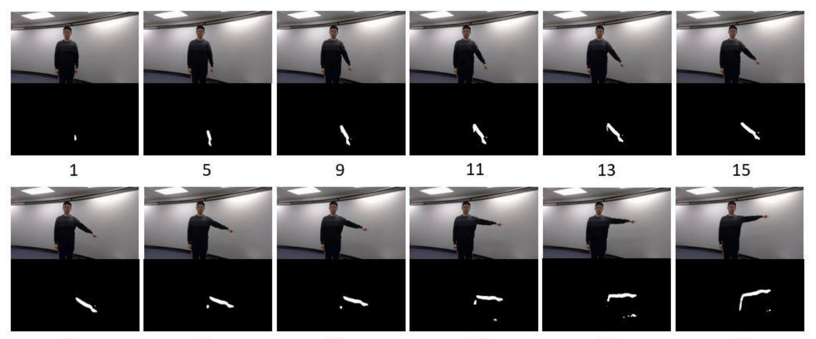
Technical Approaches:

Gesture Design: Design ten dynamic gestures based on the Iconic (gestures present images of concrete entities and/or actions) and Deictic (the prototypical deictic gesture is an extended 'index' finger) principles.

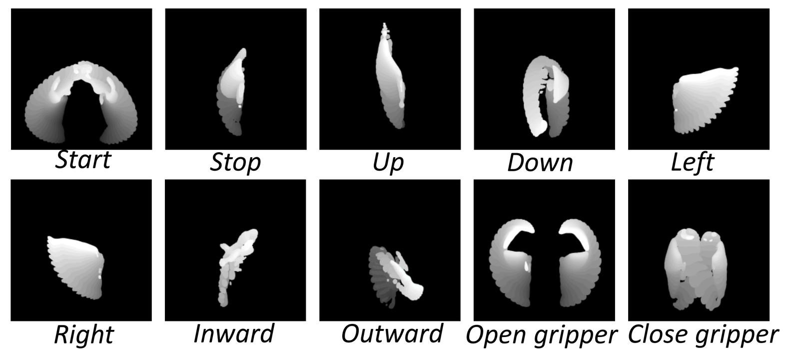


The ten dynamic gesture commands. (The gripper is the end-effector of the robot).

Feature Acquisition: The MHI approach is adopted to realize the feature extraction of human movements. This approach is a view-based template method that records the motion history of a movement and converts it into static images. The results are scalar-valued images where more recently moving pixels are brighter and vice-versa.



Binary images of the gesture *left* on different frames.



The MHIs of the ten dynamic gestures.

Gesture Recognition: Design a CNN model. Collect a gesture dataset with 4570 samples. The classification accuracy and F-score of our CNN model are >99% for the ten dynamic gestures on this dataset.

