Graduate School of Creative Science and Engineering
Waseda University

博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

Development of Robot Hand with RCM Mechanism for Covering Joints with Thick Skin
皮膚カバーで連続的に覆うことが可能な機構を有するロボットハンドの開発

申 請 者
(Applicant Name)

Chincheng	Hsu
キョ	シンセイ

Department of Modern Mechanical Engineering
Research on Intelligent Machines

May, 2020

Robot grippers and hands are commonly used to grasp various objects. However, for multi-link fingers, it is challenging to cover the joints with tactile sensors, which limits the safety and sensitivity of such fingers. In the current paper we use a remote center of motion (RCM) mechanism for the joints, which enables us to cover also the joints completely with soft and thick tactile sensors, in particular distributed 3-axis sensors. The RCM joints are implemented as 6-bars, and we evaluate their robustness in simulation. A real implementation of the gripper is tested by grasping various objects, and the resulting tactile sensor readings are presented.

Multi-link fingers have the benefit of being able to wrap around the object, and thereby increase the contact surface, which reduces the required contact pressure and enables more delicate and dexterous grasping. Moreover, covering fingers with soft and sensitive skin is beneficial for sensitive grasping. While sensor solutions for soft skin exist, however, it is typically difficult to cover the joints with such sensors. Therefore, such fingers have substantial gaps in the soft and sensitive covers for the joints. Contacts in these areas can go unnoticed, no soft material cushions the fingers, and small objects can get squeezed in the joints.

Stretchable sensors could cover joints, but existing stretchable skin sensors typically have limitations, in particular they cannot measure distributed force vectors, only distributed 1-axis forces, and including the digitization electronics in stretchable material is still challenging. Furthermore, to cover the palmar side of typical joints, which is the one typically in contact with the grasped object, the sensors have to be thin, which limits the softness that can be implemented.

In the past, our lab developed the uSkin sensors, which can measure distributed 3-axis forces, and each 3- axis sensor already provides digital output, enabling to put many sensors on the same digital communication bus, vastly reducing the number of required cables to readout the sensor signals. uSkin is 4 mm thick and soft. However, uSkin is not stretchable. Therefore, in previous work we introduced the concept of a remote center of motion (RCM) mechanism for the joints of a robotic gripper. We furthermore implemented adaptive coupling of the RCM joints. In the current paper, for the first time, we implement tactile sensors that completely cover the palmar side of the finger. Overall, the gripper presented in this paper has the following benefits:

- The palmar side of one finger is completely covered with soft and sensitive skin. To the best of our knowledge, this is the first time this has been achieved. The softness aids the grasping of delicate objects, and it is guaranteed that soft material will be in contact with the grasped object, irrespective of the contact location on the palmar side of the finger. The sensors provide feedback about the contact with the object, again regardless of the contact location. Both softness and sensors enable safe and delicate grasping.

- Because also the joints are covered with the sensors, more information about the contact with the object is available, potentially benefiting machine learning approaches (for example for tactile object recognition) or aiding even just simple feedback control. The surface area, and therefore the potential contact and sensing area, does not get smaller when the finger flexes.

- The thickness of the skin that can be implemented with RCM joints has no principal limit. In our case, we implemented 4 mm thick uSkin, which provides distributed 3-axis measurements. Thereby, one finger, which has 2 joints and is about 90 mm long and 27 mm wide, provides 64 3-axis measurements.

- There is no risk of pinching or squeezing the grasped object in the joints between the finger segments when flexing the fingers.

- Adaptive joint coupling between the two joints in each finger is implemented. Therefore, only one actuator suffices, and the fingers wrap automatically around various object shapes.

In this thesis, the structured as follows:

Chapter 1 is the introduction, in this chapter will explain the motivation, background, objectives of this research. The important relation of robotic hand and tactile sensor will be described. After this will focused on the related works and the state of art of robotic hand.

Chapter 2 introduced the conceptual idea and design of the RCM based robotic hand. The mechanical design will be explained. This chapter will show how to achieve RCM(virtual remote center) and shows that the center of rotation for both the virtual PIP and DIP joint are at the surface of the soft skin layer. For each virtual joint, implementation of two 4-bar parallelograms, will present after the concept idea.

Chapter 3 introduced the passive coupling mechanism of 6-bar mechanism. This chapter shows that the design of how to implement the passive coupling in the RCM mechanism robotic hand. The finger is underactuated, and the two virtual joints are coupled with linkages, the actuation force is distributed on the phalanges, and the robot can passively adapt to a wide variety of object shapes,
as will be described. In particular, the current paper demonstrates that a linkage-based coupling mechanism can be also used in combination with RCM joints.

Chapter 4 introduced the improvement of the design and the ANSYS simulation of the parts for creating stronger structure for the desirable robotic hand. The 6-bar mechanism enables the integration of tactile sensors at the joints. However, the mechanism also has downsides, in particular it includes 4 relatively thin bars, which could limit the achievable stiffness of the finger. Therefore, in this section we investigate the robustness of the finger.

Chapter 5 and 6 introduced the implementation of developed RCM robotic hand and 3-axis tactile sensor uSkin. The integration of tactile sensor created a novel end-to-end continuous sensing surface. Instead of a conventional robot finger, which has the rotation points located inside of the finger, implemented with revolute joints at the rotation points, the proposed design has the rotation point located outside the finger structure. The position of the rotation point was adjusted to the desired skin thickness. Therefore, in our case, this design allows the finger segments to rotate without creating a significant gap between the skin of each phalange.

