Safe and Efficient Robot Collaboration System for Next Generation Intelligent Industrial Co-Robots

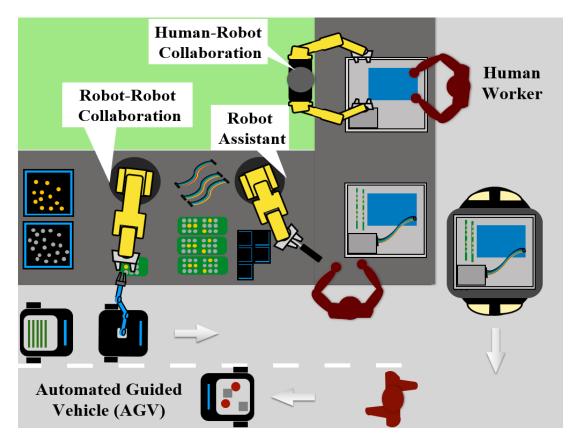
Jessica Leu, Yujiao Cheng, Shiyu Jin, Liting Sun, Weiye Zhao^{*}, Tianhao Wei^{*}, Changliu Liu^{*}, and Masayoshi Tomizuka

02/28/2020

Objective

Safe and efficient robot collaboration systems (SERoCS)

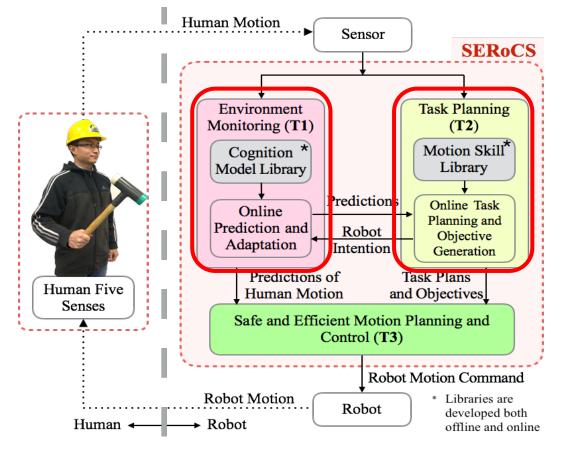
- Smart factories
- Next generation co-robots
- Design principles



Overview

Safe and efficient robot collaboration systems (SERoCS)

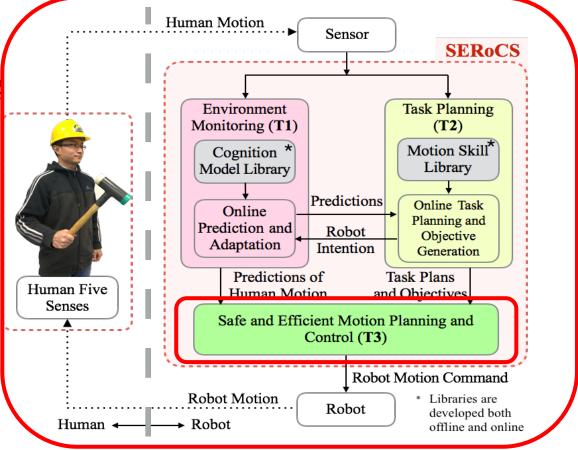
- Task 1. Environment Monitoring with Human Motion Prediction
- Task 2. Task Planning with Skill Library



Overview

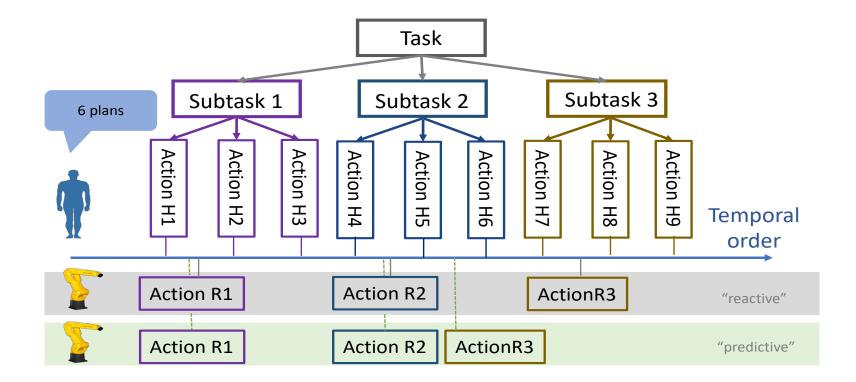
Safe and efficient robot collaboration systems (SERoCS)