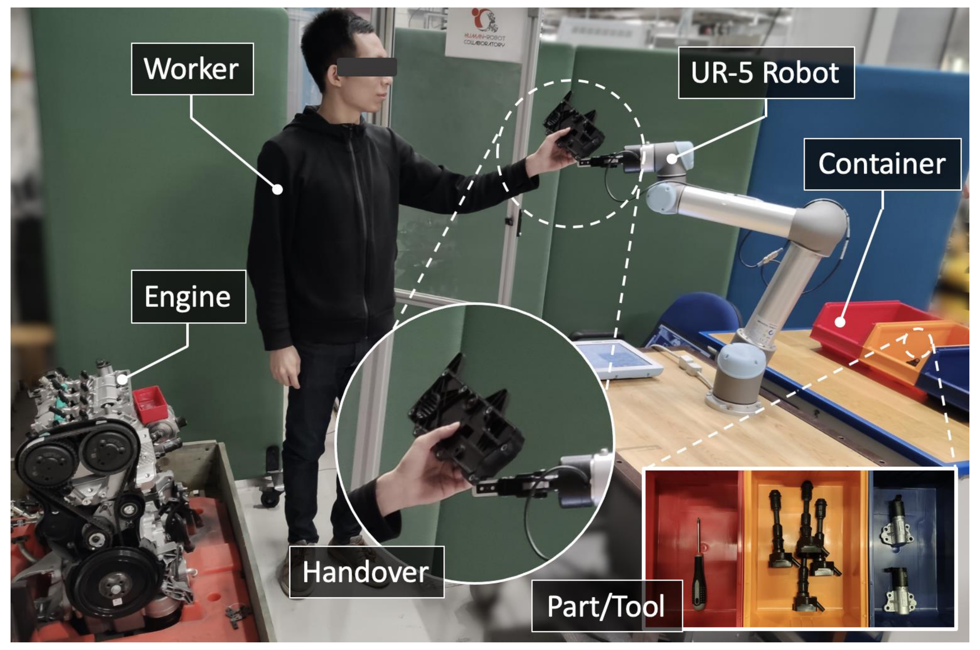
Prediction

Human Motion Trajectory Prediction for Human-robot Collaboration Based on Recurrent Neural Networks

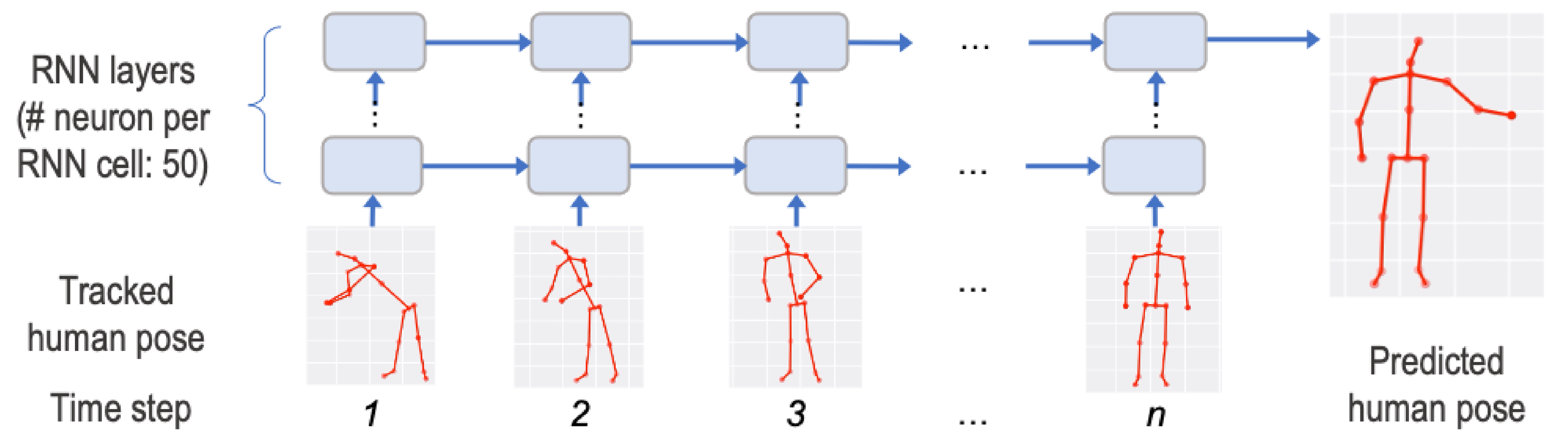
Task Objective: Parse visual observations of human operator's actions in an assembly setting and forecast future human motion trajectory for online robot action planning and execution based on Recurrent Neural Network (RNN).

Technical Approaches:

