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

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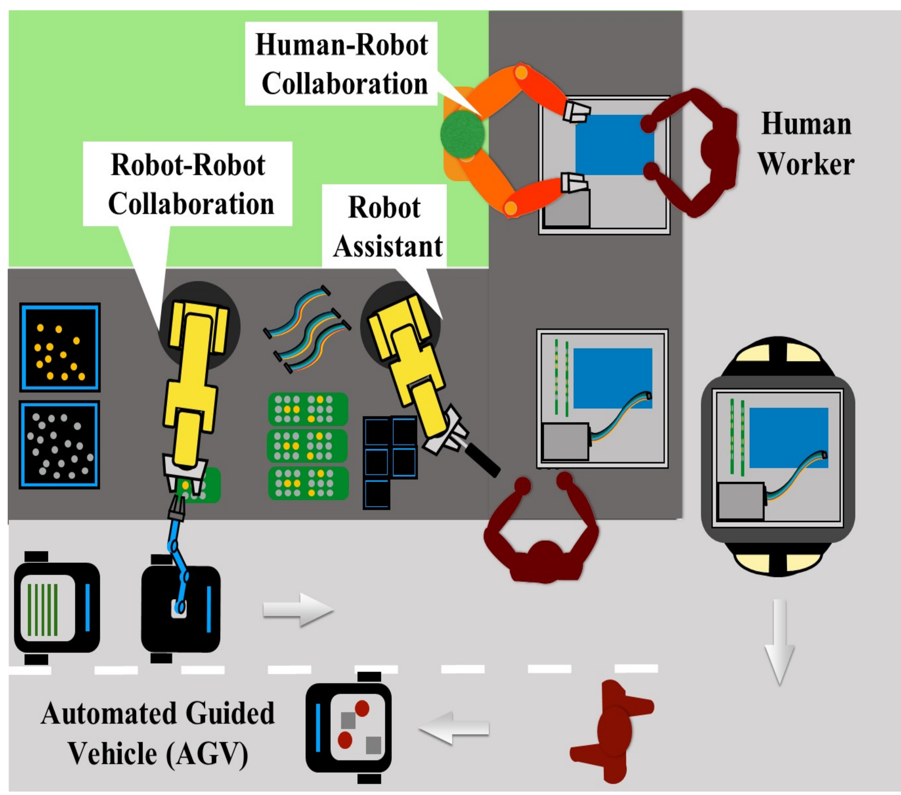
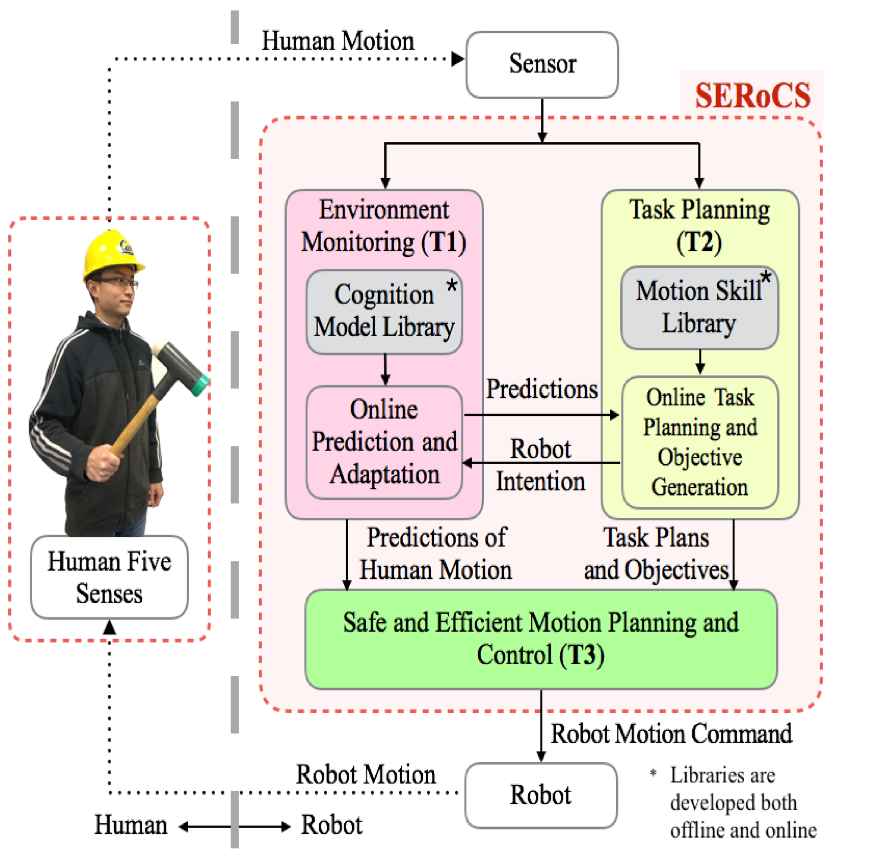
## OVERVIEW