- Task 3. Safe and Efficient Motion Planning and Control in Real Time
- Task 4. Evaluation of the SERoCS by Analyses, Simulations and Experiments



Task 1. Environment Monitoring with Human Motion Prediction

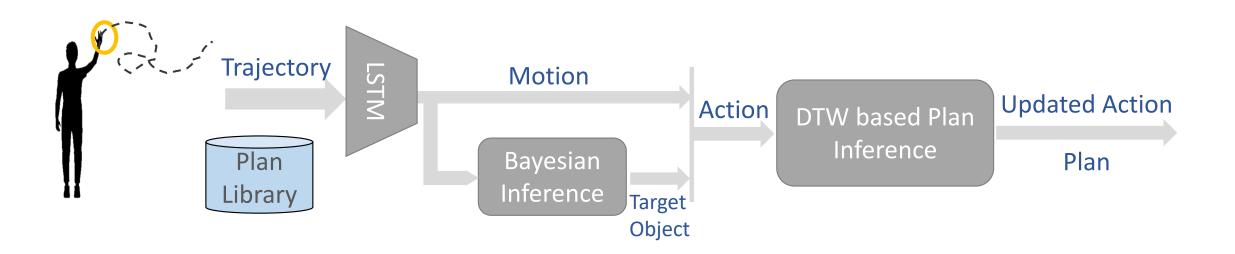
• Structure of collaborative tasks



Y. Cheng, et al. "Towards Efficient Human Robot Collaboration with Robust Plan Recognition and Trajectory Prediction." in IEEE Robotics and Automation Letters, 2020.

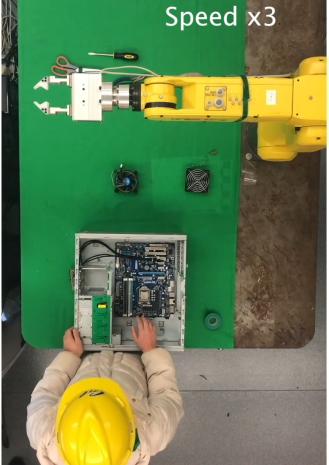
Task 1. Environment Monitoring with Human Motion Prediction

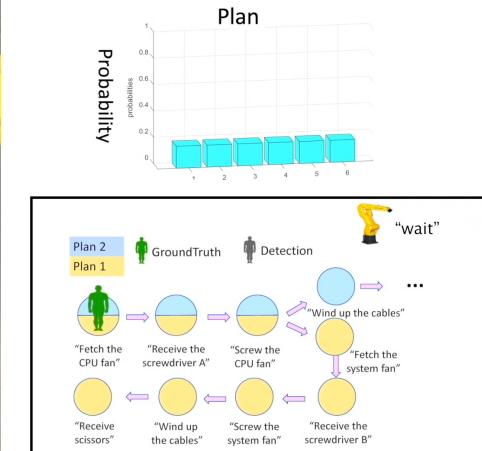
• Predictor



Y. Cheng, W. Zhao, C. Liu, and M. Tomizuka, "Human Motion Prediction using Adaptable Neural Networks." in Proc. American Control Conference (ACC 2019).