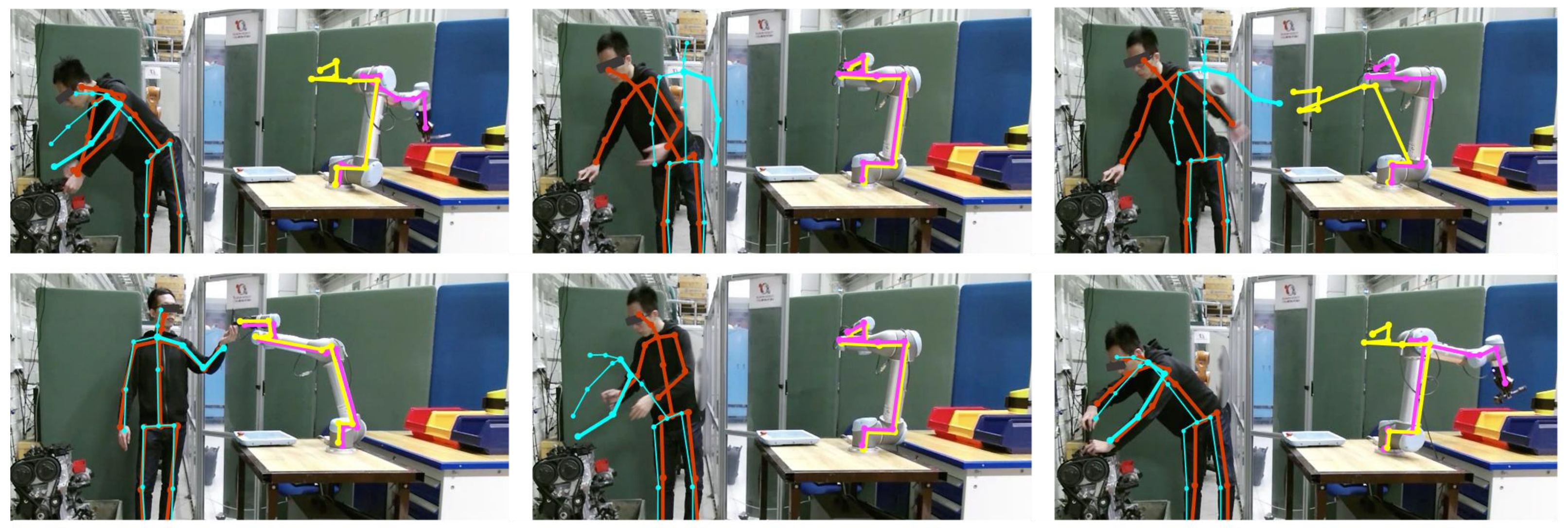
Assembly scenario: human-robot collaborative car engine assembly. The collaboration is presented by the robot responding to the *predicted* human motion trajectory, following the human hand in real time as it extends for handover and picking up of relevant part & tool during installation.



Sequential modeling: RNN captures motion evolution pattern by concurrently analyzing the influence of the motion state at each of the time steps on the state at the subsequent step. Motion state is a feature of the motion pattern learned by RNN from the raw observation of human poses, expressed as coordinates of human body joints.



Trajectory prediction: RNN-based algorithm has shown to complete on prediction cycle in less than 30 ms, thus enabling real-time HRC collaborative assembly when human pose is captured at video imaging rate of 30 Hz.



Actual human pose: red; Predicted human pose: cyan; Actual robot position: pink; Target robot position: yellow

Action

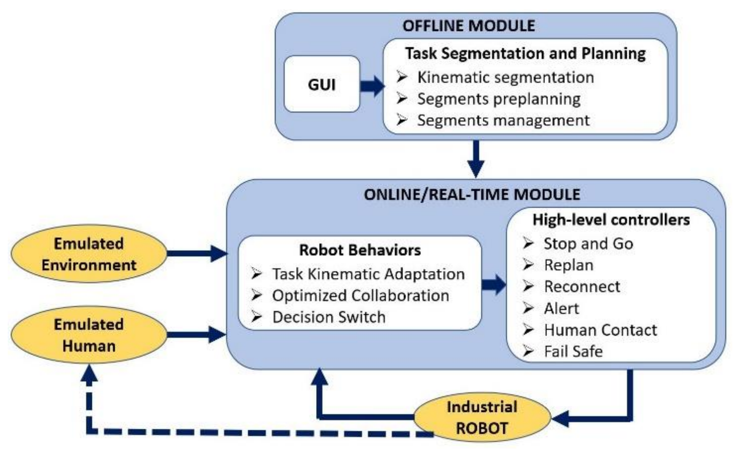
Human-Robot Reactive Behavior Intelligence

Task Objective: Seamless integration of sensing, cognition and prediction into the robot controller. To provide the robot Proactive Adaptive Collaboration Intelligence (PACI) and switching logic within its control architecture in order to give the robot the ability to optimally and dynamically adapt its motions, given a priori knowledge and predefined execution plans for its assigned tasks.

