Learning to Detect Slip through Tactile Measures of the Contact Force Field and its Entropy

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Motivation

- Robotic grasping and manipulation has found application in numerous industries.
- However, one of the biggest challenges in this field is detecting and preventing slip during manipulation.
- Slip can lead to dropped objects, damage to the robotic hand or the object itself, and safety hazards for nearby humans.
- Detecting and preventing slip is critical safe object handling.

Background

- Traditional methods of slip detection rely on either visual or force feedback, which prove to be unreliable.
- Tactile sensing has emerged as a better alternative due to rich contact surface information available.
- GelSight, an optical-tactile sensor, is able to provide surface contour and contact forces of contact surfaces.
- We use this rich information to develop a robust algorithm for slip detection and prevention by formulating slip detection as a classification problem by using sensor readings as features.

Hardware Setup

- UR5e robot fitted with custom machined metallic grippers to house GelSight mini sensor.
- Robotiq Hand-E robotic gripper used as the end effector for the UR5e robot.
- Robot controlled using ROS Noetic running on PC with Ubunutu 20.04.

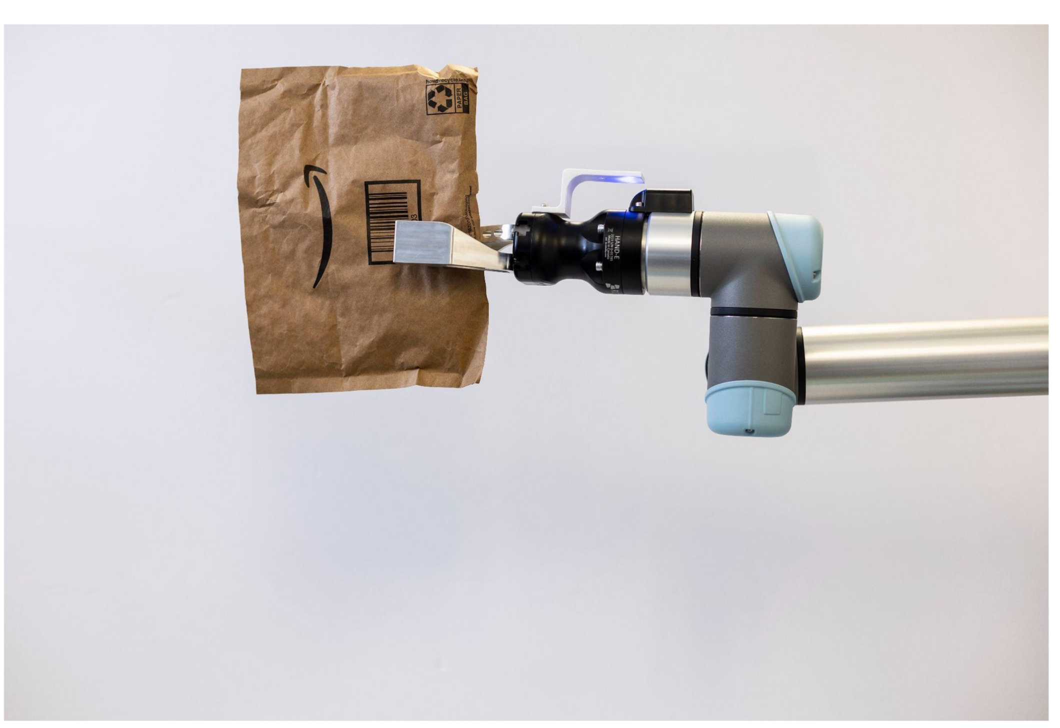
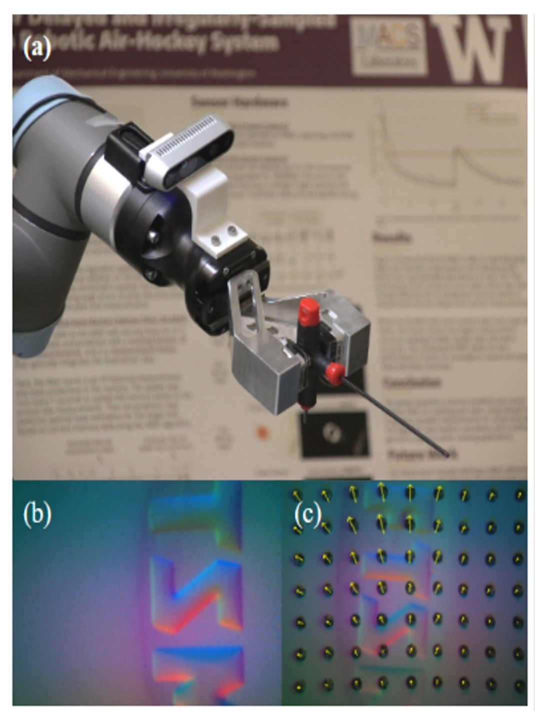


