Cable Manipulation with a Tactile-Reactive Gripper

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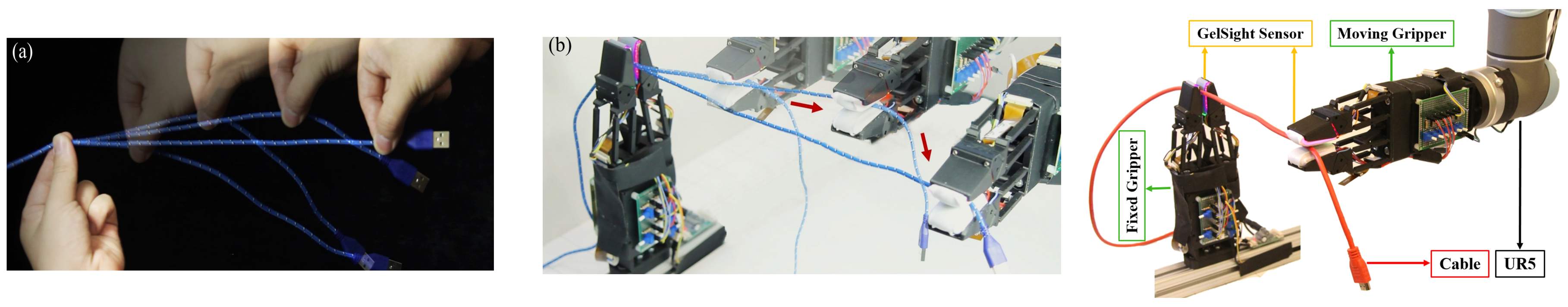
Motivation



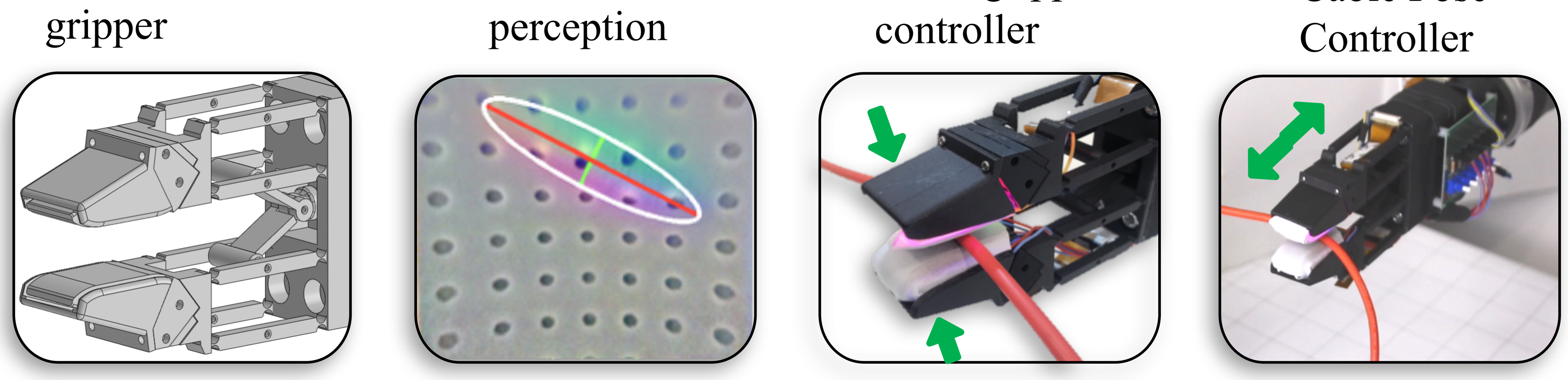
- Apart from screw assembling and bin picking, cable manipulating may be the other most essential task in industry robotic manipulation.
- Neither cable pose nor the contact force are directly observable with vision sensors.
- None of existing robots can perform the task due to the high model uncertainty and flexibility of the cables.
- We want robots have the capability to do the task.

Challenges

- Cable pose is difficult, if not possible, to estimate using mechanical-based tactile sensors;
- Grasp force should be large enough for tactile sensing while small enough for cable sliding;
- Gripper pose should be automatically modulated based on cable pose to prevent the cable falling.