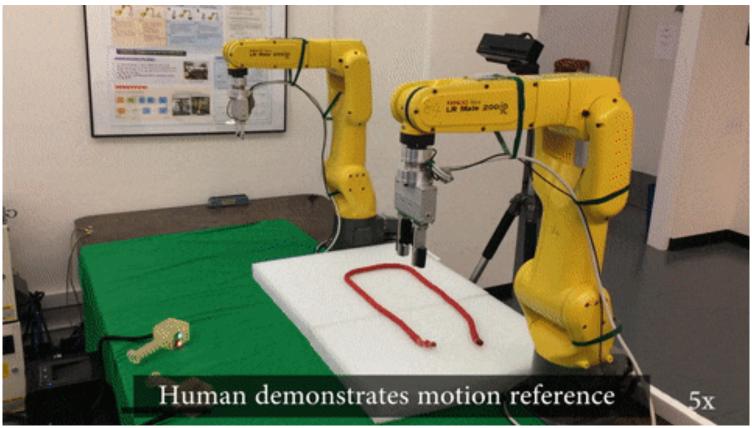
Task 1. Environment Monitoring with Human Motion Prediction





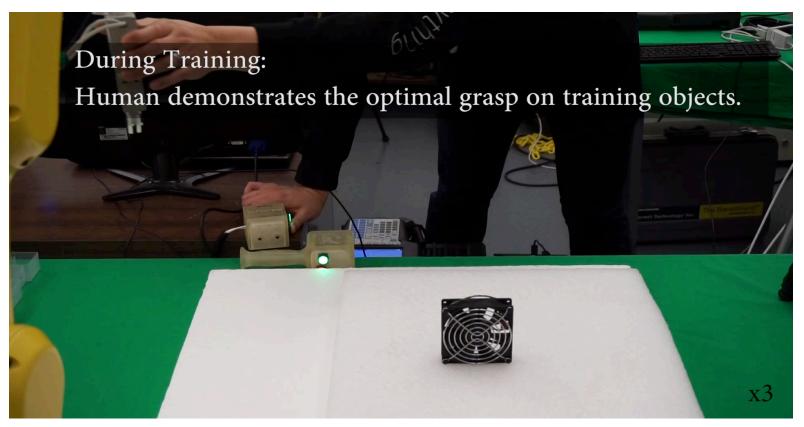
Task 2. Skill Library For intelligent co-robots

Task 2. Skill Library For intelligent co-robotsLearning from Human demonstration



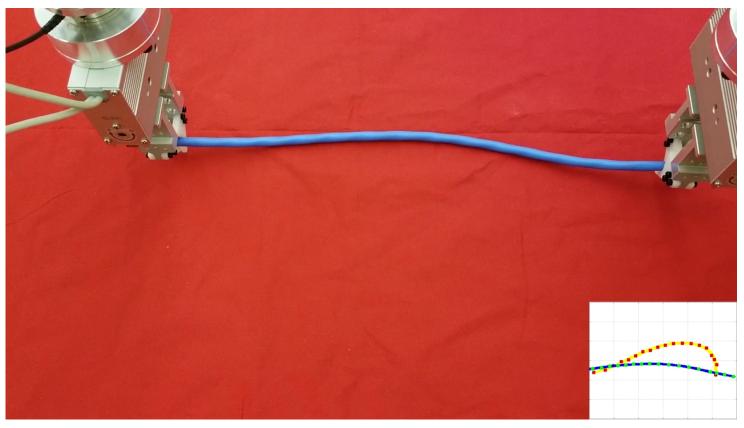
Te Tang, Changhao Wang, and Masayoshi Tomizuka. A framework for manipulating deformable linear objects by coherent point drift. IEEE Robotics and Automation Letters, 3(4):3426–3433, 2018.

