Vib2Move: In-Hand Object Reconfiguration via Fingertip Micro-Vibrations

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***Abstract*—We introduce Vib2Move, a novel approach for in-hand object reconfiguration that uses fingertip micro-vibrations and gravity to precisely reposition planar objects. Our framework comprises three key innovations. First, we design a vibration-based actuator that dynamically modulates the effective finger–object friction coefficient, effectively emulating changes in gripping force. Second, we derive a sliding motion model for objects clamped in a parallel gripper with two symmetric, variable-friction contact patches. Third, we propose a motion planner that coordinates end-effector finger trajectories and fingertip vibrations to achieve the desired object pose. In real-world trials, Vib2Move consistently yields final positioning errors below 6 mm, demonstrating reliable, high-precision manipulation across a variety of planar objects. For more results and information, please visit https://vib2move.github.io.**

I. Introduction

In-hand manipulation—the ability to reposition an object within the robot's grasp—is central to achieving dexterous and versatile robotic applications. Among the myriad of available end-effectors, parallel jaw grippers stand out for their simplicity, low cost, and widespread adoption across various industries. However, their single degree of freedom (DoF) poses a fundamental challenge: it severely restricts the types of in-hand reconfiguration that can be performed. This gap in capability not only limits the range of tasks that can be executed but also underscores the need for new methods to enhance the dexterity of these otherwise robust and practical grippers.

Prior research on in-hand reconfiguration can be broadly categorized into two classes: methods that adapt single DoF end-effectors (primarily parallel jaw grippers) and those that exploit dexterous multi-fingered hands. In the former group, one common strategy is to leverage environmental features, such as walls or shelves, effectively treating them as additional "virtual fingers." These approaches often rely on known geometry, friction properties, and precise force control to achieve the desired manipulations. While effective under controlled conditions, they falter when the environment is not well-defined or when real-time adjustments in grasping force are required—a nontrivial feat for conventional parallel jaw grippers. Meanwhile, multi-fingered robotic hands circumvent many of these issues by offering richer manipulation capabilities, but their inherent complexity, cost, and calibration overhead often make them impractical for industrial contexts. As a result, a method that marries the simplicity of a two-finger design with the dexterity of more advanced end-effectors remains highly desirable.

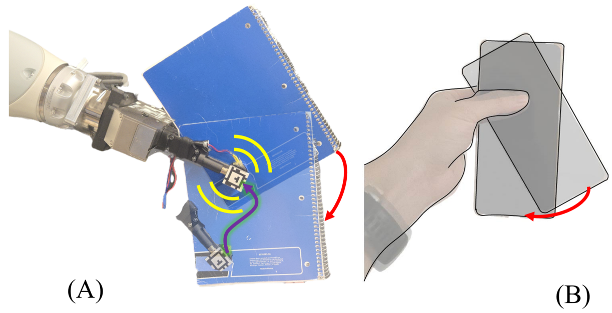
(A) (B)

Fig. 1: (a) Robot pivots a notebook in free space, using gravity and fingertip vibrations. (b) Human pivoting a cellphone in free space, utilizing gravity and precise control of grasping force

To address this need, we propose a vibration-based gripper design that dynamically modulates the effective friction between the fingertips and the grasped object. By introducing micro-vibrations at the contact interface, our design induces rapid transitions between stick and slip regimes, effectively providing high-frequency control over the "equivalent" grasping force. Building on this mechanism, we develop a friction and motion model specifically for planar objects grasped vertically in free space, where gravity is the sole external force. Unlike previous approaches requiring detailed knowledge of contact properties or object mass, our model depends only on the geometry of the finger contact area. This characteristic grants a notable degree of robustness by tolerating uncertainties in friction and object weight, thus avoiding the fine-tuned parameter calibration that often hampers manipulation tasks. While we demonstrate our approach on a parallel jaw gripper, the underlying principle of vibration-based friction modulation can seamlessly extend to more sophisticated or multi-fingered end-effectors, broadening its applicability to a wider range of hardware platforms.

We implement this approach on a parallel jaw gripper outfit-

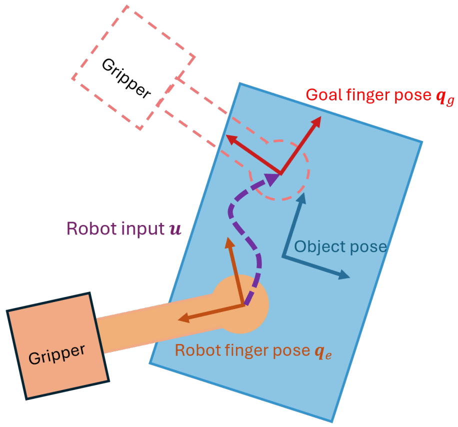

Fig. 2: Problem statement: Given the robot finger pose $\boldsymbol{q}_e$, find the robot input $\boldsymbol{u}$ to drive the finger to goal pose $\boldsymbol{q}_g$.

ted with low-profile vibration motors in each finger, employing only on-off vibration signals for rapid friction control. By integrating a heuristic-based subgoal generation scheme and a closed-loop visual controller, our system can reposition planar objects in free space without specialized fixtures or intricate force sensors. Prior work has explored environmental-assisted manipulation [1] and multi-DoF vibration-based end-effectors [2, 3], but these approaches demand additional resources, known geometry, or more complex hardware. In contrast, our design retains the inherent simplicity and reliability of standard parallel jaw grippers while offering a versatile method for in-hand reconfiguration.