**Objective**: to establish a set of design principles of safe and efficient robot collaboration systems (SERoCS) for the next generation co-robots.

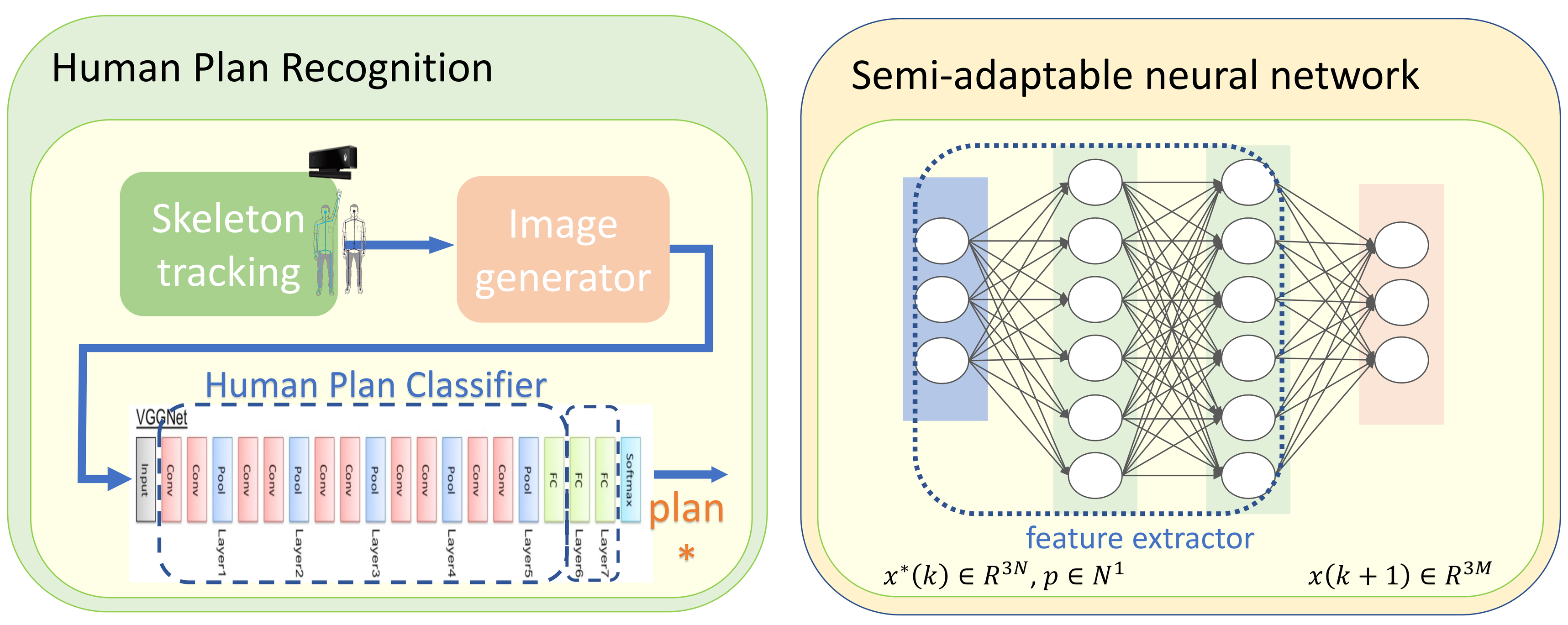
**Task 1**. Environment Monitoring with Human Motion Prediction
**Task 2**. Task Planning with Skill Library Learned from Human Demonstration
**Task 3**. Safe and Efficient Motion Planning and Control in Real Time
**Task 4**. Evaluation and Validation of the SERoCS by Analyses, Simulations and Experiments



