DexiTac: Soft Dexterous Tactile Gripping

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Abstract: Grasping objects—whether they are flat, round, or narrow and whether they have regular or irregular shapes—introduces difficulties in determining the ideal grasping posture, even for the most state-of-the-art grippers. In this paper, we presented a reconfigurable pneumatic gripper with fingers that could be set in various configurations, such as hooking, supporting, closuring, and pinching. We propose a tactile kernel density manipulation strategy for simple and versatile control, including detecting grasp stability and guiding dexterous manipulations. The gripper is relatively easy to fabricate and customize, offering a promising and extensible way to combine soft dexterity and tactile sensing for diverse applications in robotic manipulation.

Keywords: Grasping, dexterous manipulation, visuotactile sensing

1 Introduction

Human activities encompass interactions with an extensive range of objects. While this comes naturally to us, it presents significant challenges for designing robotic grippers [1]. Traditional grippers are engineered for specialized tasks with fixed designs, and are not intended to be modified once manufactured, which restricts their versatility [2]. While the reconfigurability of the gripper broadens its dynamic gripping capabilities, it also introduces new complications. Due to the use of soft materials to enhance safety and adaptability, there may be difficulties in assessing the success of a grasp during physical tasks [3], which could inadvertently result in damage to either the gripper or the objects being held [4]. Therefore, it is important to develop reconfigurable grippers equipped with integrated tactile sensing ability.

Image-based tactile sensors provide good solutions for gripper integration owing to the rich information they provide from high-resolution camera images [5, 6]. Their inherent compliance makes them well-suited for manipulation tasks, such as grasping and accurately detecting phase changes. However, the existing sensors are customized for specific grippers, their sizes and non-modularity make them ill-fitted for reconfigurable grippers. This motivates a need for a compact, seamlessly integrated sensor with modular compatibility.

2 Gripper Design

Our design aims to allow many configurations by simply rearranging the assembly of palms and joints, and customizing the gripper to specific object-grasping needs and tasks.

HookGrip: With the 3-DoF Dex joint positioned at the top and the 1-DoF Rot joint below, this setup allows the finger's joint section to curve into a hook shape, suitable for tasks like hanging a bag handle. This gripper configuration is ideal for high-load grasping activities.

SupportGrip: The 3-DoF Dex joint is oriented internally and the 1-DoF Rot joint is external. By using its body to cradle objects, this configuration offers stability during holding tasks.

ClosureGrip: With the 3-DoF Dex joint externally positioned and the 1-DoF Rot joint internally located, this setup facilitates the encircling of sizable objects.

8th Conference on Robot Learning (CoRL 2024), Munich, Germany.

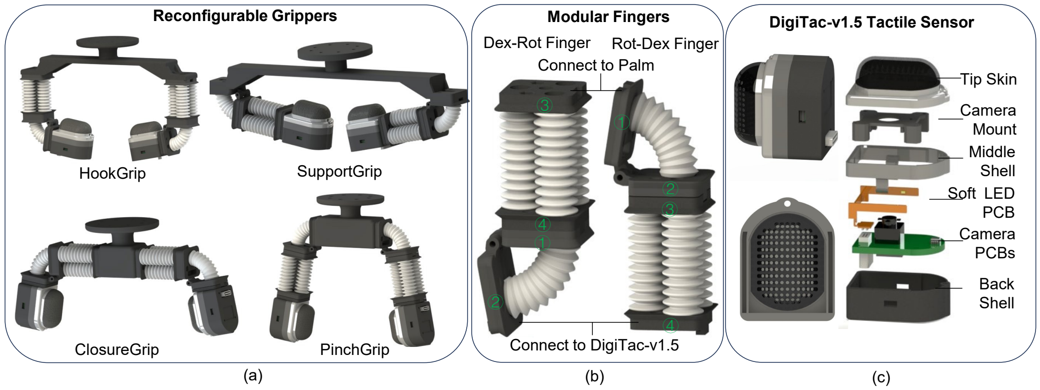

Figure 1: Design of reconfigurable grippers, fingers and sensor: (a) Different reconfigurable grippers. (b) Different assemblies of connectors and configurable fingers after assembly. (c) Overall view of DigiTac-v1.5 and its component design.

