Preliminary Design of Vision-Based Tactile Sensor with Nail and Soft Structures

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***Abstract*—The tactile sensing is an essential function in human-robot interaction and object manipulation. Particularly, soft tactile sensors contribute to improving safe interaction between humans and robots, as well as enhancing the stability of grasping objects. Consequently, research on Vision-Based Tactile Sensor (VBTS) has been actively conducted in recent years. In this paper, we report the results of increased grasping force achieved by introducing a structure that mimics the nail and bone of human fingers into VBTS made of soft materials, and by statistically analyzing the data obtained with the Robotiq FT300-S Force Torque Sensor.**

***Index Terms*—vision based tactile sensor, nail, bone, robot finger, soft robot**

I. Introduction

Tactile sensing is a crucial function used by humans to enable the recognition of various characteristics of the grasped object such as stiffness, shape, and surface roughness during manipulating or grasping objects. Similarly, to accommodate increasing demands on stable object manipulation in complex and dynamically changing environments, robots also require tactile sensing capabilities to acquire information about the interaction state with objects.

Vision-Based Tactile Sensors (VBTS) have recently gained attention from the community as a new tactile sensor addressing the aforementioned challenges. VBTS can be broadly categorized into two categories: GelSight-based [1] and TacTip-based [2]. TacTip-based tactile sensors feature a soft, dome-shaped membrane with markers. When an object touches the membrane, the marker movements are captured by a camera to acquire contact information. Furthermore, Han *et al.* [3] demonstrates that the presence of nail structure significantly enhances grasping efficiency by increasing frictional force between artificial fingers and objects.

In this paper, we attempt to study whether grasping performance can be improved by incorporating the nail structure of human fingers and tactile sensing functionality (marker-based system) into artificial fingers. To the best of our knowledge, no studies have reported on the variation in grasping force resulting from the introduction of artificial nail and bone structures within the VBTS research field.

This work was supported by JST SPRING, Grant Number JPMJSP2102.

II. Design

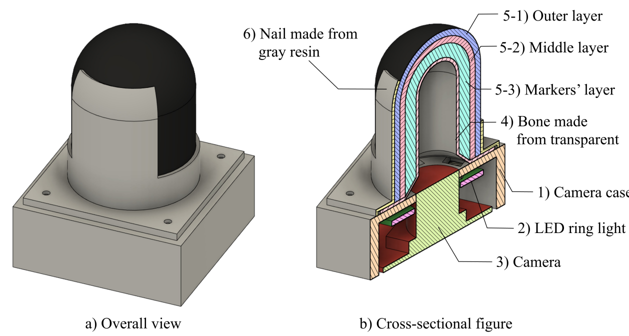
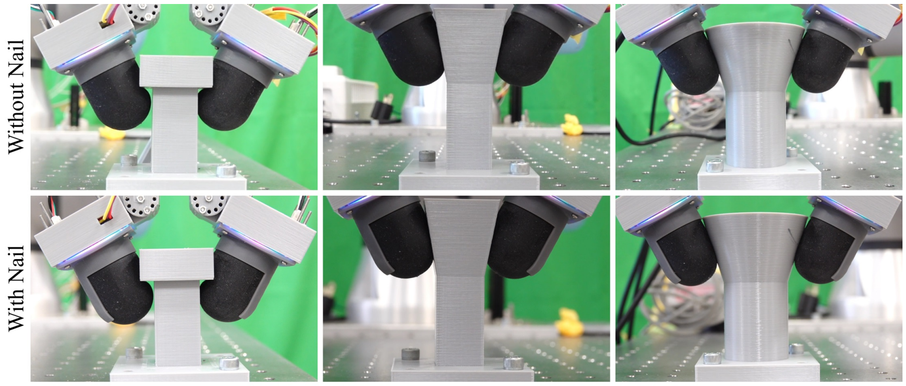


Fig. 1. Overview of our sensor device

The design of our VBTS is presented in Fig.1(a). As you can see in Fig.1(b), our VBTS consists of five parts, from the inside to the outer parts. Considering the transparency of the silicone used in this study, it's important to keep the distance between the marker and the transparent bone at 3mm or less, otherwise, the camera won't be able to capture the marker. Also, the Middle Layer is added to improve the flexibility of the fingertip's skin. Lastly, the Outer Layer is black to block external light and illuminate the fingertip's interior with light from the LED light ring.

