Soft Camera-based Tactile Sensor for Compliant Grasping and Manipulation

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project: https://github.com/Tacxels/SofTac

***Abstract*—The rigid structure of camera-based tactile sensors limited their perception compliance and the manipulation dexterity. To address these problems, we proposed an integrated perception-structure soft design, which reuse the elastomer for perception layer and support structure, simultaneously. Specifically, we design round headed cylinder structure to provide stability and compliance, as well as enlarge the perception range, which integrally casts and cure the camera and lights into it. To adapt the focus length in high index elastomer, we design a equivalent focus adjust suit for the camera to imaging the perception surface clearly. Besides, programmable ring illumination is introduced to provide satisfied imaging appearance. Experiments show the proposed sensor can output high-quality tactile images and provide flexibility in manipulation. Details will be present at https://github.com/Tacxels/SofTac.**

I. Introduction

High-spatial resolution, compact measurement data format, and low-cost fabrication make camera-based tactile sensors (CBTS) attract impact attentions in robotics community[1], [2], [3], [4]. However, most of existing camera-based tactile sensors [5], [6], [7] are consist with hard components (such as an acrylic piece or shell for supporting) and lack of compliance. The rigid structure make these sensors hard to adapt the deformation in perception and manipulation, especially for targets with complex shapes, which limits their abilities of perception, flexibility and dexterity. Besides, the inflexibility is difficult to absorb impact collision and buckling in the interaction process, which may greatly shorten the service life, even lead to structure damage of camera-based tactile sensors.

Previous researches have paid attention to this prospect and proposed diverse designs to address these problems, such as flexible endo-skeleton [8] and composite material backbone [9] in fabrication, to provide compliance for tactile sensors. These works present the advantages of compliance for curved surface perception, secure grasping, and real application tolerance. However, there are still limitations on the degree of compliance, the quality and range of perception, the complexity of fabrication, the robustness under collision, the manipulation dexterity and the integration of these designs.

To address these problems, we propose a structure-sensing integrated soft design for tactile sensor, and integrally casts and cures the camera and lights into the soft transparent elastomer, which simultaneously provide high compliant support structure and optical-friendly soft sensing layer.

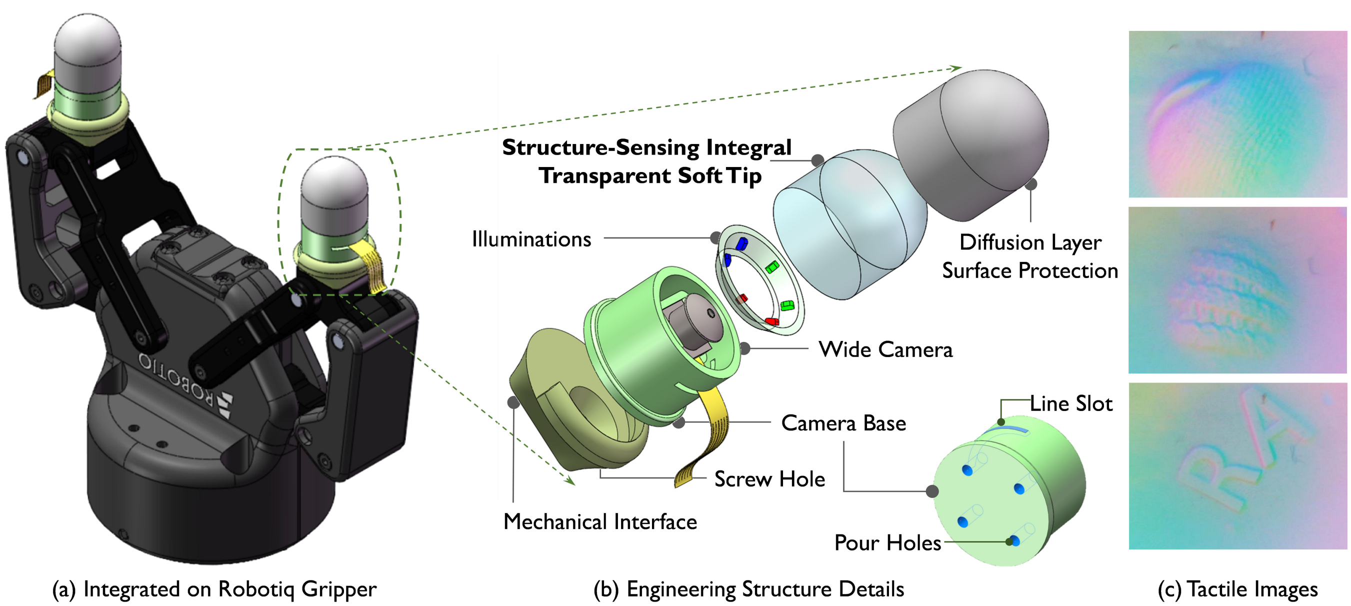

Fig. 1. Proposed compliant sensor. Integration with robot gripper (a), the structure details of proposed sensor (b) and (c) tactile images on different objects.