Method

Tactile-reactive gripper | Tactile perception | Cable gripper controller | Cable Pose Controller

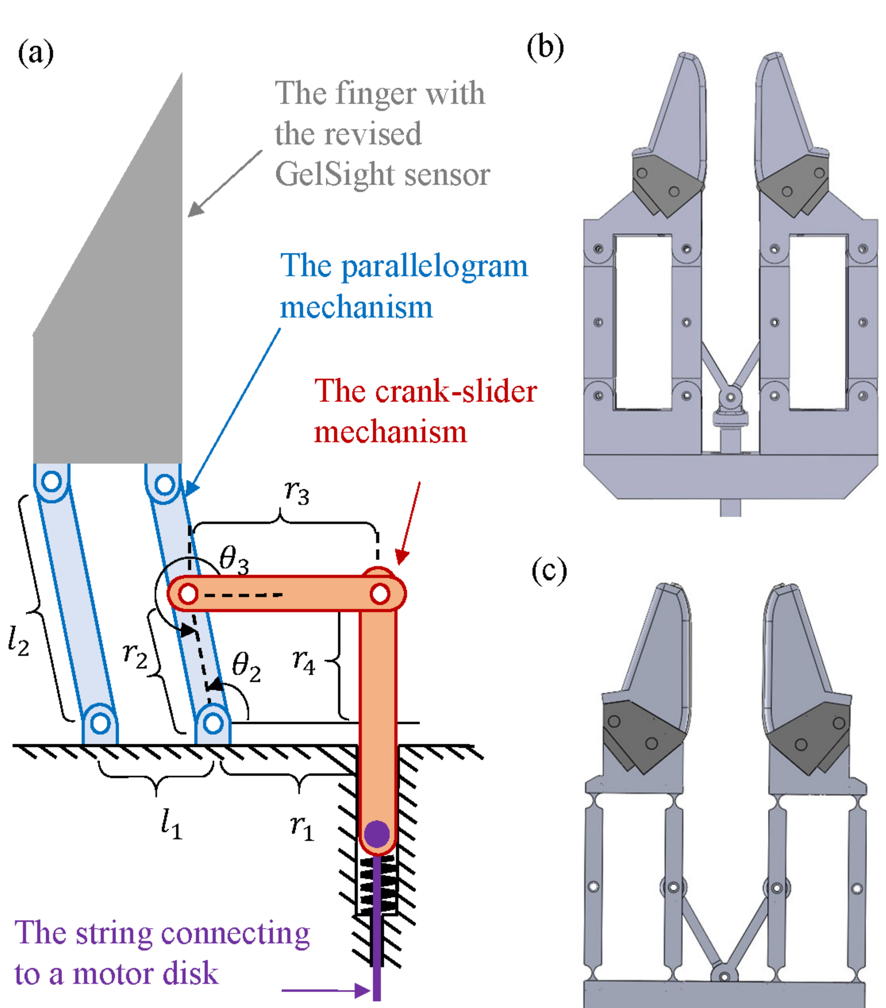


To address challenges, we build and integrate a system with:

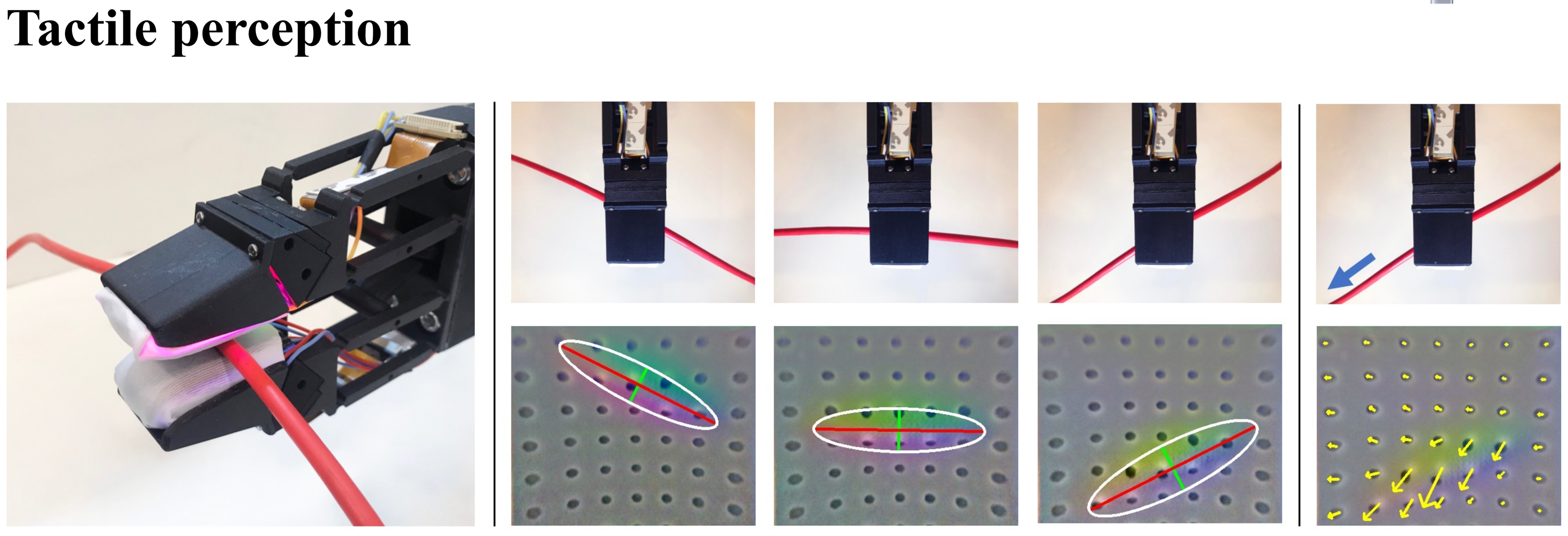
- Tactile-reactive gripper;
- Tactile perception. We estimate in real-time the pose of the cable in the gripper, the friction force, and the quality of the tactile imprints;
- Cable grip controller;
- Cable pose controller.

Tactile-reactive gripper

(a)A slider-crank mechanism, a slider-string-spring system, a parallelogram mechanism,
(b) The rigid parallelogram mechanism includes 28 parts,
(c) The compliant parallel-guiding mechanisms replaces the rigid parallelogram mechanism reducing the assembly parts from 28 pieces to a single piece.



Tactile perception



(a) Gripper grasping a cable (b) Cable pose estimation (c) Force estimation

<u>Cable pose estimation</u> Fast Poisson Solver to compute depth images; Thresholding the depth image to extract the contact region; Principal Component Analysis (PCA) to obtain the principal axis.
<u>Cable friction force estimation</u> Blob detection to locate the center of the black markers. The mean of the marker displacement field approximately proportional to the friction force.
<u>Cable grasp quality</u> Grasp quality evaluation based on the area of contact region.

