A uSkin Fingertip with a Tactile Fingernail for Contact-Rich Dexterous Manipulation

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***Abstract*— We present a tactile robotic fingertip that extends a conventional uSkin fingertip with a sensorized fingernail. While soft fingertip tactile sensing is effective for grasping and contact monitoring, fingernails enable interactions that require edge engagement, thin-gap access, scraping, and concentrated force application. To extend tactile sensing to this regime, our design adds a rigid fingernail with 6D force-torque sensing while preserving dense tactile sensing on the compliant finger pad. We evaluate the proposed design through contact force and localization experiments across multiple interaction directions. We further demonstrate its benefit in an imitation-learning card-manipulation task and several real-world nail-assisted manipulation behaviors. These results suggest that sensorized fingernails can expand the capabilities of tactile robotic hands beyond conventional fingertip-pad interactions.**

I. Introduction

Dexterous manipulation has been a long-standing challenge in robotics. In humans, the fingernail serves as an important piece of biological hardware: it complements the soft finger pad, enables interactions that fingertips alone cannot easily perform, and supports fine-grained tactile sensing. This allows humans to apply concentrated forces and engage with small geometric features during tasks such as picking up thin objects, separating layers, peeling, scraping, and manipulating edges.

Many existing dexterous robotic hands incorporate fingertip-style tactile sensors, which are useful for grasping, state estimation, and contact-rich manipulation. However, soft rounded fingertip pads alone are limited in the types of interactions they can support. For example, they are poorly suited for picking up thin edge-like objects or exerting concentrated forces required for forceful dexterous motions such as peeling.

Although fingernail-like structures have been incorporated into several robotic hands, they are often passive mechanical components [1], [2], or their sensing capability is limited to sparse, low-dimensional, or indirect measurements [3]–[5]. For example, acoustic or vibration-based approaches can capture dynamic contact cues, but they often depend on interaction-induced vibration and are less direct for sustained quasi-static contact. Strain-gauge-based fingernails provide useful force-related measurements, but are typically limited in the dimensionality and spatial distribution of the measured contact state. Vision-based fingertip designs with nail-like structures have also been explored [6]; however, when the nail and finger pad share the same sensing elastomer, it can be difficult to clearly distinguish whether contact occurs on the nail or the finger pad. These limitations motivate a fingertip design that provides dedicated tactile sensing on the fingernail while preserving sensing on the finger pad. Table I summarizes representative robotic fingernail and nail-inspired fingertip designs.

Fig. 1: We extend a conventional uSkin fingertip with a 6D force-torque sensorized tactile fingernail, enabling nail-assisted interactions such as edge engagement, peeling, scraping, and thin-object manipulation.

In this work, we present a tactile fingertip designed by XELA Robotics that extends a uSkin fingertip [7] with a sensorized fingernail. The proposed design provides 6D force-torque sensing beneath the fingernail while preserving dense tactile sensing on the finger pad, forming a fingertip with tactile perception on both the nail and pad regions. We show that the sensorized fingernail can estimate contact force and localize contact from different directions. We further demonstrate its benefit for imitation learning and show its applicability to several real-world dexterous manipulation tasks.

II. Tactile Fingernail Design

We set the nail length to 2 mm based on Uetake et al. [8], who studied the relationship between human nail length and task performance in everyday manual activities such as sewing, knot tying, writing, and peg insertion. Their findings suggest that a nail length of 2 mm or less is suitable for manipulation tasks, and we therefore adopt 2 mm in our design. The proposed fingernail has a sensing area of approximately $20\ \mathrm{mm} \times 27\ \mathrm{mm}$ and can capture 6D deformation.

III. Experiments

This section aims to answer two main questions: (1) How well does the sensorized fingernail estimate and localize contacts from directions important for dexterous contact-rich manipulation? (2) How does utilizing the fingernail sensor improve imitation learning policy performance?

TABLE I: Comparison of robotic fingernail and nail-inspired fingertip designs.

Reference	Sensorized Fingernail	Sensing Mechanism	Resolved Contact State	Sensorized Finger Pad
DEXOP [1]	✗	–	–	✓
PLATO [2]	✗	–	–	✗
Miyazaki et al. [6]	✓	vision	contact region	✓
Murakami et al. [3]	✓	strain-gauge	1D	✗
Kõiva et al. [4]	✓	Hall-effect + barometric	2D	✗
Xu et al. [5]	✓	acoustic/vibration	1D	✓
Ours	✓	**Hall-effect**	**6D**	✓

A. Contact Localization and Force Estimation

To evaluate the sensing capability of the proposed fingernail, we built a perturbation setup using a UR5e robot equipped with a wrist-mounted 6-axis force–torque sensor, as shown in Fig. 2. The robot was programmed to repeatedly contact the fingernail sensor from three representative interaction directions. Direction (a) corresponds to interactions with the back of the nail, such as separating or scraping objects. Direction (b) corresponds to contact at the nail tip, such as touching or pressing against a surface. Direction (c) corresponds to edge-engagement interactions, such as picking up thin objects while maintaining sufficient contact force. For each direction, the perturbation region was defined on the fingernail surface, and the contact position was randomized within this region. The robot also applied different force magnitudes by pressing into the fingernail surface. This setup allowed us to collect paired data consisting of 6D force-torque signals, ground-truth force measurements, and end-effector positions. We then trained a simple regression model to estimate contact force and contact location from the fingernail tactile signals.

