Title	マーカベース光学式触覚センサを用いた人型ロボットフィンガーの開発と把持動作への応用および検証
Author(s)	友水, 豪志
Citation	
Issue Date	2026-03
Type	Thesis or Dissertation
Text version	ETD
URL	https://hdl.handle.net/10119/20579
Rights	
Description	Supervisor: HO, Anh Van, 先端科学技術研究科　, 博士

氏　　　　　名	Tomomizu Takeshi
学 位 の 種 類	博士（情報科学）
学 位 記 番 号	博情第 566 号
学位授与年月日	令和 8 年 3 月 25 日
論 文 題 目	マーカベース光学式触覚センサを用いた人型ロボットフィンガーの開発と把持動作への応用および検証
論文審査委員	HO Anh-Van　北陸先端科学技術大学院大学　教授
	岡田 将吾　同　教授
	白井 清昭　同　教授
	吉高 淳夫　同　准教授
	下ノ村　和弘　立命館大学　教授

論文の内容の要旨

This dissertation aims to demonstrate the multifunctionality of a vision-based tactile sensor (VBTS) that mimics the human finger structure nail, bone, flexible skin and thereby establish the utility of anatomical imitation for VBTS design. The human finger exhibits a highly optimized morphology rarely observed in other species. In robot fingers employing tactile sensors based on electrical principles, mimicking this structure has been reported to enable diverse capabilities, including detection of minute steps, manipulation of thin objects, and reorientation (rotation) using the finger pad.

In recent years, vision-based tactile sensors that capture internal images of the skin with an embedded camera have gained attention for their ability to observe contact phenomena at high resolution. However, the benefits of mimicking finger structure within this modality have not been systematically verified. Building on a design that integrates a hard nail and skeletal support with a compliant skin, this study conducts an integrated evaluation of VBTS functionalities enhanced holding force, enlarged contact area, stress concentration, detection of fine asperities, and grasping of thin objects.

First, we established stable fabrication methods for a With-Nail VBTS (w-VBTS) incorporating nail and bone, and a Without-Nail VBTS (wo-VBTS) with bone only, and performed comparative experiments on holding force, contact area, and internal marker deformation. Consistent with previous work, w-VBTS exhibited greater holding force and contact area than wo-VBTS. Moreover, when a flat surface was pressed onto the sensors at various angles analogous to the contact area tests differences emerged in internal marker deformation trajectories, and w-VBTS reached the target load more quickly. This suggests that the nail suppresses excessive skin deformation and promotes efficient load transfer.

Next, we devised a robust process for fabricating a new Nail-Bone VBTS (NB-VBTS) with an internal support where nail and bone are integrated, closer to the human finger anatomy, and compared it to a Bone-VBTS (B-VBTS) with only bony support of identical size. We conducted experiments on contact area, detection of fine asperities, and manipulation of thin objects. As with the w/wo results, NB-VBTS achieved a larger contact area,

and the findings underscored the importance of material selection for reproducing human-like skin mechanics. In the fine-asperity detection experiments, NB-VBTS produced the ideal frequency peak at the fingertip for asperities spaced down to 1 mm, whereas B-VBTS did not. This outcome is attributed to localized concentration of contact force at the nail tip, indicating a structural advantage of NB-VBTS in detection performance.

Furthermore, leveraging a single VBTS with data-driven force estimation from internal markers, we achieved grasping of thin objects including those of ISO/IEC 7810 ID-1 size, an ability seldom reported for conventional VBTS. Taken together, the results consistently show across multiple independent metrics that mimicking human finger structure confers functional advantages to VBTS.

Keywords:
Vision based tactile sensor, Computer Vision, Bio inspired fingertip structure, Thin object grasping, Deep learning.

論文審査の結果の要旨

This thesis studies the relationship between sensor structure and tactile information acquisition in vision-based tactile sensors (VBTS). While structural imitation of the human finger has been shown to improve performance in electrically based tactile sensors, its effect on tactile information representation and inference in vision-based modalities has not been systematically analyzed.

This thesis designs and evaluates VBTS with different internal structural constraints and compares their ability to acquire and represent contact information. Sensor performance is quantitatively assessed using information-relevant metrics, including effective contact area, force transmission efficiency, spatial frequency response of tactile signals, and the accuracy of interaction state inference for manipulation tasks.

Results show that VBTS incorporating nail-like rigid structures produce more informative and stable internal visual signals than structurally simplified designs. These sensors achieve larger effective contact areas, faster convergence to target loads, and enhanced sensitivity to high-spatial-frequency surface features, enabling detection of asperities with spacing down to 1 mm. Furthermore, data-driven estimation of contact force from internal marker motion enables reliable inference of grasp states, allowing manipulation of thin objects using a single sensor.

The results demonstrate that appropriate structural constraints improve the observability and quality of tactile information in VBTS. This thesis establishes structural design as an important factor in vision-based tactile sensing systems and provides design insights for optimizing tactile information acquisition and inference in robotic manipulation.

The student prepared journal paper and presented conference papers in English. Accordingly, the dissertation merits the award of the doctoral degree.