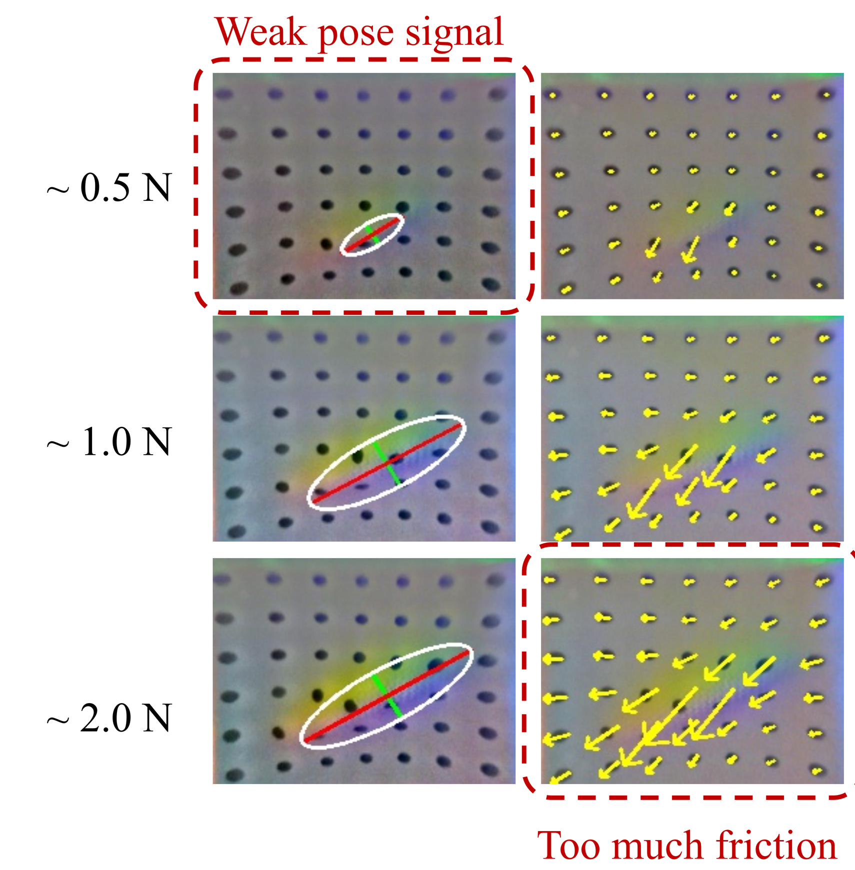
Cable grip controller

<u>PD controller to keep target friction</u>

$$u_{pd}[n] = K_p e[n] + K_d(e[n] - e[n-1])$$
$$e[n] = D[n] - D_t[n],$$

<u>Leaky integrator to ensure good signal quality</u>

$$D_t[n] = \alpha D_t[n-1] + (1-\alpha)(1-S),$$
$$S = \begin{cases} 1 & \text{if good quality} \\ 0 & \text{if poor quality} \end{cases}$$



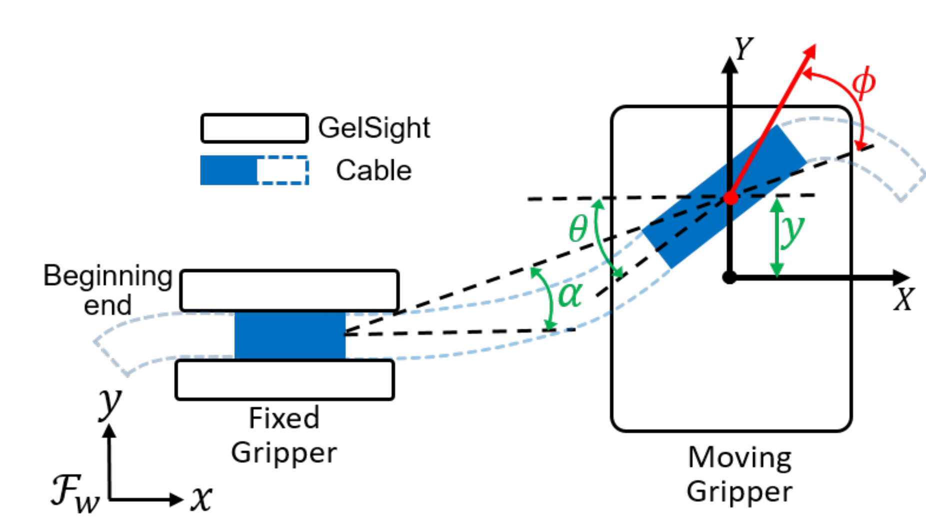
Cable pose controller

<u>A learned linear model</u>

$$\text{State } \boldsymbol{x} = \begin{pmatrix} y \\ \theta \\ \alpha \end{pmatrix}, \text{ input } u = \phi$$
$$\dot{\boldsymbol{x}} = A\boldsymbol{x} + B\, u$$

