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論文題目	Study of Tactile Transference from Humans to Robots and Its Applications		
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論文の内容の要旨

The demand for robots working alongside humans has been steadily increasing over the past decade. While robots have become increasingly popular, traditional robots pose safety risks due to their lack of soft touch and human-like perception. Recently, soft robots have emerged, offering the advantage of safe interaction with humans and the environment. One key component of this technology is the tactile sensor. With its ability to gather rich tactile information and its inherent softness, the tactile sensor presents a promising solution for improving robot interaction with the environment, especially when interacting with humans.

Humans heavily rely on touch to interact with their environment. Transferring this ability to robots operating in complex environments presents a significant challenge. Researchers have addressed this challenge by recording human hand actions to capture human tactile perception. Deep neural networks then analyze this data to extract the underlying perception. However, the availability of human hand action data, especially for large-scale vision-based tactile sensors, is limited. Additionally, the transfer of this tactile perception to robots using large-scale vision-based tactile sensors has not been widely researched.

To overcome this challenge, a method is proposed that involves extracting information about human tactile perception and then transferring it to robots to enable them to perform tasks. This method relies on data collected through experiments where participants interact with these large-scale vision-based tactile sensors. This tactile sensor consists of two cameras and a soft, silicone interface that mimics human skin. As participants interact with the interface, the cameras capture the deformations, allowing the extraction of physical interaction information from these visual cues using machine learning techniques. By analyzing the knowledge gained from the collected dataset, robots can distinguish between various human-hand interactions. Besides, with the development of the Internet of Things (IoT), robots controlled remotely can explore the environment and interact with surrounding objects through vision-based tactile sensor. To improve the understanding of robot-environment interaction, visualizing tactile sensor data within a virtual environment becomes essential. Deformations in the silicone

interface shape during interaction can be visualized in real-time within a virtual environment, providing a clear and intuitive representation of the physical interaction. In addition, the extracted perception can be applied to multi-robot systems to improve their performance in tasks such as navigation. To extend the benefits of tactile perception, this thesis also introduces the development of a tactile sensor specifically designed for multi-robot systems operating in complex environments. The sensor integrates a fish-eye camera with strategically placed markers to capture surface deformations during contact. A key aspect of this research is the sensor's ability to detect multiple contact points simultaneously and its rapid response time under these conditions, achieved by leveraging tactile perception. The proposed system is evaluated by analyzing its sampling rate and its limitations due to processing power and camera constraints. The findings suggest that the sensor achieves a sampling rate between 18Hz and 23Hz, with potential for improvement through hardware upgrades. This research paves the way for robots equipped with a human-like sense of touch, enabling them to navigate and manipulate objects more effectively in intricate settings.

Keywords: Soft tactile sensor, Swarm robotic system, Human robot interaction, Virtual reality, Robot navigation.

論文審査の結果の要旨

Humans rely extensively on touch to interact with their surroundings. Replicating this capability in robots that operate in complex and confined spaces presents a significant challenge. Bridging the gap between human and robot perception is crucial for enabling robots to effectively integrate into our world. By incorporating elements of human perception, particularly touch, robots can achieve a deeper understanding of their environment. This tactile perception enhances the safety and efficiency of interactions with both humans and objects. Moreover, tactile perception is fundamental to the concept of embodied intelligence in robots, greatly enhancing their adaptability to dynamic environments. This advancement paves the way for future collaborative partnerships between humans and robots.

This thesis aims to implement a sense of touch in robots to enhance their interaction with and response to the surrounding environment. Specifically, it demonstrates the capabilities of soft tactile sensors in two key areas: human hand classification and multi-robot navigation. First, the candidate explored how the touch sensor can be utilized for classifying human hands using machine learning methods. Second, he investigated the integration of tactile sensors within a multi-robot system to improve navigation tasks in very narrow environment. To validate these functionalities, the thesis provides detailed insights into the experimental system, covering aspects such as hardware, firmware, design, and fabrication processes. Additionally, it will describe the two primary objects used in the experiments.

Overall, the thesis succeeds in emphasizing the role of touch in both human-robot interaction and

multirobot system. Also, obtained results contribute to fulfilling knowledge of touch perception for robots in interacting with the surrounding environments. The student could prepare papers, thesis, and present the content in English without any problem. Therefore, this thesis is sufficient to be rewarded as doctoral thesis.