DexiTac: A Reconfigurable Gripper with Tactile Sensing Ability

Chenghua Lu, Nathan F. Lepora

***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 abstract, we presented a reconfigurable pneumatic gripper with fingers that could be set in various configurations, such as hooking, supporting, closuring, and pinching. Each finger incorporates a dexterous joint, a rotating joint, and a customized plug-and-play visuotactile sensor, the DigiTac-v1.5, to control manipulation in real time. We propose a tactile kernel density manipulation strategy for detecting grasp stability. The gripper is relatively easy to fabricate and customize, offering a promising way to combine soft dexterity and tactile sensing for diverse applications in robotic manipulation.**

I. Introduction

Traditional grippers are engineered for specialized tasks with fixed designs and are not intended to be modified once manufactured, which restricts their versatility [1]. This limitation has paved the way for the rise of reconfigurable grippers. 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 [2], which could inadvertently result in damage to either the gripper or the objects being held. 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, which make them well-suited for applications like object shape reconstruction and tactile control. The TacTip family [3] employs biomimetic pins and markers to amplify the contact on their surface. 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.

II. Design

A. 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. Each finger features a rotating joint (Rot joint), for fundamental flexion and extension, and a dexterous joint (Dex joint) to provide a high DoF, so the finger has better control and lower energy consumption.

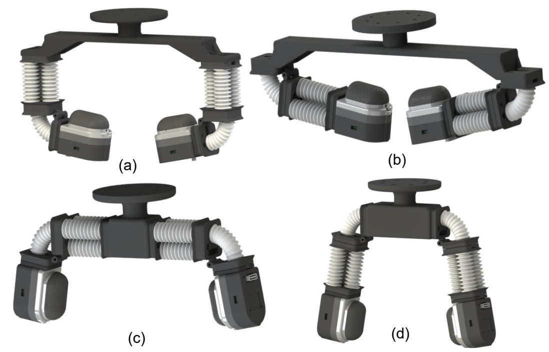

Fig. 1. Design of reconfigurable grippers, include (a) HookGrip, (b) SupportGrip, (c) ClosureGrip and (d) PinchGrip.

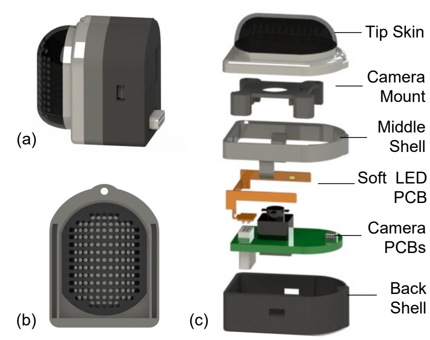

Fig. 2. Design of Digitac-v1.5. (a) Overall view. (b) Markers' arrangement. (c) Explosive view of Digitac-v1.5.

Configurations 1 and 2 employ a horizontal assembly:

Configuration 1 (HookGrip, Fig. 1(a)): 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.

Configuration 2 (SupportGrip, Fig. 1(b)): 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.

Configurations 3 and 4 employ a vertical assembly:

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

Configuration 4 (PinchGrip, Fig. 1(d)): 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 and is suitable for handling cuboid objects.

Chenghua Lu and Nathan F. Lepora are with the School of Engineering Mathematics and Technology, Bristol Robotics Laboratory, University of Bristol, Bristol, U.K. Email: chenghua.lu@bristol.ac.uk.

B. DigiTac-v1.5 Design

For improved grasping versatility and dexterity, we set various expectations on the tactile sensing capabilities:
a) be of a suitable morphology and size to apply to multiple types of grasping tasks and dexterous manipulations;
b) be compact and lightweight to be suitable for integrating the fingertips of soft pneumatically actuated grippers;
c) be relatively low-cost, easily fabricated and versatile to apply for many applications.

In response to these requirements, we developed the DigiTac-v1.5 that implemented the following changes as an improved version of our previous DigiTac [4], see Fig. 2.

We 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, which is significant improvements over DigiTac (45%) enhancing interaction with manipulated objects. To make it compact, 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 9.8 g. To enable easy fabrication, we have transitioned the LED to a 10-pin flexible LED board in DigiTac-v1.5. 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. The assembly is straightforward, culminating in an easily replicable tactile fingertip sensor.