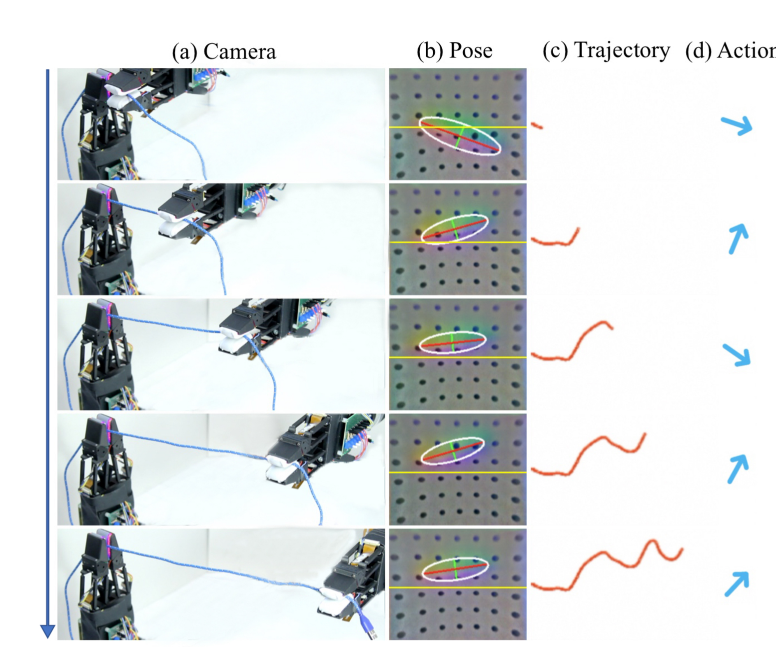
<u>LQR controller</u>

$$\bar{u} = -K\boldsymbol{x},\ \boldsymbol{x}^* = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, u^* = 0$$

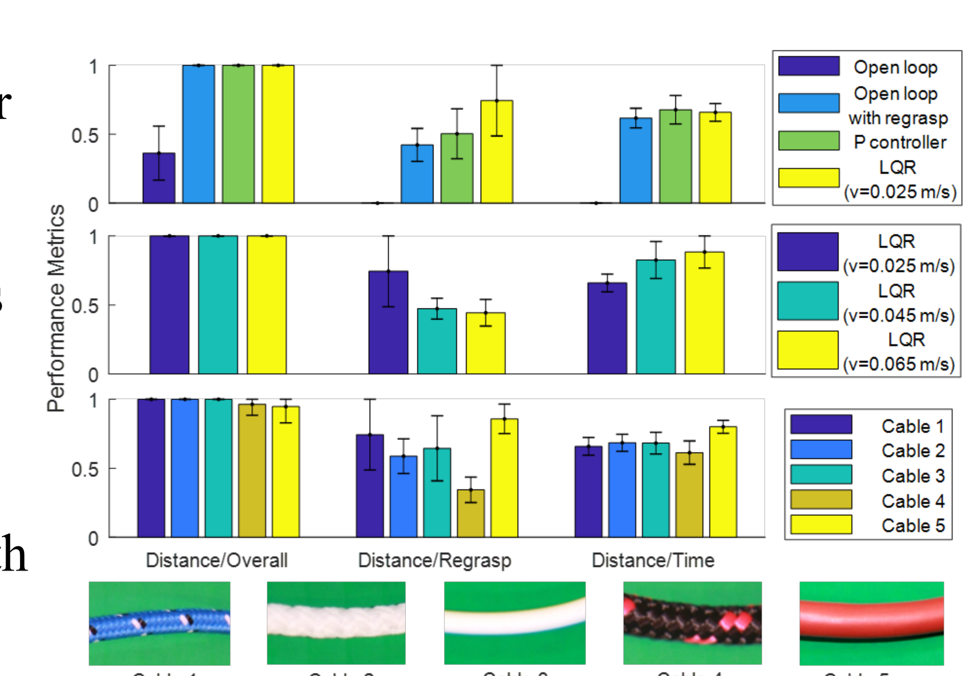


Results

Cable following experiment
(a) camera view,
(b) pose estimation from tactile imprints,
(c) top view of the trajectory of the end-effector,
(d) velocity input to the LQR controller.



Experimental results
<u>Different robot controllers</u> (**Top**)
LQR controller uses the least number of regrasp.
<u>Different velocities</u> (**Middle**)
Model learned at 0.025 m/s performs well on other velocities.
<u>Different cables</u> (**Bottom**)
Model learned from one cable performs well on different cables with different properties (diameters, materials, stiffness).



Conclusions

- An assembly-reduced parallel gripper;
- Cable pose estimation via high dimensional vision sensor;
- Cable grip controller via PD controller and leaky integrator;
- Cable pose controller based on a learned linear model via a single cable with a single velocity;
- **The first tactile reactive gripper that can perform cable following**;
- The perception and control framework offers a solution for manipulation tasks such as tying knots, sorting cables, routing ropes, etc.