Task 2. Skill Library For intelligent co-robotsAnalogy Learning



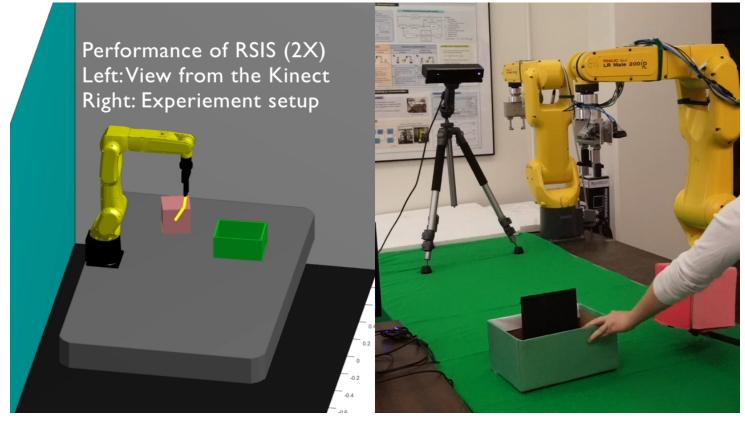
H-C. Lin, T. Tang, Y. Fan, and M. Tomizuka, "A Framework for Robot Grasp Transferring with Non-rigid Transformation." in IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2018.

Task 2. Skill Library For intelligent co-robotsCable Manipulation



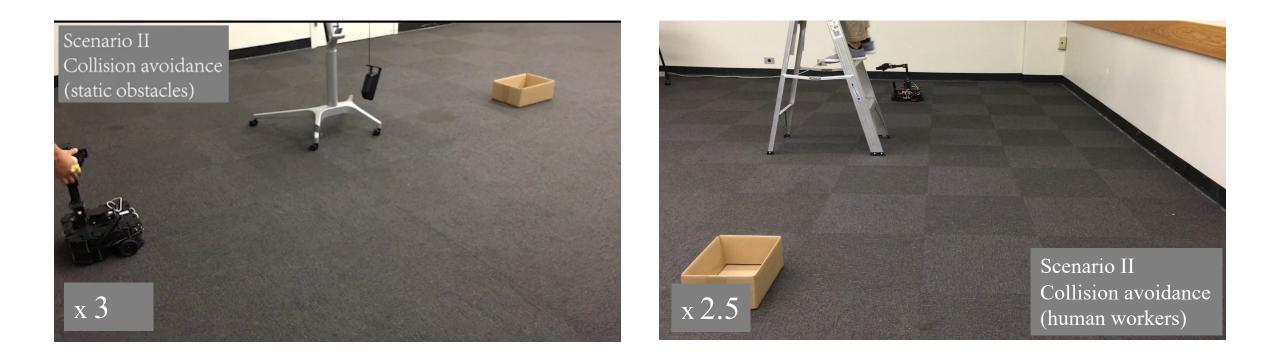
S. Jin, C. Wang, and M. Tomizuka. "Robust Deformation Model Approximation for Robotic Cable Manipulation." 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2019.

Task 3. Real Time Safe and Efficient Motion Planning and ControlHuman-robot interaction/collaboration



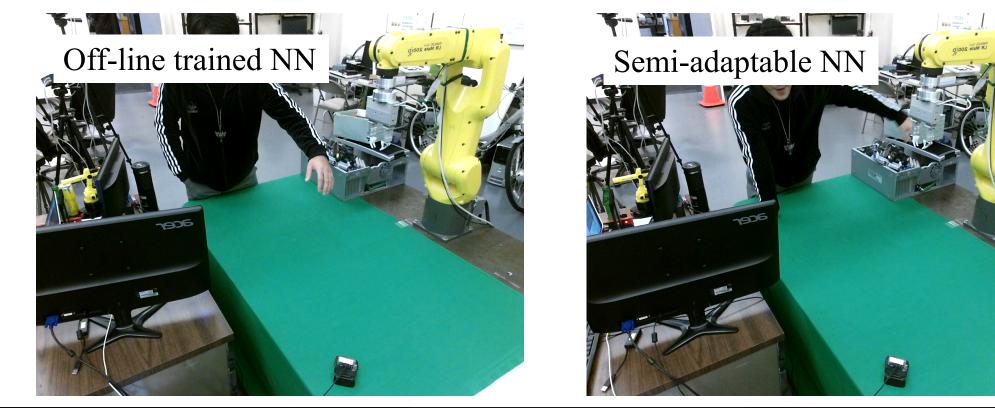
C. Liu, T. Tang, H-C. Lin, Y. Jiao, and M. Tomizuka. "SERoCS: Safe and Efficient Robot Collaborative Systems for Next Generation Intelligent Industrial Co-Robots." arXiv:1809.08215.

