Development of a Customized Multi-sensory Detection Tactile Sensor Module for Commercial Robot Hands

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***Abstract*— We have developed a hybrid tactile sensor module that is customized for the Allegro robot hand, a commercial robot hand. The tactile sensor module consists of a 3-axis force sensor and temperature sensor and pressure sensor. Four commercial semiconductor strain gauges are attached to a specially designed metal mechanism to implement the three-axis force sensor. Based on the three-axis force measurements, it detects various physical quantities such as the direction, magnitude, and vibration of the force. The pressure sensor consists of a total of 64 high-performance pressure cells arranged in an 8 x 8 array, covering an area of about 3 cm x 3 cm to detect pressure distribution with high spatial resolution. The temperature sensor uses a commercial thermistor capable of measuring from -10°C to 80°C to detect the object's temperature. We have demonstrated through experiments that the robot fingertip module developed can detect various senses using the internal 3-axis force sensor, pressure sensor, and temperature sensor.**

Keywords-tactile sensor module; 3 axis force; pressure; temperature; robot hand.

I. INTRODUCTION

The advancement of robotics has enabled robots to play a significant role in daily life and industrial environments. However, robots still show a substantial difference in their ability to manipulate objects compared to humans. The superior manipulation ability of the human hand arises from its ability to integrate various sensory information to handle objects precisely. Significant progress is needed to implement such abilities in robotic hands, with tactile sensing being the most crucial aspect. Tactile sensing is the ability to detect various physical quantities, such as pressure, vibration, and temperature. Human tactile sensing capability is determined by the mechanoreceptors distributed at the fingertips [1][2]. These receptors are located in the dermis and epidermis of the skin. To implement sensors that mimic the structure of human skin, a hybrid structure is required.

In this study, we developed a robot fingertip-shaped hybrid tactile sensor module integrating three-axis force, pressure, and temperature sensors to meet these requirements. Experiments were conducted to confirm the sensing characteristics of each sensor.

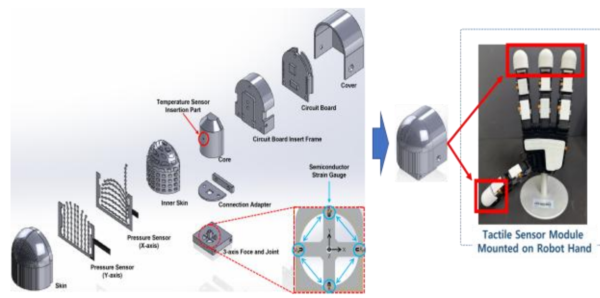

Figure 1. Configuration and Assembly View of Tactile Sensor Module.

Our development will be explained by dividing it into the following sections. Section 2 explains the design and production method of the developed product, Section 3 discusses the characteristics of each sensor in the paper, and the final conclusion includes the results and future plans of the work.

II. DESIGN AND FABRICATION

A. *Design*

In order to realize multi-sensory detection at the fingertips of the robot, a tactile sensor module was designed using an aluminum metal frame and a silicone rubber mold. The Maltese cross-type metal frame houses a three-axis force sensor and a temperature sensor at the core of the module. The silicone rubber mold can accommodate an 8 x 8 pressure sensor array. The overall size of the tactile sensor module is designed to be about 30 mm x 30 mm x 25 mm, allowing for the integration of three sensors and driving boards within this area. Figure 1 shows the complete configuration and assembly of the module. The ultimate goal of our research and development is to customize the tactile sensor module for various robot hands and apply it practically.

 ISBN: 978-1-68558-305-7

B. Fabrication

The three-axis force sensor, consisting of a Maltese cross-type metal frame, takes advantage of the physical characteristics of this structure. Four commercial 'U'-shaped semiconductor strain gauges (USA) are placed at optimal positions on this frame to improve the ability to detect various forces. Additionally, the central pillar part of the structure has been expanded to increase the sensor's sensitivity. Commercial thermistors (SHIBAURA Electronics Co., LTD., JAPAN) are placed in a hole in the center of the core to detect the temperature of an object in contact with the sensor. The epidermis is designed to detect the pressure of the entire fingertip using a silicone rubber mold that mimics the form of human fingertips and integrates 64 high-performance pressure cells. A Flexible Printed Circuit Board (FPCB) is required to attach a flat FPCB sensor to the three-dimensional surface of the fingertip.

Figure 2. Components of Module.

Figure 3. Assembled Module.

This is achieved by dividing the pressure sensor into the X-axis and Y-axis layers. The pressure cells are manufactured by screen printing pressure-sensing ink onto an electrode made of FPCB. The three-axis force, pressure, and temperature sensors had to be miniaturized to integrate the driving board that measures the signal into the module. This is achieved by designing the PCB as a multilayer structure and compactly integrating all the required components into the robot fingertip module. Figures 2 and 3 show the components and assembled module of the tactile sensor module with robot fingertips.