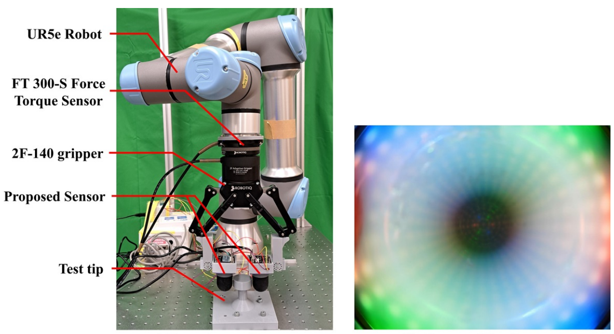
III. Experiment

For our experiments, we used a UR5e robotic arm, Robotiq FT300-S Force Torque Sensor, and Robotiq 2F-140 gripper, as shown in Fig. 3(a). Also, Fig. 3(b) is an image taken by the internal camera. We used the Robotiq FT300-S Force Torque Sensor in our VBTS to measure the downward resistance when gripping an object and pulling it vertically upwards. Then, we installed our proposed VBTS at the tip of the Robotiq 2F-140 gripper whose control parameter ω is used to vary the distance Δ between two fingertips. As a result of calibration, we set the initial state of the gripper (fully open) corresponding with



a) Grasping Cube Test Tip b) Grasping Trapezium Test Tip c) Grasping Circle Test Tip

Fig. 2. Grasping of specimens by With/Without Nail



a) Experiment Setup b) Captured by Camera

Fig. 3. Experiment setup and Captured camera

$\omega = 0$ and $\Delta = 9\,\text{mm}$. Whereas, $\omega = 255$ is corresponds to the fully-close state, *i.e.,* $\Delta = 0\,\text{mm}$. We used the proposed VBTS to pull a variety of specimens upward while maintaining contact with the object (Fig. 2).

IV. Experimental Result

In this section, we show the effectiveness of our proposed VBTS equipped with the nail-like structure in grasping objects. Table I shows the average vertical force value measured by the Robotiq FT300-S Force Torque Sensor during driving the fingertips upward with different Position Parameters (*i.e.,* equivalent to gripping force) and with nail or without nail. Additionally, if the downward force value is greater when using "With Nail" compared to "Without Nail", the cells in the Table I are highlighted in red with hatching. Furthermore, we did a t-test to determine whether there is a statistically significant difference in the downward force between "With Nail" and "Without Nail", and the resulting p-value is shown in Table II. We observed a significant difference except for the Position Parameter of 200 for the Circle specimens. These results suggest that our sensor device exhibits performance equivalent to that observed in the previous study by Kumagai *et al.* [4], where the presence of nails led to increased contact area with objects due to the geometric constraint of flexible skin, resulting in greater gripping force.

TABLE I
The experiment result value(average force).

	Cube		**Trapezium**		**Circle**	
Δ**[mm]**	7.78	7.84	7.3	7.4	7.65	7.72
Without Nail [N]	12.6	12.7	8.4	12.4	11.9	12.6
With Nail [N]	14.6	14.7	14.6	14.0	13.4	13.1

TABLE II
The experiment result of P value.

	Δ**[mm]**	**P value**
Cube	7.78	0.4×10^{-3} (Sudent's t test)
	7.84	0.1×10^{-2} (Welch's t test)
Trapezium	7.3	2.2×10^{-9} (Welch's t test)
	7.4	8.8×10^{-6} (Sudent's t test)
Circle	7.65	0.4×10^{-3} (Welch's t test)
	7.72	0.3 (Sudent's t test)

V. Conclusion and Future Work

In this study, we experimentally study the improvement in grasping force by installing a structure mimicking human fingernails integrated with a Vision-Based Tactile Sensor composed of flexible skin in the TacTip system. We measured the downward force using a Robotiq FT300-S Force Torque Sensor while pulling upwards on three types of specimens with both VBTS configurations: with and without nail structure. Statistical analysis of the data collected from the Force Torque sensor showed that the VBTS with nail structure exhibited a significantly higher vertical force compared to the VBTS without nail. This indicates that installing a nail structure in the VBTS, which is composed of flexible skin, contributes to stably grasping objects.

In the future, we plan to use image data from the camera installed within the VBTS to estimate grasping force and extract tactile information when the VBTS comes into contact with the grasped object.

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