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

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***Abstract*— Slip detection in object handling is crucial and traditionally relies on visual cues. However, for optimal performance, artificial tactile sensing is needed, especially with unfamiliar objects. This study introduces a real-time, physics-informed, data-driven method for continuous slip detection using the GelSight Mini optical tactile sensor. The sensor's inhomogeneity during slip events helps create unique features and recasts slip detection as a classification task. Tested on ten diverse objects, the best model achieved 99% accuracy. The work's practical use was demonstrated in a dynamic robotic manipulation task incorporating real-time slip detection and prevention.**

This study endeavors to elucidate the crucial parameters for slip detection, an essential component of tactile sensing that significantly augments the stability of robotic systems' grasp. Despite the vital role tactile feedback plays in human-object manipulation and its potential utility in robotic applications, the influence of different inhomogeneity metrics on the probability of slip remains hitherto indistinct.

We propose a novel methodology, which markedly enhances the success rate of slip detection to exceed 99%, thereby providing an efficacious real-time slip detection mechanism capable of triggering instantaneous remedial actions. Furthermore, this research undertakes a comprehensive comparative analysis of various data-driven techniques employed in slip detection across an array of common objects. This systematic evaluation promises to yield valuable insights into the optimization of tactile feedback-based slip detection in robotic systems.

To refine slip detection accuracy, we employ GelSight sensor images and replicate human perception mechanisms. We extract entropy from GelSight images as a feature, reflecting image randomness and serving as a reliable slip indicator. This entropy-based approach captures minute texture and surface roughness variations, indicative of slip, thereby enhancing slip detection performance. Notably, it eliminates the need for prior object and grasping condition knowledge, advantageous in real-world settings where such information is limited or unavailable. The research evidences that an entropy-based strategy enhances accuracy, making it highly effective for slip detection and prevention.

An innovative algorithm premised on entropy-based slip detection was developed and subjected to empirical testing. This involved the UR5e robotic arm, equipped with a GelSight sensor, tasked with executing the dynamically complex task of extracting a book from a bookshelf. In the absence of the formulated algorithm, the manipulation task consistently resulted in failure. Conversely, the integration of the developed algorithm facilitated the successful execution of the task, thereby empirically validating the efficacy of our entropy-based slip detection approach within a real-world context.

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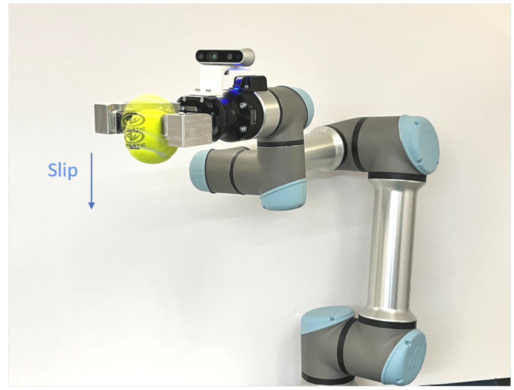

Fig. 1. Hardware Setup: An UR5e robot arm, a hand Robotiq parallel gripper, the fingertips were replaced by a customized metallic adapter equipped with two Gelsight tactile sensors. An Intel real sense depth camera D435i is mounted on the top of the gripper

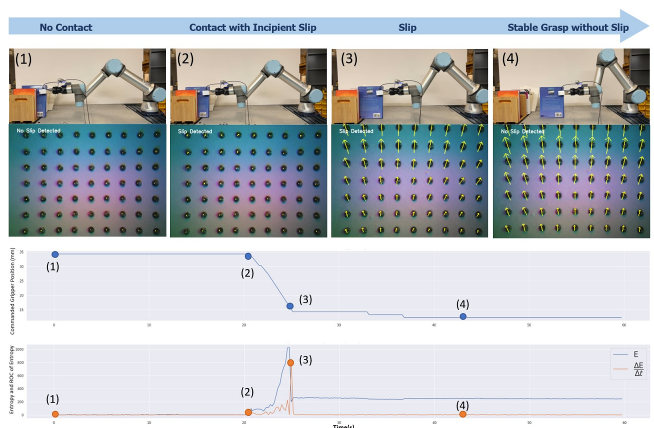

Fig. 2. A demonstration of sliding a book out of a shelf is presented, consisting of multiple stages of grasping. The initial row of images portrays the progressive grasping stages, commencing from (1) static initial grasp, advancing towards (2) an incipient slip at the start of manipulation, further to (3) an actual slip, and culminating at (4) a stable grasp. The subsequent row exhibits the data obtained from a tactile sensor and the corresponding real-time detection of slip. The third row displays the command gripper distance to forestall slippage, whereas the fourth row depicts the entropy and the rate of its alteration throughout the grasping procedure.

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