PinchGrip: Placing the 1-DoF Rot joint at the top and the 3-DoF Dex joint at the bottom, the pinch grasp is the most common grasping method. This gripper configuration is highly flexible and suitable for handling cuboid objects.

3 DigiTac-v1.5 Design

For enhanced sensing functionality, we developed the DigiTac-v1.5 that implemented the following changes as an improved version of our previous DigiTac [7].

Material & Marker Design: Given the requirements for superior elasticity and wear resistance, we have chosen the Agilus-30 material, which is more robust and offers superior elongation at break, tear resistance and tensile strength. In addition, we have updated the design of the skin surface to have semi-cylindrical and 1/4 spherical surfaces to heighten sensitivity over the flat-skinned sensors, with the cross-section area of the skin occupying about 75% of the total volume.

Camera & Circuitry Integration: We innovated a camera driver board (with the OV5693 camera, 120° view) shaped to the fingertip's contours, built on the efficient SPCA2650A chip. In addition, the camera connects to the driver using a 20-pin FPC ribbon cable, improving modularity and saving circuit board space. Using the Vero-series resin and multi-material 3D printing (Stratasys J826), the entire sensor weighs a mere 9.8 g, halving the DigiTac's weight.

Assembly & Adaptability: We have transitioned from the LED board for lighting in DigiTac, to a 10-pin LED board in DigiTac-v1.5. This soft FPC ribbon cable enhances adaptability to various installation points. In addition, the Type-C port manages both power and signal connections, introducing a more usual plug-and-play feature uncommon in camera-based tactile sensing.

Overall, DigiTac-v1.5 builds on the merits of diverse camera-based tactile sensors, presenting a compact, easy-to-use, low-cost, and customizable method for tactile sensing. Hereafter, we will simply refer to the DigiTac-v1.5 as DigiTac.

3.1 Control Strategy

The raw tactile images are first transformed to grayscale images of dimension 640×480 pixels. The positions of the tactile markers on the image are then detected using DoH blob recognition [8]. Subsequently, marker densities are estimated using a Gaussian kernel density with kernels located at marker centroids. The extent of the low marker-density region in the kernel density map depends on the contact depth and gives information about the contact region. The center of contact is extracted as the point with the lowest density. Changes in the contact center represent the interaction with the environment. Thus, we can get the trajectory of the contact area by calculating the moving Euclidean displacement that connects the contact center between frames, which can be used for real-time dexterous grasp control. To gauge the success of the grasp, we evaluate whether the contact center remains stable from whether it moves less than $T_1 = 0.5$ mm within a 3 sec span.