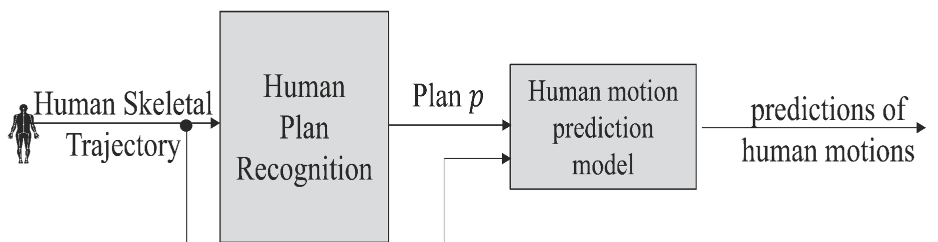



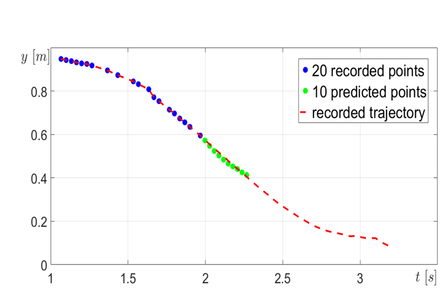

## TASK 1 – Environment Monitoring with Human Motion Prediction

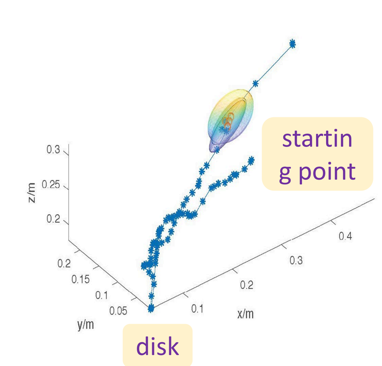
### Prediction process




### Prediction result





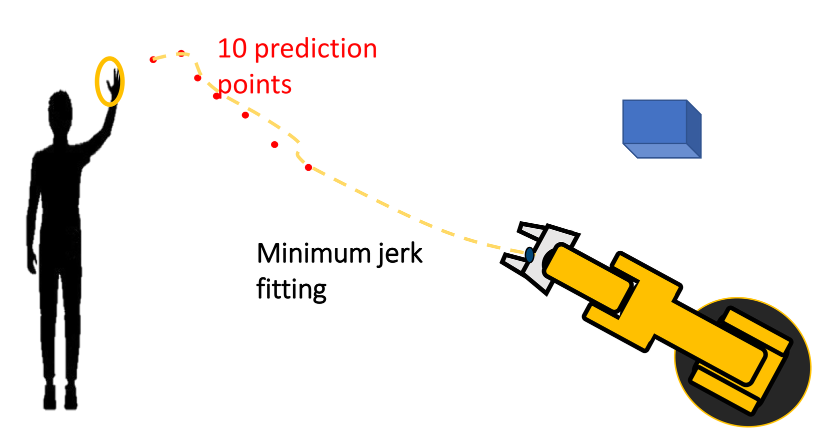

### Human intention determination using Minimum jerk method

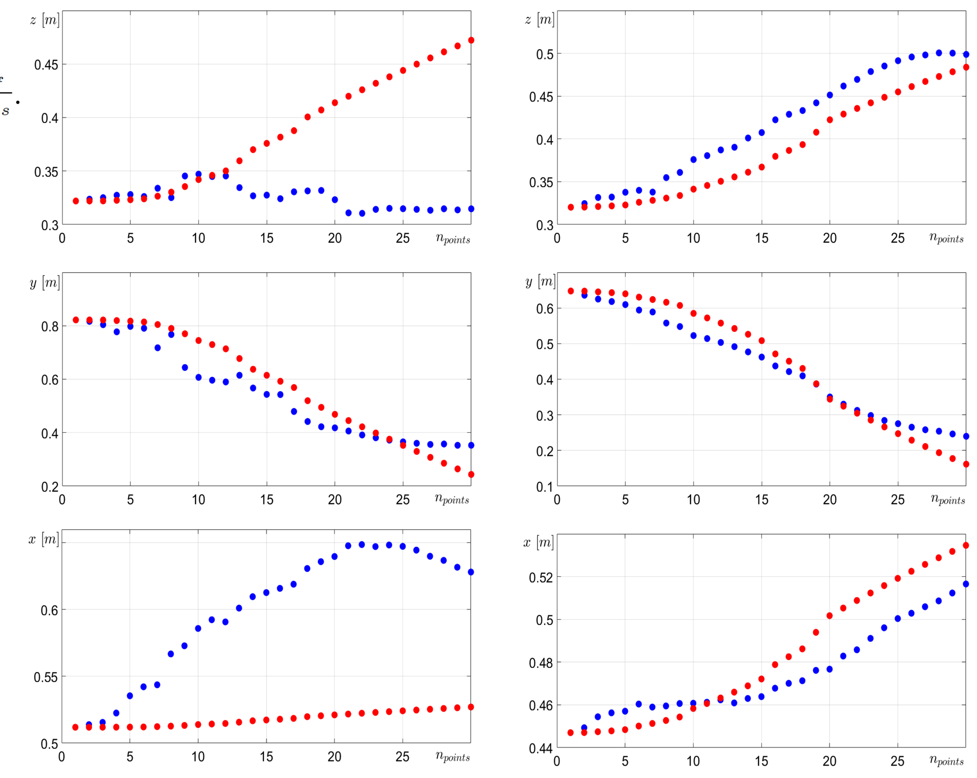