Figure 1: UR5e robot fitted with Robotiq Hand-E Gripper adapted to house GelSight Mini

Methodology

- GelSight sensor outputs images which provide qualitative information about the contact forces and also surface contour as shown in Figure 2
- The image needs to be parameterized so they can be used as features for the classifier
- Arrows indicate the direction and magnitude of the shear force
- The rate of change of arrows indicate the rate of change of the shear force.



$$V_{x_i}(t) = f \cdot (D_{x_i}(t) - D_{x_i}(t - \Delta t))$$

$$\bar{V_x} = \frac{1}{n}\sum_{i=1}^{n} v_{x_i}$$

$$\bar{V_y} = \frac{1}{n}\sum_{i=1}^{n} v_{y_i}$$

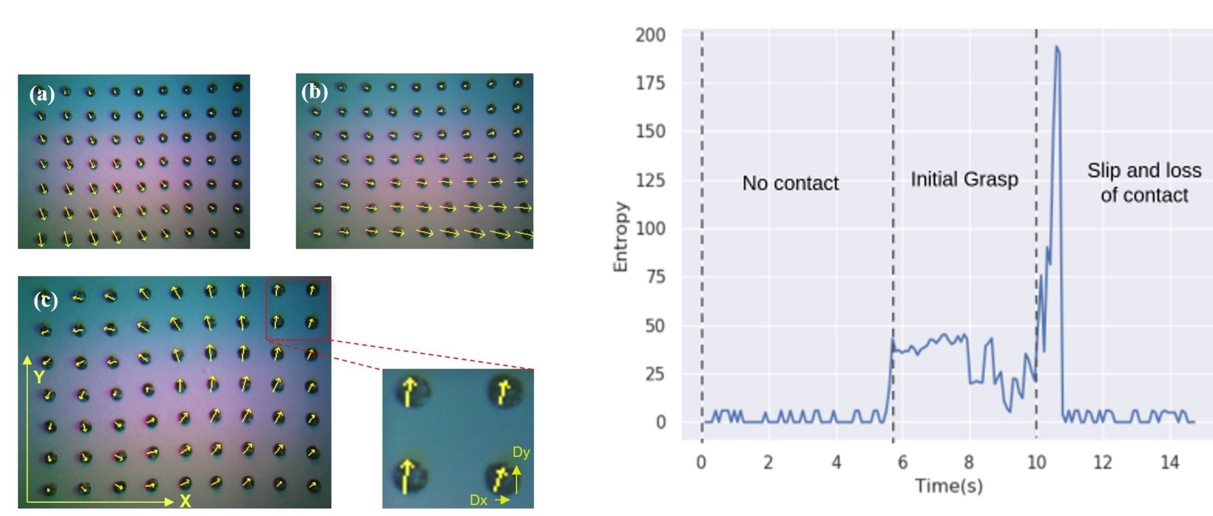


Figure 2: Output from GelSight and Entropy as object starts to slip

- In prior research, the inhomogeneity of the marker displacement field has been used as a metric detect slip.
  - This inhomogeneity is called entropy, given by:

$$H(X) = -\int_X p(x) log p(x) dx$$

  - Rate of change of entropy and entropy can be used as features for the classification problem.

$$\frac{dE(t)}{dt} \approx f \cdot (E(t) - E(t - \Delta T))$$

Results

Classifier	Accuracy%	Precision%	Recall%	F1 Score%
Logistic Regression	52.25	100	0	0
SVM	94.42	100	88.59	93.95
KNN	96.72	99.34	93.93	96.55
RF	96.83	96.83	94.66	96.69

Classifier	Accuracy%	Precision%	Recall%	F1 Score%
Logistic Regression	87.60	92.83	80.88	79.52
SVM	90.26	98.89	80.98	89.85
KNN	97.61	99.88	95.23	97.50
RF	99.14	99.14	98.80	99.11