III. EVALUATION

The performance of the tri-axial force, pressure, and temperature sensors embedded in the robotic fingertip-shaped tactile sensor module was evaluated.

The pressure sensor of module was evaluated using a precision scale and a tri-axial translation stage. The pressure detection range was 3 to 20 N (Figure 4 (a), (b)).

For the tri-axial force sensor, the evaluation was conducted according to the ISO 376 international standard [DIN EN ISO 376:2011] calibration procedure using a 20 N deadweight force standard device at the Korea Research Institute of Standards and Science. The sensor's detection characteristics were observed by applying loads in the vertical and horizontal directions. When vertical forces Fz up to 10 N and horizontal forces Fx and Fy up to 5 N were applied (see Figure 5 (a), (b), (c)), the sensor demonstrated a repeatability error of less than 0.5%, hysteresis error of less than 0.5%, and non-linearity error of less than 1.5 % (Figure 5 (c)). Crosstalk between the X and Y axes during horizontal force measurements was within approximately 3%, indicating minimal interference between the axes (Figure 5 (a), (b)).

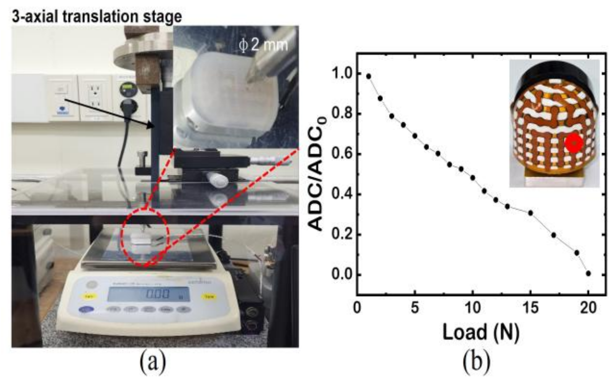

Figure 4. (a) Pressure sensor measurement system.
(b) Detection characteristic of the pressure sensor.

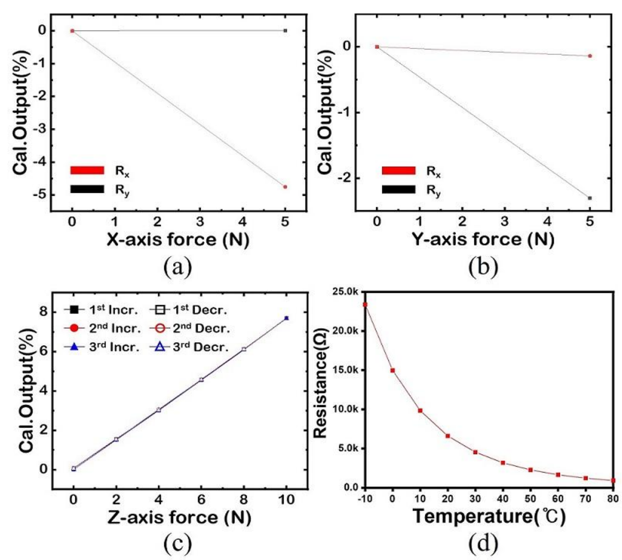

Figure 5. Detection characteristics of a 3-axis force and temperature sensor. (a) Interference characteristics in the X-axis direction. (b) Interference characteristics in the Y-axis direction. (c) Characteristics of repeatability, hysteresis, non-linearity in the Z-axis direction. (d) Detection characteristics of the temperature sensor.

The temperature sensor, a commercial thermistor, demonstrated the capability to detect temperatures within the range of –10 °C to 80 °C (Figure 5 (d)).

IV. CONCLUSION

We have developed a tactile sensor module for robot fingertips that can be attached to a robot hand. This module is approximately 30 mm × 30 mm × 25 mm in size, tailored

 ISBN: 978-1-68558-305-7

to fit the hand of a commercial robot. The related technologies offer the advantage of customization to accommodate the forms of various robot hands.

The built-in three-axis force sensor has demonstrated reliable results, with low repeatability, hysteresis, and nonlinearity errors, as well as minimal crosstalk between axes. The pressure sensor has achieved high spatial resolution and sensitivity, and the commercial thermistor-based temperature sensor stably detects a wide temperature range.

A comprehensive evaluation of the robot fingertip tactile sensor module confirmed its performance and reliability, meeting the requirements for accurate tactile feedback. Currently, the module is designed to be mounted on the Allegro Hand by Wonik Robotics, and it is being tested in various applications to assess the durability of the module and the performance of each sensor.

In future studies, we aim to address current issues, further miniaturize the module, improve sensor accuracy, and explore additional sensory capabilities to expand the module's functionality.

ACKNOWLEDGMENT

This work was supported by the National Research Council of Science & Technology (NST) grant by the Korea government (MSIT) (CRC23021-000).

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 ISBN: 978-1-68558-305-7