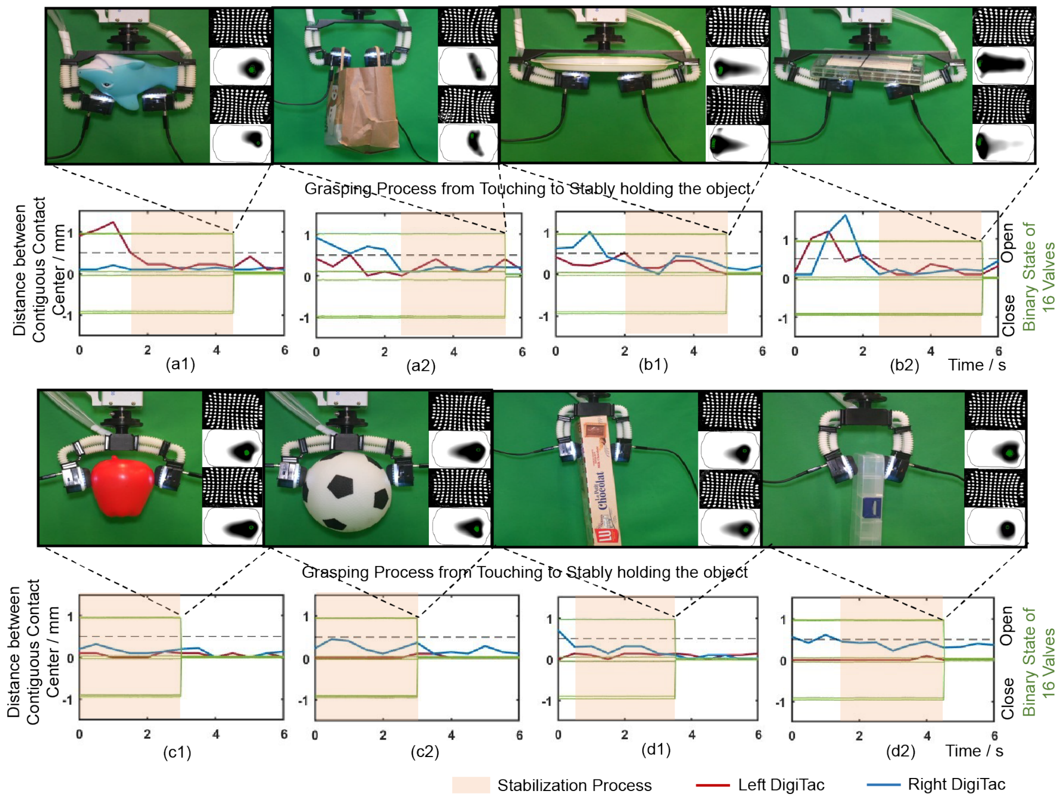

Figure 2: Representative grasping tests of each configuration and states of contact. The objects include (a1) a soft shark toy, (a2) a paper bag, (b1) a flat plate, (b2) a bolt toolbox, (c1) a round pepper, (c2) a mini soccer ball, (d1) a cookie box, (d2) a toolbox.

4 Experiment Results

4.1 Grasping Test

To test the grasping and its adaptability for each configuration of gripper, we utilized each gripper to grasp household objects for which they are best suited. The processes from contacting the object to stably holding the object as well as data-capture by the tactile fingertips are shown in Figure 2.

We show tactile images of grasping to depict the moments when the grasp becomes stable in Figure 2, and the red and blue lines on the underlying plots display the changes in the corresponding two contact centres. Overlaid on these plot are step functions that shows the binary open/close status of the 8 inflating valves and 8 deflating valves: 1 denotes the inflation valve is open, -1 indicates the suction valve is open and 0 indicates the valve is closed. The value closes when the grip is assessed as stable, with the air then sealed within the gripper.

4.2 Dexterous Manipulation

To indicate the dexterous capability of the grippers with tactile guiding, we give an illustrative demonstration for each configuration. In each manipulation, tactile information identifies the status and decides the next action.

a) **Ball-pouring using HookGrip**. A cup containing a 30 mm diameter ball is handed to HookGrip, then securely grasps it. Once tactile information confirms a stable hold, HookGrip proceeds to the next step: tilting backward to pour the ball into a beaker. The cup's angle and pouring trajectory are both tracked using an ArUco marker, confirming a precise pouring angle of $47.5°$.

b) **Rubik's cube-rotating using SupportGrip**. A Rubik's cube was put beneath the palm of the gripper. Once the gripper achieved stable contact, the gripper began to rotate the cube's bottom face,