For all three interaction directions, we used the same multilayer perceptron architecture with hidden layers of 128, 128, and 64 units and ReLU activations. The model was trained with Adam using a learning rate of 10^{-3}, with both input tactile signals and output targets standardized before training. We used an 80/20 train–test split with a fixed random seed of 42, and applied early stopping using 15% of the training data as an internal validation set.

The main results are shown in Fig. 2. The force estimation error in Direction (c) is relatively higher than in the other directions. This is mainly because the experimental setup could not safely apply large forces in this direction without risking damage to the fingernail link. As a result, the data were collected mostly in a low-force regime, where the ground-truth force measurements from the wrist force–torque sensor were relatively noisy.

B. Imitation Learning Performance

To evaluate whether the sensorized fingernail benefits dexterous manipulation learning, we set up a bimanual teleoperation pipeline inspired by [9]. We use the bilateral teleoperation leader device from [10] and apply optimization-based retargeting [11] to map human hand motion to the robotic hand. Using this setup, we collect 50 paired hand-arm state-action demonstrations for a card manipulation task, in which the robot must first engage the card edge with the fingernail and then transfer the card into the finger pad. We train an Action Chunking Transformer (ACT) [12] on the collected demonstrations. To isolate the effect of fingernail sensing, we compare two policies trained with the same demonstration data and input modalities, except that one policy additionally receives nail sensing tokens. This comparison allows us to evaluate whether contact information from the sensorized fingernail improves policy robustness during imitation learning.

TABLE II: Imitation learning success rate on the card manipulation task.

	Nail sensing	No nail sensing
Success rate ↑	**13/20**	11/20
Pre-hook failure among failures ↓	**0/7**	4/9

The policy with nail sensing showed a modest improvement in overall success rate and fewer pre-hook failures, as shown in Tab II. In particular, we did not observe the misgrasp failure shown in Fig. 3, where the finger fails to hook the object using the nail. In contrast, the policy trained without fingernail tactile inputs failed in this manner several times, suggesting that fingernail sensing provide useful contact information for detecting and stabilizing edge engagement. The remaining failures with fingernail tactile input were mainly caused by the object not being sustained within the fingerpad after the initial nail-assisted interaction. This suggests that future work should further study how fingernail sensing and fingerpad sensing can be jointly used to improve the full manipulation sequence.

C. Application to Other Real-World Tasks

Finally, we demonstrate the applicability of the sensorized fingernail on several real-world manipulation tasks. As shown in Fig. 4, the fingernail is used to scrape along the edge of a thin tape, press into the gap between adjacent cardboard pieces, hook under the rim of a bottle cap, and lift a thin flat object from the table. Across these trajectories, the nail enables localized edge contact, insertion into narrow gaps, peeling-like motion, and concentrated force application. These motions are difficult to achieve with a soft rounded fingertip alone, since the fingertip geometry limits