Macro Avg:	Screw driver	Tennis ball	Contact Solution	Mouse	Box	Highlighter	Toy Raccoon	Sponge	Toy Owl	Floss
Accuracy	99.63%	100%	100%	99.74%	99.35%	99.73%	99.35%	100%	99.44%	97.59%
Recall	99.60%	100%	100%	99.57%	99.35%	99.67%	99.34%	100%	99.34%	98.07%
F1 Score	99.61%	100%	100%	99.66%	99.35%	99.70%	99.34%	100%	99.38%	97.82%

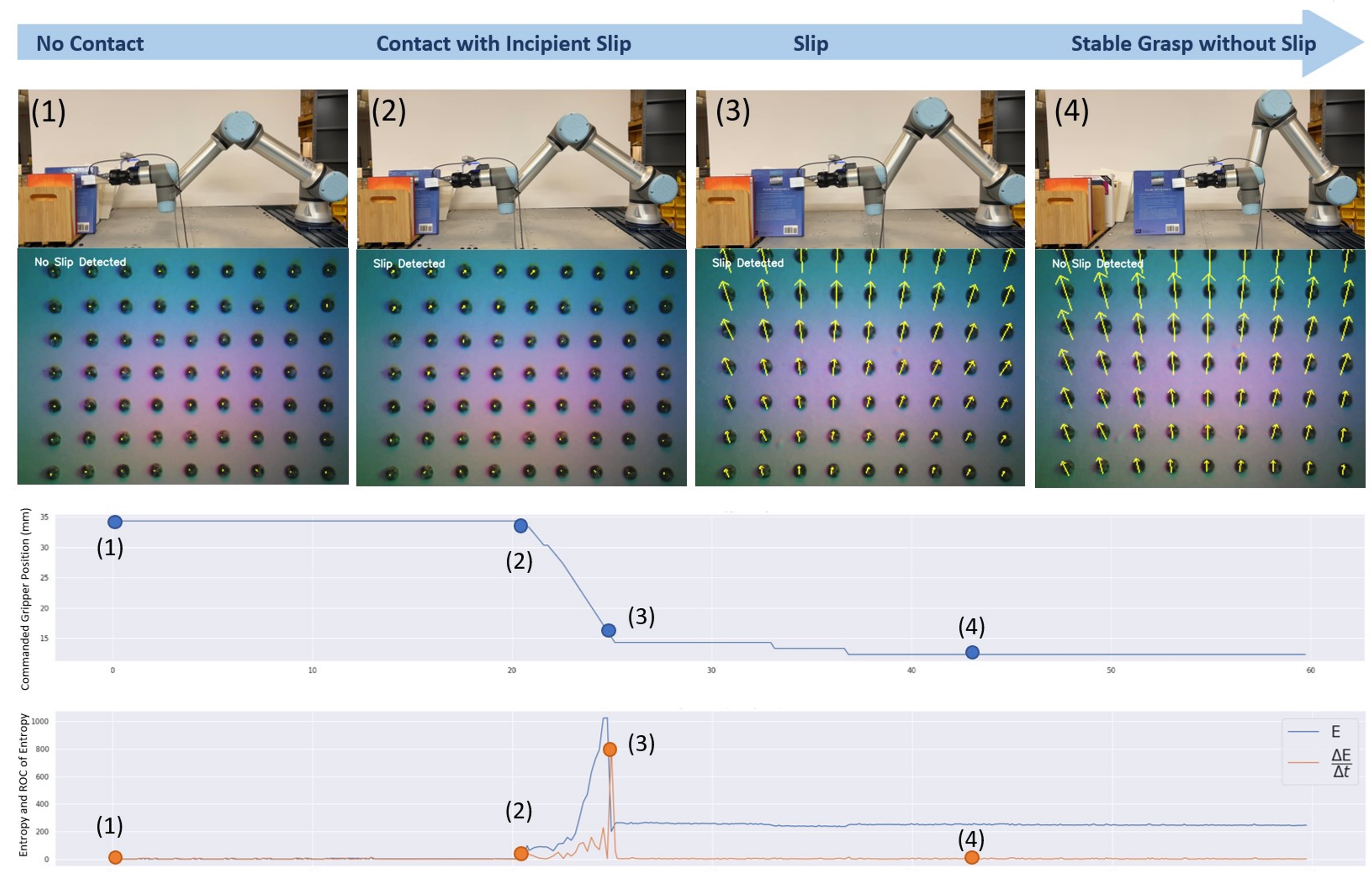


Figure 3: Example trial with slip detection algorithm embedded

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