- **Polynomial solution results**

$$\mathbf{x} = \mathbf{x}_i + (\mathbf{x}_f - \mathbf{x}_i)\left(10\tau^3 + 15\tau^4 + 6\tau^5\right) \quad \text{,where } \tau = \frac{t - t_i}{t_f - t_s}.$$

- **Minimum jerk fitting**

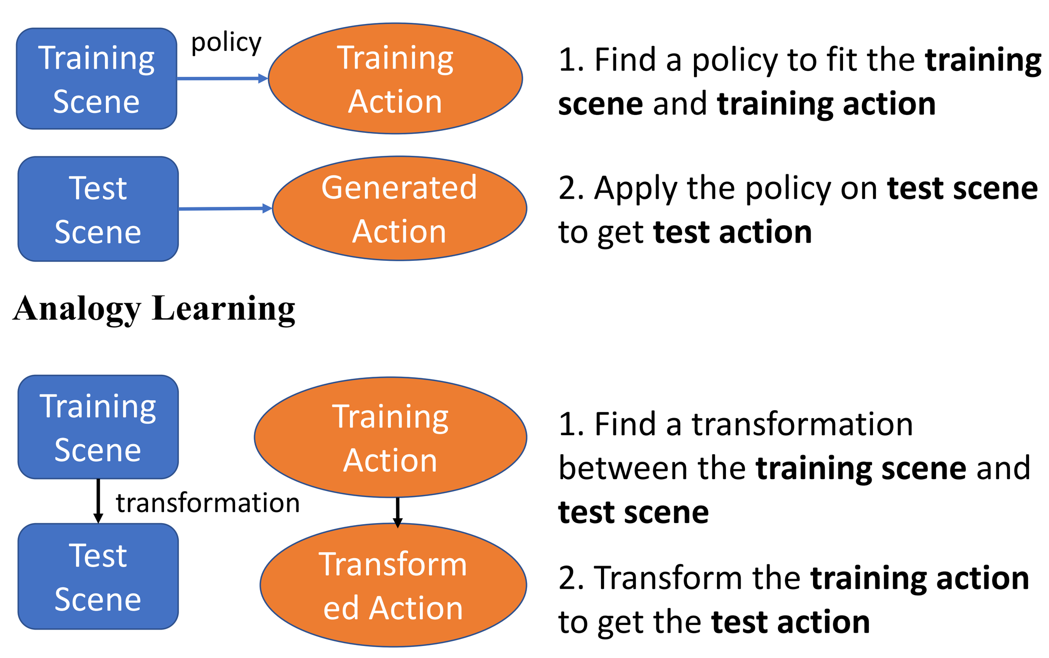
$$\min_{t_f} \; C(t_f) = \frac{1}{2}\sum \|\mathbf{x} - \hat{\mathbf{x}}\|^2.$$



