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

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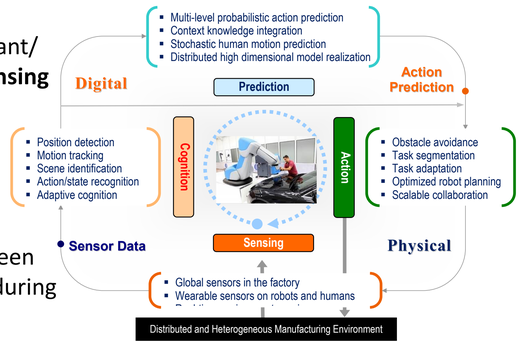
Research challenges in realizing human-robot collaboration in smart factories:

- Separating and highlighting relevant content from irrelevant/ ambiguous information in **sensing** data for human action and command **recognition**.
- Accounting for uncertainty in human action and trajectory **prediction**.
- Estimating collision risk between robot and human trajectory during collaborative **action**.

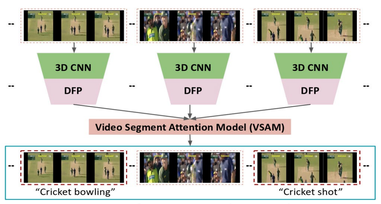


Sensing/ Cognition

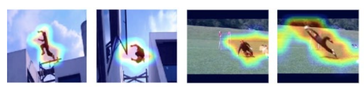
Human Action Recognition by Discriminative Feature Pooling and Video Segment Attention Model [1]

Objective: Recognize human actions from long untrimmed videos (contain many unrelated frames).

- Designed a novel **discriminative feature pooling** to integrate spatial, temporal, and channel-wise attentional pooling on top of 3D Convolutional Neural Network to highlight most discriminative features in video segments.
- Developed a video segment **attention** model to ensemble discriminative features before applying temporal attention to rank video segments based on their relevance to action class.



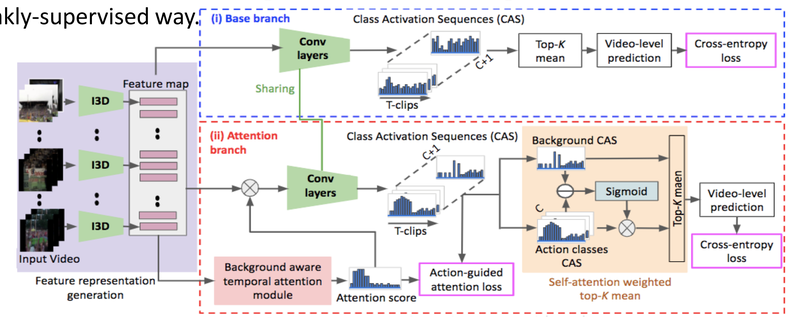
Discriminative feature pooling and attention



Visualization of video attention

Action Completeness Modeling with Background Aware Networks for Weakly-Supervised Temporal Action Localization [2]

Objective: Localize and recognize actions from long untrimmed videos in a weakly-supervised way.



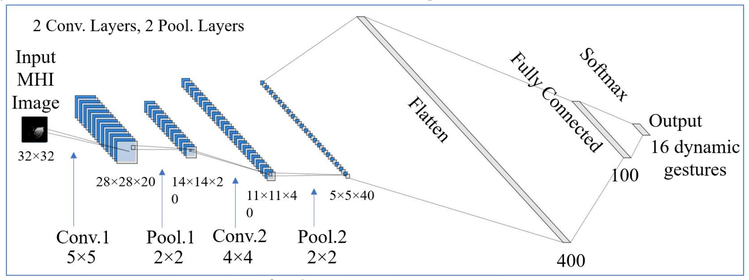
Background aware network

- Developed a novel **background aware network** to suppress both highly discriminative and ambiguous background frames.
- Developed an **action completeness modeling** framework to localize action instances in both highly discriminative and ambiguous action frames.

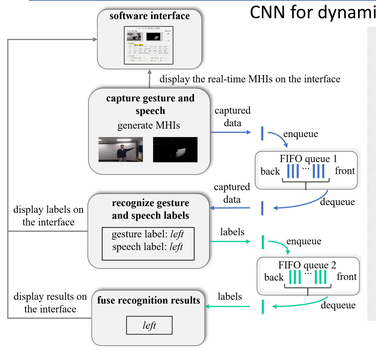
Dynamic Gesture and Speech Recognition for Human-Robot Collaboration based on Convolutional Neural Networks (CNN)

Objective: Design real-time communication system based on gesture and speech recognition.

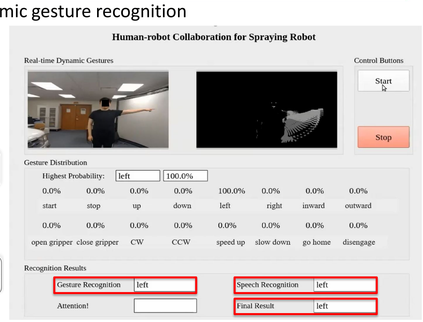
- Designed 16 gestures based on Iconic (concrete entities and actions) and Deictic (extended 'index' finger) principles. Developed a **CNN** with **motion history image**-based feature, achieving classification accuracy >95%.
- Developed a multi-threading **control system** and **software interface** for parallel tasks execution and results viewing.