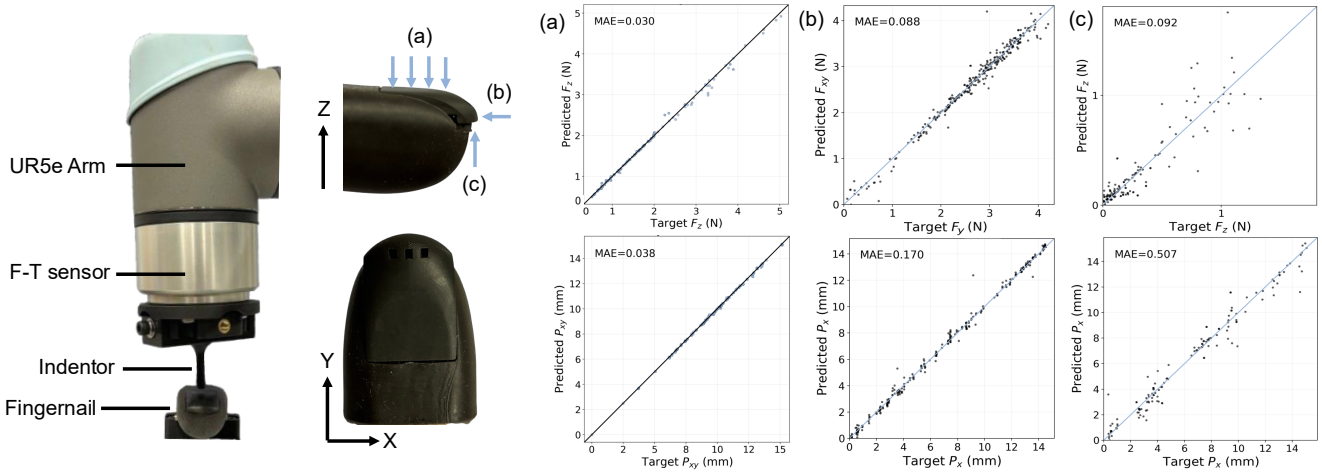

Fig. 2: Experimental setup and regression results for force and contact localization estimation on the sensorized fingernail. A UR5e robot equipped with a wrist force–torque sensor was used to apply repeated contacts to the fingernail sensor from three interaction directions: (a), (b), and (c). The corresponding MLP regression results are shown on the right. The low force and localization MAE across all three directions suggest that the sensorized fingernail captures meaningful contact-dependent signals for estimating both contact force and location.

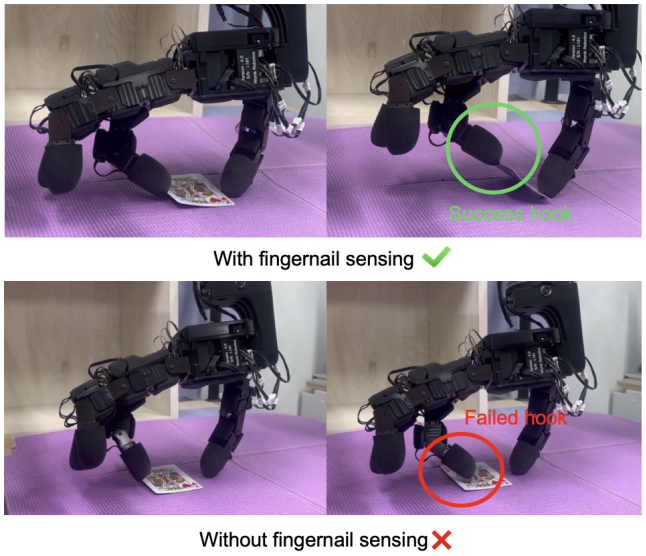

Fig. 3: Representative imitation learning failure mode.

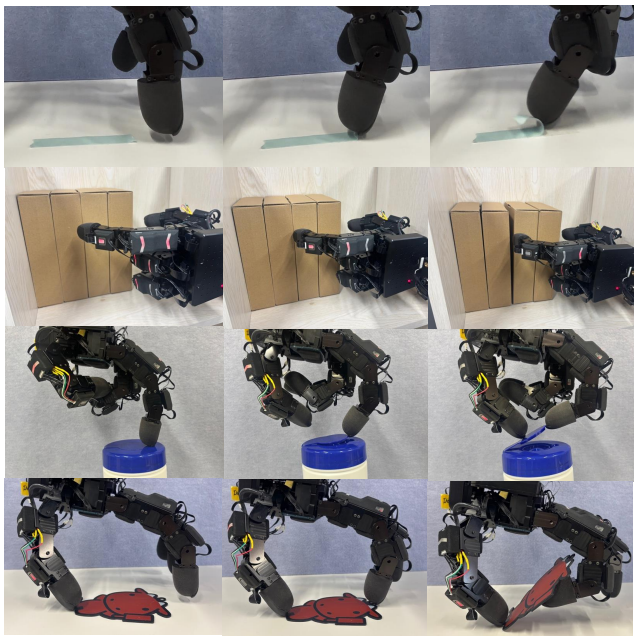

Fig. 4: Real-world manipulation demonstrations using the proposed sensorized fingernail.

access to thin edges, narrow gaps, and small contact regions. By introducing a rigid, sensorized nail structure, the fingertip can engage with these geometrically constrained contacts while still providing tactile feedback. These demonstrations show that the proposed fingernail design can expand the manipulation capabilities of tactile robotic hands beyond conventional fingertip-pad interactions.

IV. Conclusion

In this work, we presented a uSkin fingertip extended with a sensorized fingernail for contact-rich manipulation. By adding 6D force-torque sensing to the fingernail, the fingertip can sense contacts on both the compliant finger pad and rigid nail region. Our experiments showed that the fingernail can estimate contact force and localize contact across multiple interaction directions. We further demonstrated that fingernail tactile input can improve robustness in nail-assisted manipulation and can support many nail-assisted manipulation behaviors, including scraping, gap insertion, hooking, and lifting thin objects. These results suggest that sensorized fingernails are a promising direction for extending tactile robotic hands beyond conventional fingertip-pad interactions.

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