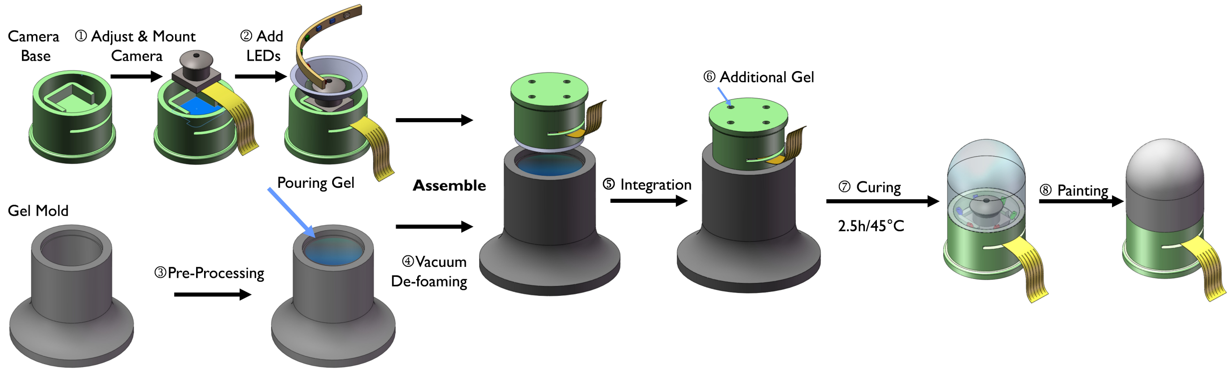

Fig. 2. Fabrication process of sensor. We adopt 3D printing to fabricate connect and mold, and cast the camera and lights into gel layer, integrally.

II. Design and Fabrication

a) Structure: We first design an uniform mechanical interface to accommodate the camera base by snap-fit and connect with robot gripper by screw. Camera base has a rectangular groove on the top to host the camera and lights ring, and holes on the bottom for gel pouring and air vent. The rounded cylinder gel is integrally cast on the top camera and light. A diffuse reflection layer and an protect layer cover on the top of the gel. A USB cable provides image interface.

b) Fabrication: We take 3D printing to fabricate the connector and the casting mold. The camera will be stuck to on the slot base, and the LEDs ring will be placed with the help of dowel pins (at proper angular). The cable will be led out from side slot. We introduce the rounded cylinder to provide large field of view and reliable contact [7], [10]. A micro step ring is cut to host the connector. In the casting process, we first pour half gel into the mold, then inversely insert the connector part on the top of mold. The rest gel will be poured into the mold from the holes, and the bubble can escape from the hole in the vacuum dying box. After curing, we will paint diffuse layer to provide uniform reflection for imaging, and paint a protect layer to improve the surface endurance, as Fig. 2.

c) Optical Design: The integrally design provide uniform refractive index for the propagation of light, which greatly reduces the complexity of optical design. For illumination, we take LEDs as light source and optimize the elevation angle of emitting with consideration of camera field of view and LED beam angle. It is challenge to accurately focus the camera in high refractive index medium, especially for the curve gel surface. For camera optical design, we design a equivalent focus suit to adjust the focus length before casting, which can ensure the imaging performance consistently.

III. Experiments

a) Tactile Perception: We present the tactile image from proposed sensor, the surface shape and the details are clear present in the right part of Fig. 1 (finger, clothes and convex letters). We also tried the calibrated method to reconstruct target geometry as [5]. It is worth noting that the base shape of sensor should be taken into account for geometry perception[7]. The performance of tactile imaging quality, the reconstruction accuracy, and the perception range are comparable with previous camera-based tactile sensors.

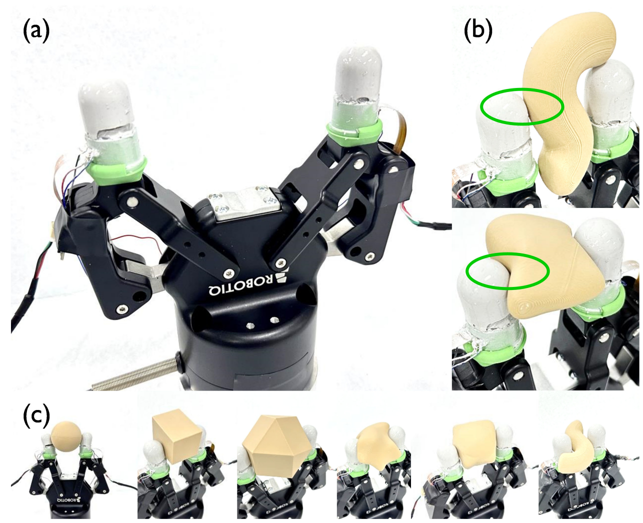

Fig. 3. Grasping experiments of compliant CBTS. (a) is experiment setting, (b) is the compliance of soft probe, (c) shows diverse objects grasping.

b) Compliance: We test the advantage of soft compliance in perception, grasping and manipulation scenario, as shown in the bottom of Fig. 3. The soft gel sense more structure and range than the rigid counterpart. Besides, compliance provide fault tolerance for grasping, which lower the requirement of controlling. Specifically, the soft structure can also provide intrinsic mechanical intelligence in manipulation from the compliance physically, which can make adaptive adjustment of the contact angle and pose to ensure the reliable interaction. Quantitative testing also shows the compliance and strength.

IV. Conclusion

In this paper, we proposed a structure-sensing integration design for camera-based tactile sensor, which casts the camera and the lights into transparent gel, and provides uniform refractive index, as well as the important compliance for perception, grasping and manipulation. In future work, we will simplify the fabrication process, develop equivalent focus estimation method for medium, proposed adjustable compliance for structure, and present applications on diverse robot tasks.

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