Task 3. Real Time Safe and Efficient Motion Planning and ControlHuman-robot interaction



J. Leu, R. Lim, and M. Tomizuka, "Safe and coordinated hierarchical receding horizon control for mobile manipulators," in Proc. American Control Conference (ACC 2020), Accepted, Jun. 2020

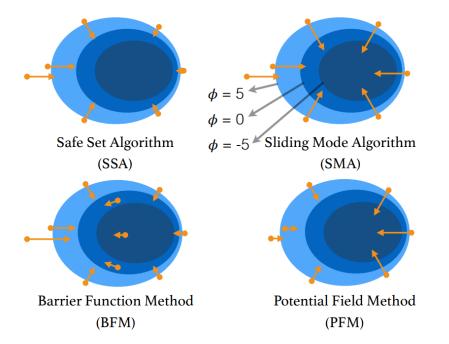
Task 4. Evaluation and BenchmarkingExperimental evaluation for T1 +T3

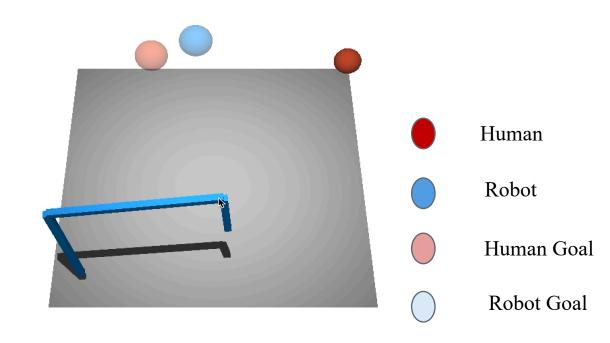


W. Zhao, et al. "Experimental Evaluation of Human Motion Prediction: Toward Safe and Efficient Human Robot Collaboration." in Proc. American Control Conference (ACC 2020). Ravichandar, Harish Chaandar, and Ashwin P. Dani. "Human intention inference using expectation-maximization algorithm with online model learning." *IEEE Transactions on Automation Science and Engineering* 14.2 (2016): 855-868.

Task 4. Evaluation and Benchmarking

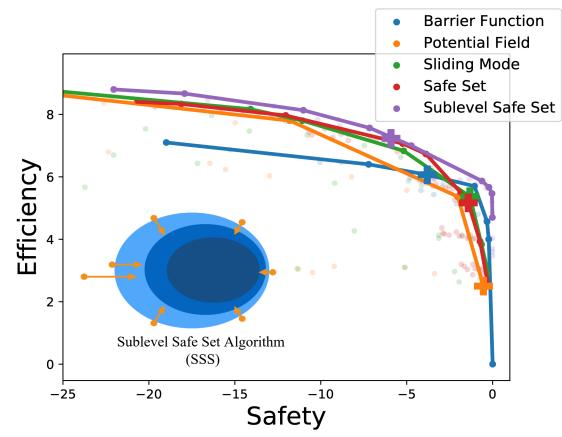
• Unified Framework





T. Wei, and C. Liu. "Safe Control Algorithms Using Energy Functions: A Unified Framework, Benchmark, and New Directions." *in* Proc. IEEE Conference on Decision and Control (CDC 2019).

Task 4. Evaluation and Benchmarking



Conclusion and Future work

- Modules for Prediction, Skills, Planning, and Evaluation have been developed.
- During the remaining funding period, we will
 - Enhance each module,
 - Conduct comprehensive experiments to demonstrate the strength of the whole SERoCS system.