III. Control Strategy

We propose a strategy for manipulation using DigiTac tactile images for feedback. As the lower-level MCU activates the grasping valve, leading the fingers to open, the grasping process initiates. Concurrently, the higher-level controller monitors the tactile image feedback from the DigiTac sensor. The raw tactile images I_{raw} are first transformed to grayscale images of dimension 640×480 pixels. The positions (x_m, y_m) of the M tactile markers on the image are then detected using Determinant of Hessian (DoH) blob recognition. Subsequently, marker densities are estimated using a Gaussian kernel density with kernels located at marker centroids:

$$\bar{d}(x,y) = \frac{1}{M}\sum_{m=1}^{M}\frac{1}{\sqrt{2\pi}h^2}\exp\left(-\frac{||(x,y)-(x_m,y_m)||^2}{2h^2}\right), \tag{1}$$

where (x,y) represents the point at which the density is to be estimated; h is a constant kernel width. The center-of-contact (x^*, y^*) is extracted as the point with the lowest density using

$$(x^*, y^*) = \arg\min_{(x,y)\in R} \bar{d}(x,y), \tag{2}$$

where R is the contact region identified as the largest contiguous region with kernel densities below a threshold

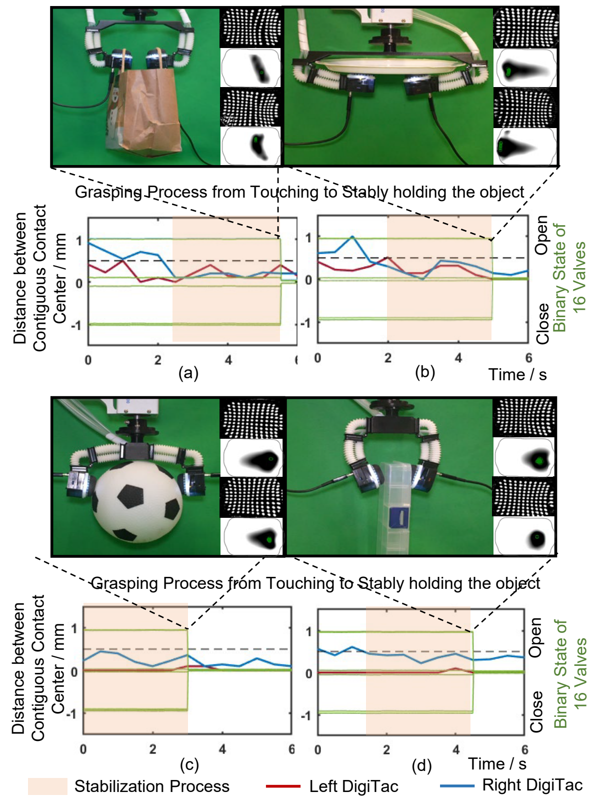

Fig. 3. Representative grasping tests of each configuration and contact information. The objects include (a1) a soft shark toy, (a2) a paper bag, (b1) a flat plate, (b2) a bolt toolbox, (c1) a round pepper, (c2) a mini soccer ball, (d1) a cookie box, (d2) a toolbox.

value. 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

$$D(t) = ||\,(x^*(t+1), y^*(t+1)) - (x^*(t), y^*(t))||, \tag{3}$$

which can be used for real-time grasping control.

IV. Results

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 Fig.3 . We use the methodology for assessing the stability of the grasp detailed in Sec. III. In essence, if the shift in the contact centers across the two tactile fingertips remains below a threshold for 3 sec, then we deem the grip to be steady. We show tactile images of grasping to depict the moments when the grasp becomes stable in Fig.3 , and the red and blue lines on the underlying plots display the changes in the corresponding two contact centres. Overlaid on these plots are step functions that show the binary open/close status of the pneumatic valves: 1 denotes the inflation valve is open, -1 indicates the suction valve is open and 0 indicates the valve is closed. The valve closes when the grip is assessed as stable, with the air then sealed within the gripper.

References

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