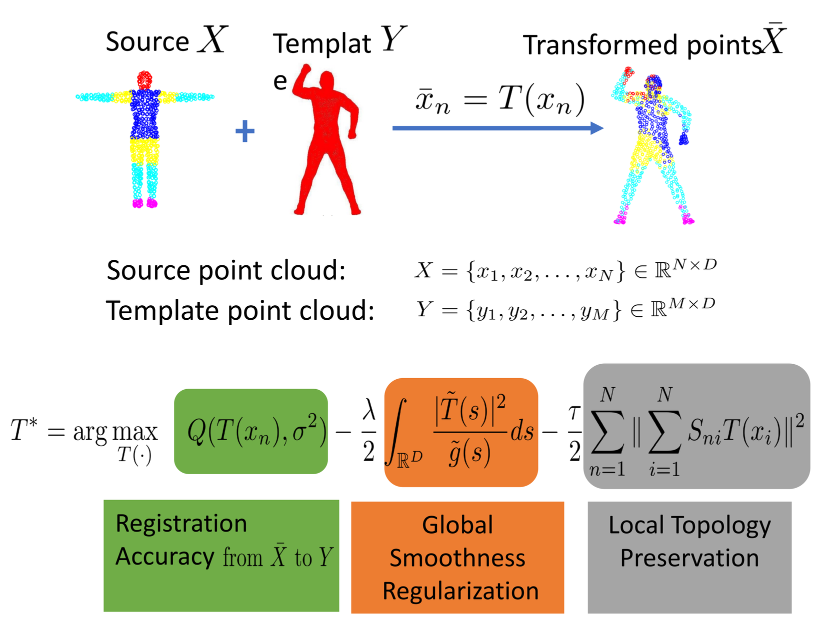



## TASK 2 – Task Planning with Skill Library Learned from Human Demonstration

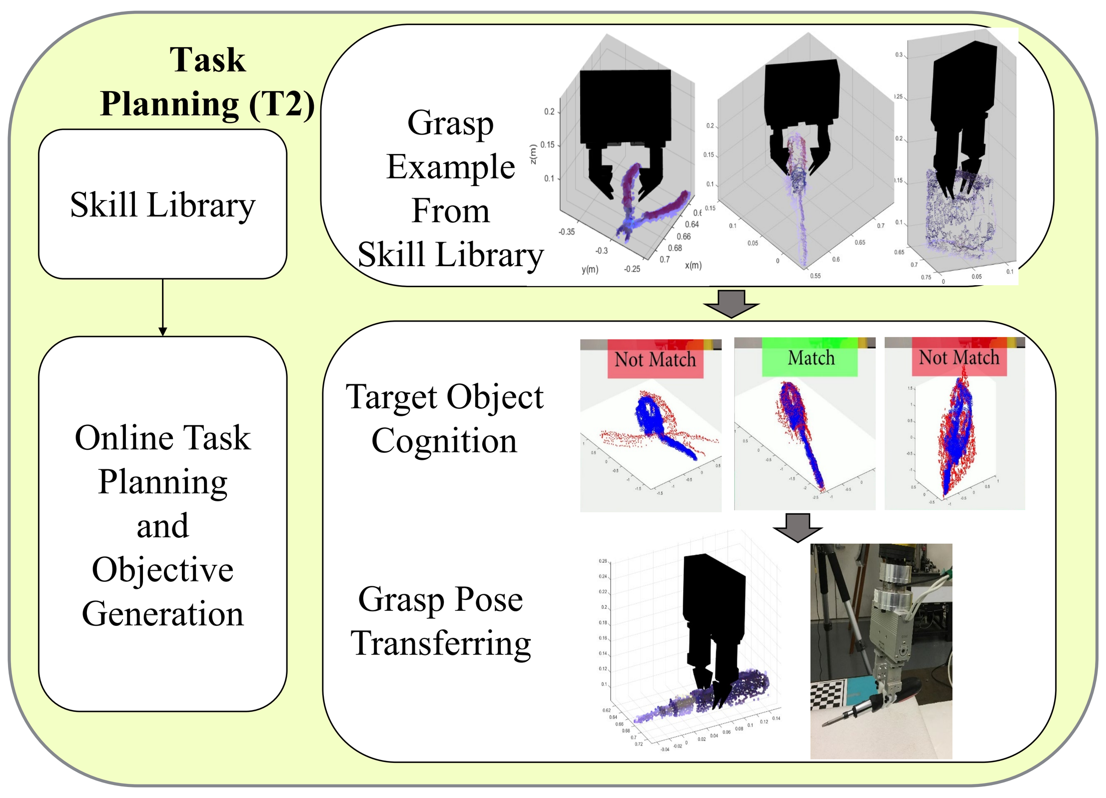
### Analogy Learning

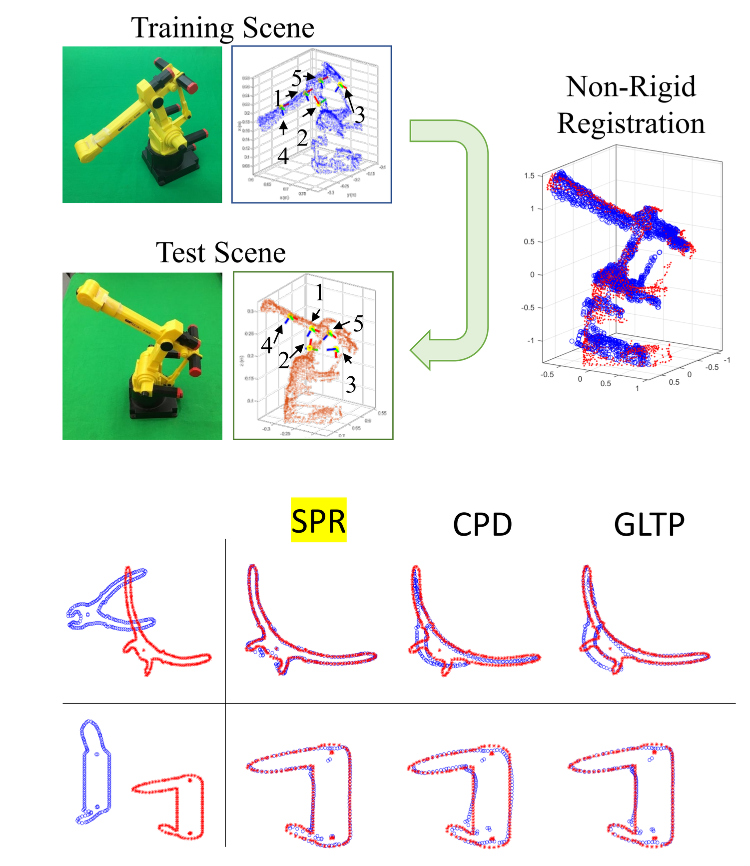



### Structure Preserved Registration (SPR)



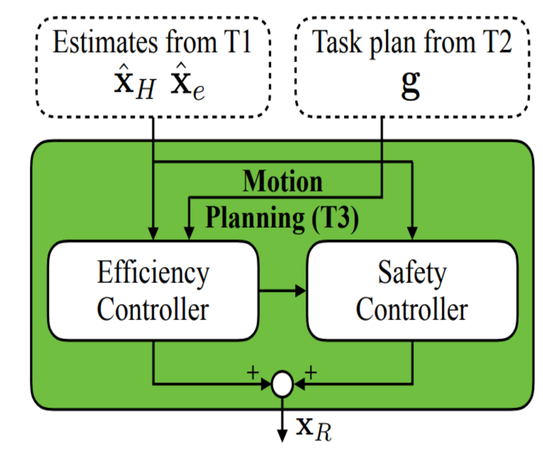