Chapter 7 discuss the evaluation experiments and result of this work. Due to the design is completely different from conventional one, in this chapter will also describe the potential of this design. Research of the robotic hand has been done for many years, but to make a novel robot hand can fully optimized with tactile sensor, the topic is not been done yet. With this new RCM methods, we hope to inspire a new type of grippers and hands, that are covered with a thick layer of soft material, or also very thick sensors like the Gelsight tactile sensors could be implemented in all finger phalanges.

Finally, Chapter 8 is the conclusion and future work for the proposed prototype. We mentioned the achievements of the is research and described the certain limitation in the experiments. The future work described the next generation improvement design and implementation.

早稲田大学　博士（工学）　学位申請　研究業績書

(List of research achievements for application of doctorate (Dr. of Engineer), Waseda University)

氏 名　(Chincheng Hsu)　印(　　　　　　　　　)

（As of April, 2020）

種 類 別 (By Type)	題名、　発表・発行掲載誌名、　発表・発行年月、　連名者（申請者含む）(theme, journal name, date & year of publication, name of authors inc. yourself)
Academic Papers (International conferences)	○ 1. **Chincheng, HSU**, Alexander SCHMITZ, Kosuke KUSAYANAGI, Shigeki SUGANO, “Continuous Sensing Ability of Robot Finger Joints with Tactile Sensors”, Proceedings of the 2019 IEEE/ASME International Conference on Advanced Intelligent Mechatronics(AIM), Hong Kong, China, 2019, pp. 1440-1444 ○ 2. **Chincheng, HSU**, Alexander SCHMITZ, Kosuke KUSAYANAGI, Shigeki SUGANO, “Robot Finger with Remote Center of Motion Mechanism for Covering Joints with Thick Skin”, 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Macau, China, 2019, pp. 3172-3178 ○ 3. **Chincheng HSU**, Alexander SCHMITZ, Gagan KHULLAR, Harris KRISTANTO, Zhen WANG, Prathamesh SATHE and Shigeki SUGANO, “Implementation of a Remote Center of Motion Robot Finger with Tactile Sensors in the Joints”, 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO), Dali, China, 2019, pp. 247-252, 4. Harris KRISTANTO, Prathamesh SATHE, Alexander SCHMITZ, **Chincheng HSU**, Tito Pradhono TOMO, Sophon SOMLOR and Shigeki SUGANO, “Development of a 3-axis Human Fingertip Tactile Sensor Based on Distributed Hall Effect Sensors”, 2019 IEEE-RAS International Conference on Humanoid Robots (HUMANOID), Toronto, Canada, 2019, 5. Harris KRISTANTO, Prathamesh SATHE, **Chincheng HSU**, Alexander SCHMITZ, Tito Pradhono TOMO, Sophon SOMLOR and Shigeki SUGANO, “Development of a 3-axis Human Fingertip Tactile Sensor with an Ortho-Planar Spring” , 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO), Dali, China, 2019, pp. 297-302, 6. Prathamesh SATHE, Alexander SCHMITZ, Harris KRISTANTO, **Chincheng HSU**, Tito Pradhono TOMO, Sophon SOMLOR and Shigeki SUGANO, “Development of Exo-Glove for Measuring 3-axis Forces Acting on the Human Finger without Obstructing Natural Human-Object Interaction”, 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2020
Academic Papers (Domestic conference)	1. **Hsu Chin-Cheng**, Guillermo Enriquez, Shuji Hashimoto, “Development of a Flexible Optics-based Tactile Sensor System”, 2017 第 79 回全国大会講演論文集 (IPSJ), Nagoya, Japan, 2017 2. Gagan KHULLAR, **Chincheng HSU**, Alexander SCHMITZ, Shigeki SUGANO, "A Self-Adaptive Underactuacted Finger with Remote Center of Motion Mechanism for Covering Joints with Soft Skin", 日本機械学会ロボティクス・メカトロニクス講演会 2020, Kanazawa, Japan, 2020

早稲田大学　博士（工学）　学位申請　研究業績書

(List of research achievements for application of doctorate (Dr. of Engineer), Waseda University)

種 類 別 By Type	題名、　発表・発行掲載誌名、　発表・発行年月、　連名者（申請者含む）(theme, journal name, date & year of publication, name of authors inc. yourself)
Patent	1. 特開 2019-197037　特願 2018-092639 光学式触覚センサ 学校法人早稲田大学 【発明者】シュミッツ　アレクサンダー、**許　晋誠**、ソムロア　ソフォン、トモ　ティト　プラドノ、菅野　重樹 2. 特開 2019-195897　特願 2018-092616 関節構造体及びロボットハンド 学校法人早稲田大学 【発明者】シュミッツ　アレクサンダー、**許　晋誠**、草柳　晃介、菅野　重樹 3. 特開 2018-158389　特願 2017-055173 機械装置の動力伝達システム 学校法人早稲田大学 【発明者】シュミッツ　アレクサンダー、汪　偉、オルガド　アレクシス　カルロス、**許　晋誠**、小林　健人、アルバレス　ロペス　ハビエル、王　語詩、菅野　重樹 4. 特開 2018-155360　特願 2017-053823 トルクリミッタ 学校法人早稲田大学 【発明者】シュミッツ　アレクサンダー、汪　偉、オルガド　アレクシス　カルロス、**許　晋誠**、小林　健人、アルバレス　ロペス　ハビエル、王　語詩、菅野　重樹 5. 特開 2018-153898　特願 2017-053824 接触力調整エンドエフェクタ 学校法人早稲田大学 【発明者】汪　偉、**許　晋誠**、シュミッツ　アレクサンダー、オルガド　アレクシス　カルロス、小林　健人、アルバレス　ロペス　ハビエル、菅野　重樹