A. Problem Statement

Consider the exemplar task illustrated in Fig. 2. The goal of the robot is to move the object from its initial configuration in the grasp to the desired configuration. The object motion is constrained to the vertical plane, where gravity acts exclusively in the negative direction. We assume that the grasping contact remains a patch contact with a constant shape and that the friction is homogeneous. We also assume both the object and the gripper are rigid.

Let $\boldsymbol{q}_e^w(t) \in \mathrm{SE}(2)$ and $\boldsymbol{q}_o^w(t) \in \mathrm{SE}(2)$ represent the poses of the robot finger and the object in world frame, at time t respectively. We define $\boldsymbol{q}_r^o \in \mathrm{SE}(2)$ as the relative pose of the robot finger with respect to the object frame, given by $\boldsymbol{q}_r^o(t) = \mathbf{J_B}(\boldsymbol{q}_e^o(t) - \boldsymbol{q}_o^o(t))$, as illustrated in Fig. 2. The relative pose $\boldsymbol{q}_r^o(t)$, deviates from its initial value only due to slip between the finger and the object. Given an arbitrary relative robot finger goal pose $\boldsymbol{q}_g^o \in \mathrm{SE}(2)$ for the robot finger to reach on the object, our objective is to design an input consisting of the end-effector finger trajectory and vibration control input $\boldsymbol{u}(t) = [\boldsymbol{q}_e^w(t), v_e(t)]$, where $v_e(t)$ is vibration control, to minimize the final pose error:

$$\boldsymbol{u}^* = \arg\min_{\boldsymbol{u}} ||\boldsymbol{q}_e^o(T) - \boldsymbol{q}_g^o||$$

where T is time at the end of the path. To achieve the goal pose, it is necessary to regulate the relative slippage, as the relative pose is controlled through this slippage.

II. Related Works

In-hand manipulation has been extensively studied, encompassing both prehensile and non-prehensile strategies. Many works focus on leveraging high-DoF robotic hands for dexterous in-hand manipulation. Both model-based and learning-based approaches have significantly advanced these strategies. For instance, object-level impedance control ensures compliant 6-DoF positioning while maintaining grasp stability during contact reconfigurations, such as finger gaiting [4]. Contact-implicit model predictive control (MPC) enables dynamic replanning under uncertainty without predefined contact sequences [5]. Reinforcement learning (RL) has demonstrated success in handling contact variability and generalizing across objects [6, 7], while hybrid frameworks combine RL for planning with model-based controllers for stability [8, 9, 10]. Additionally, motion primitive dictionaries derived from human demonstrations simplify modeling by indirectly capturing manipulation constraints [11, 12]. Parallel grippers have also been studied for in-hand manipulation, primarily with planar objects. Due to their single degree of freedom, their manipulation capabilities are inherently limited. Karayiannidis et al. [13] proposed an adaptive control approach for pivoting with a parallel gripper using both visual and tactile feedback. However, their method focused solely on orientation and was constrained to cases with gravity-induced torque. Chavan-Dafle et al. [1] introduced motion cones, leveraging the environment as an external pusher for manipulating planar objects. In our work, we do not depend on external features. Hou et al. [14] designed a unique locking mechanism attached to the fingertips and two primitives to either roll or pivot an object in the grasp. While offering significant dexterity, this method also requires using the environment.

To address the limitations of parallel grippers, researchers have explored modifications to introduce additional DoFs. For instance, Ma et al. [15] incorporated a conveyor-like surface into the gripper to enhance its in-hand manipulation capabilities. Nahum et al. [2] and subsequent work by Binyamin et al. [3] added rotation and vibration to the gripper fingertips, enabling arbitrary planar object manipulation. In our work, we employ a commercial parallel gripper and augment it with vibrational fingertips, achieving arbitrary pose manipulation of planar objects.

The modeling, planning, and control of planar object pushing or sliding have been extensively studied. Stuber et al. [16] conducted a comprehensive survey on robotic pushing, covering both analytical and data-driven approaches. Lynch and Mason [17] proposed a motion planning algorithm leveraging sticking interactions to achieve target trajectories. These manipulation strategies—often referred to as dragging or sliding—rely on quasi-static analysis, Coulomb friction with limit surface modeling, and soft contacts for moment transfer. Kao et al. [18] examined compliance and sliding mechanics, which were later extended to the manipulation of lightweight objects, such as a business card, using two sliding robot fingers on a frictionless table [19, 20]. However, such frictionless assump-