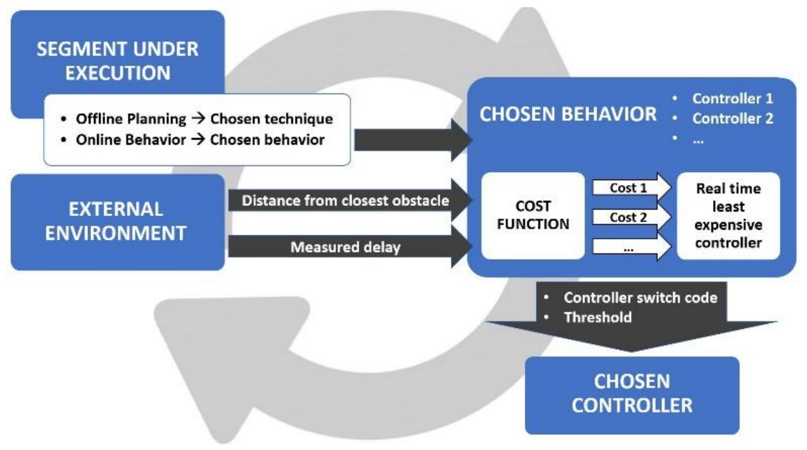
Challenge: Augmenting the robot's decision-making process to have greater situation awareness and to yield smart robot behaviors/reactions when subject to different levels of human-robot interaction, while maintaining safety and production efficiency.

Technical Approaches:

Task Segmentation and Planning: Offline module is equipped with a GUI that takes as input the requests of the user and feeds the processed information to a second module, which is in charge of the kinematic segmentation of the task(s) and the preplanning and management of the created segments.

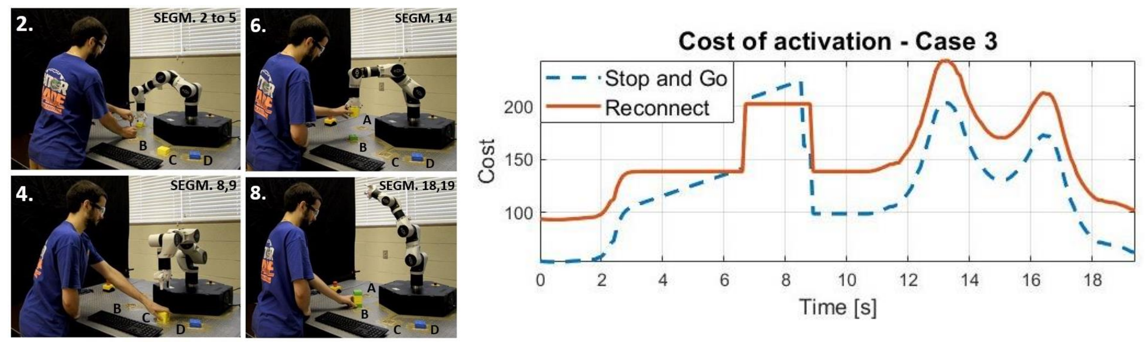


Control architecture.

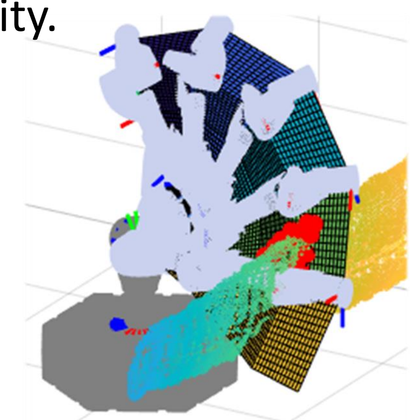


Working principle of online switching logic.

Reactive Behaviors: Online/Real-time module kinematically adapts robot motion in accordance to preplanned segmentation behavior priorities, and predicted and sensed human motion and environment. Robot reactive behaviors are achieved via cost function-based switching logic activating the best suited high-level controller (*stop-n-go, replan, reconnect replan, alert, human contact*). The PACI's underlying segmentation and switching logic framework yields a high degree of modularity and flexibility.



Cost trends – trajectory replan due to human presence detected at t=6.8 sec.



Temporal point clouds.

Predictive Collision Detection: Given the predicted human motion and employing the computational efficiency of interference detection methods, temporal point clouds sweeps are used to evaluate a robot's trajectory, evaluate the dynamic environment that the robot operates in, and predict collisions between the robot and the environment.

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