### Application and results



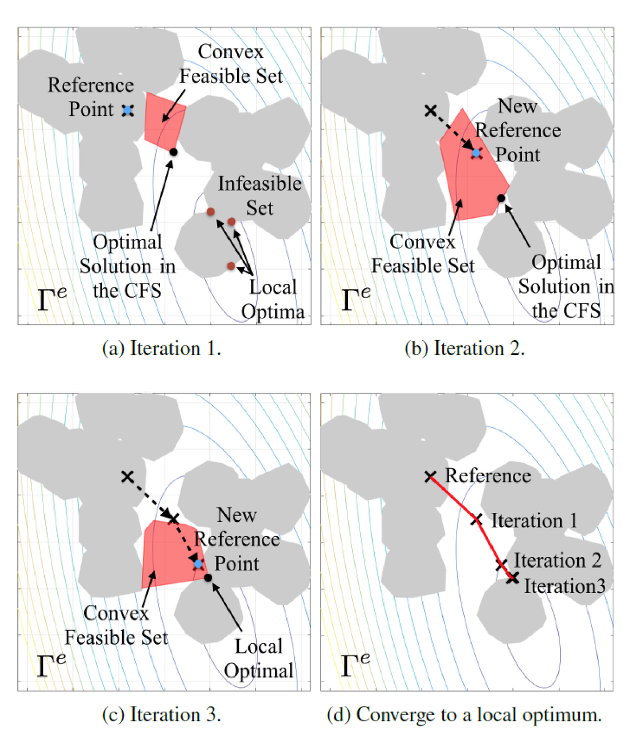




## TASK 3 – Safe and Efficient Motion Planning and Control in Real Time

### Motion planning



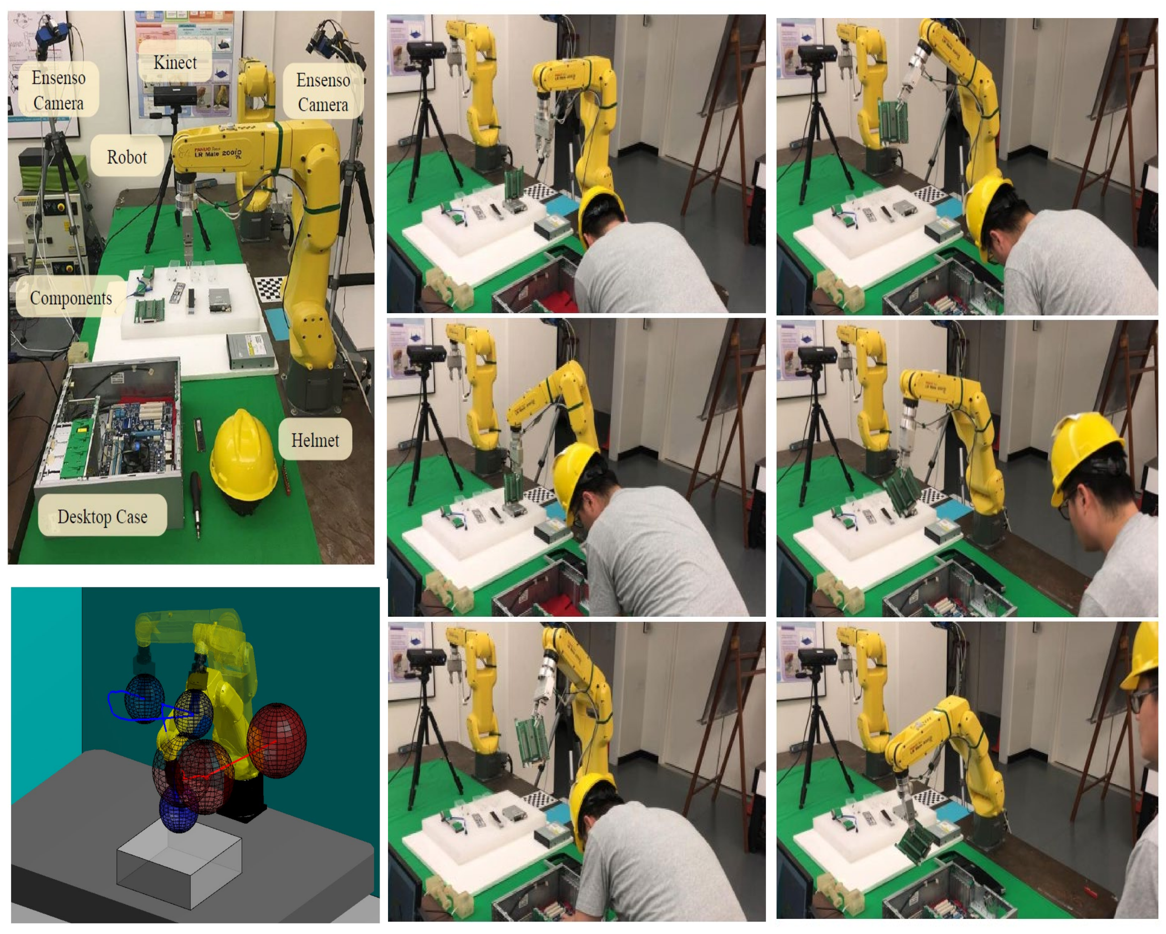

### Convex Feasible Set (CFS) Algorithm



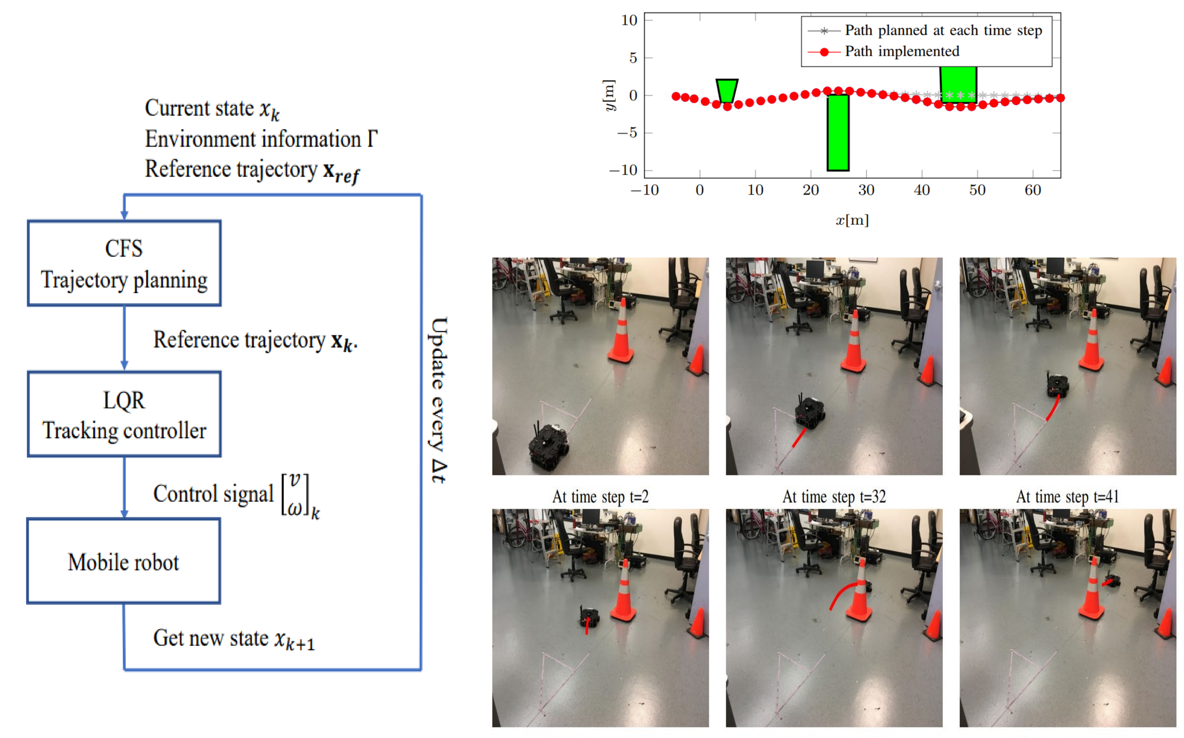

### Optimization problem

$$\begin{aligned}\min_{\mathbf{x}_k} \quad & J(\mathbf{x}_k) + \|\mathbf{S}\|_2^2, \\ s.t. \quad & x_{k+i} \in \Gamma(s_{k+i}), \forall i = 1, \ldots, H, \\ & x_k = x_0(k).\end{aligned}$$

### Application and results




### Mobile robot platform




[1] 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.
[2] H-C. Lin, C. Liu, and M. Tomizuka, "Fast Robot Motion Planning with Collision Avoidance and Temporal Optimization." in International Conference on Control, Automation, Robotics and Vision (ICARCV), 2018.
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