CNN for dynamic gesture recognition



Multi-threading architecture of control system



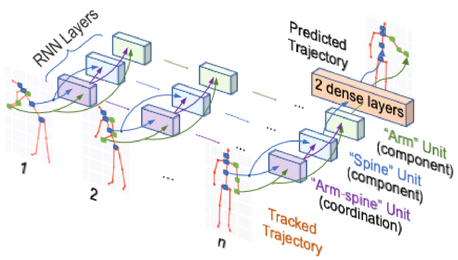
Software interface for viewing system result (Gesture: *left*; Speech: *left*, Recognition result: *left*)

Prediction

Human Action and Trajectory Prediction based on Probabilistic Recurrent Neural Networks (PRNN) [3]

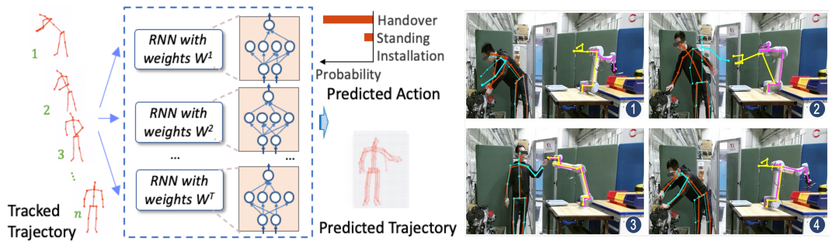
Objective: Analyze coordination among human body parts and quantify uncertainty in human action and trajectory for improved predictive accuracy and robustness.

- Designed a **functional units**-based RNN structure to explicitly analyze human body part coordination pattern in motion trajectory during assembly action and achieved reduction in trajectory prediction error of up to 44% as compared to standard RNN.



RNN with functional units

- Developed a **PRNN** to integrate action and trajectory prediction results from multiple possible models via Bayesian marginalization and Monte-Carlo drop-out for uncertainty quantification and achieved improved prediction robustness by mitigating robot mis-trigger for tool/part handover.

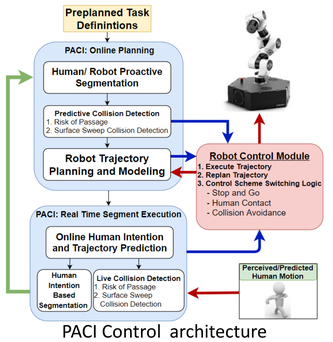


PRNN and sample collaborative assembly sequence

Action

Human-Robot Proactive-n-Reactive Behavior Intelligence

Objective: Seamless integration of sensing, cognition, and prediction into robot controller yielding efficient proactive adaptive collaboration intelligence (PACI) to ensure safe interactions with humans and mitigate production disruptions.

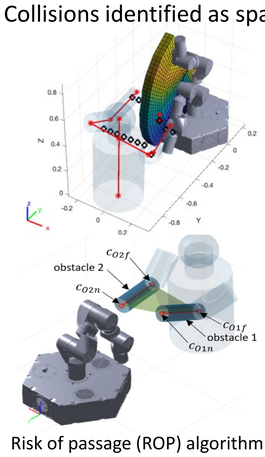


PACI Control architecture

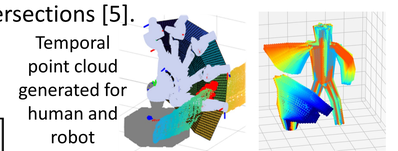
Synthesis control structure: Leveraged a priori and live information to allow robot to optimize productivity and respond to unforeseen changes in environment, achieved with a long-term module that receives feedback from a real time environment monitor.

Reactive behaviors: Robot behavior adaptations achieved via a cost function-based switching logic activating best high-level controller [4].

Predictive collision detection: Long term motion planning and online motion updates, overlaid with human prediction, all modeled as **temporal point clouds**. Collisions identified as spatio-temporal intersections [5].



Risk of passage (ROP) algorithm



Risk of passage (ROP) estimation: Robot control system detects volumes of workspace and evaluates robot future passage based on predicted human action. With **obstacle pair volume** (OPV), ROP allows robots to avoid disruptions due to stopping and replanning to avoid collision while increasing humans' comfort [6].

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Award ID#: 1954548/1830479/1830383/1830295

Related Publications
[1] M. Moniruzzaman *et al.*, "Human action recognition by discriminative feature pooling and video segment attention model," IEEE TMM, 2021.
[2] M. Moniruzzaman *et al.*, "Action completeness modeling with background aware networks for weakly-supervised temporal action localization," ACM MM, 2020.
[3] J. Zhang *et al.*, "Recurrent neural network for motion trajectory prediction in human-robot collaborative assembly," CIRP Annals, 2020.
[4] M. Nicora *et al.*, "Human-Robot Collaboration in Smart Manufacturing: Robot Reactive Behavior Intelligence", ASME JMSE, 2021.
[5] G. Streitmatter, and G., Wiens, "Human-Robot Collaboration: A Predictive Collision Detection Approach for Operation within Dynamic Environments", ASME ISFA, 2020.
[6] J. Flowers, and G. Wiens, "Collaborative Robot Risk of Passage Among Dynamic Obstacles", ASME MSEC, 2021 (in review).