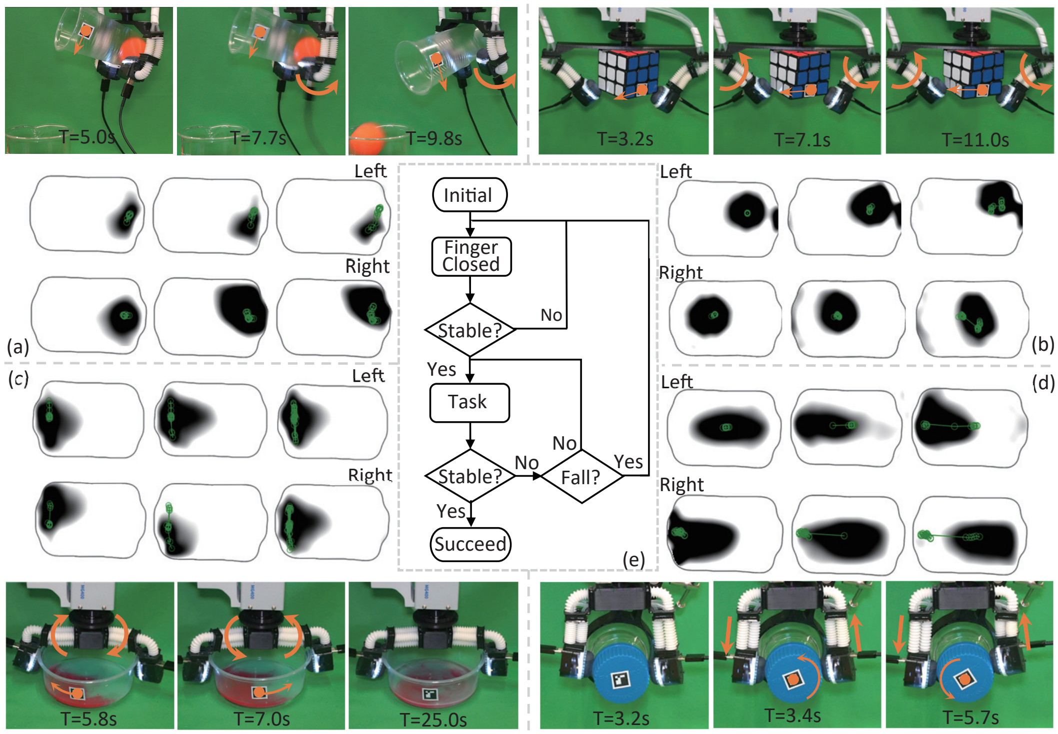

Figure 3: Dexterous manipulation with tactile sensing. (a) The HookGrip pours a ball. (b) The SupportGrip rotates a Rubik's Cube. (c) The ClosureGrip shakes the paint in the bowl until it's well mixed. (d) The PinchGrip twists a bottle's cover.

which was observed through tactile images. We conducted this rotating procedure twice. An ArUco marker was utilized to track the rotation angle, which averaged $14.5°$ per rotation.

c) **Dye-mixing using ClosureGrip**. A bowl containing 10 ml of water is handed to the gripper. Subsequently, 1.5 ml of red and 1.5 ml of green dye are quickly added to the bowl. Once stable grasping was confirmed via tactile information, the gripper began to rapidly rotate clockwise and counterclockwise while also swaying horizontally left and right. The movement recorded an average rotation angle of $\pm 22.6°$ and an average horizontal sway of ± 13 mm (Fig.5(c)).

d) **Cap-twisting using PinchGrip**. A bottle cap of diameter 50 mm is placed vertically in the gripper. After a stable hold on the cap, the gripper fingers were rotated to twist the cap until center of contact approached the edge of the tactile sensor (trajectory marked on Fig.5(d)). An AruCo marker was again used to monitor the trajectory, measuring a maximum twisting angle $25.2°$.

5 Conclusion

In this paper, a two-finger, easy-to-fabricate, biomimetic, reconfigurable pneumatic gripper with tactile sensing ability was proposed. Overall, this results in various grasping capabilities from holding flat to round shapes across a range of sizes. With the addition of tactile sensing and monitoring/control via the inferred centre of contact, we demonstrated that these grippers can undertake real-time grasping stability detection and dexterous manipulation.

Acknowledgments

If a paper is accepted, the final camera-ready version will (and probably should) include acknowledgments. All acknowledgments go at the end of the paper, including thanks to reviewers who gave useful comments, to colleagues who contributed to the ideas, and to funding agencies and corporate sponsors that provided financial support.

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