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Flexible and constant-temperature tactile sensor using fiber Bragg grating for roughness and cold sensation

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***Abstract*—We propose a flexible tactile sensor using fiber Bragg grating with constant temperature to accurately detect roughness and cold sensations.**

***Index Terms*—tactile sensor, flexible, fiber Bragg grating, cold/ warm sensation, roughness sensation, machine learning**

I. Introduction

Advancements in robotics technology have increased the expectation for their utilization in living spaces where they interact with humans. Here, tactile sensors capable of providing detailed information which visual or other sensors cannot capture, are essential. Additionally, tactile sensors with a flexible structure are necessary as the safety of robots when interacting with humans and fragile objects is crucial.

Tactile sensation includes roughness and cold/warm sensations, which humans integrate to recognize objects[1]. However, most recent studies focus on either roughness or cold/warm sensations. This study uses fiber Bragg grating (FBG) sensors to detect both strain and temperature changes on flexible optical fibers.

To acquire cold/warm sensations of objects at room temperature, the sensor must maintain higher temperature. Inspired by human skin temperature regulation through blood flow, we propose a structure that maintains a constant surface temperature at body temperature using warm water flow. This system improves the accuracy of cold/warm sensation detection. Additionally, our tactile sensor accurately identifies roughness sensations.

II. Structure of Tactile Sensor

As shown in Figure 1, the tactile sensor consists of a water-flow tube, an optical fiber with two integrated FBGs, and a base. The optical fiber is attached to the tube, whose surface maintains a constant temperature with a warm water flow. Our tactile sensor integrates two FBG sensing points in a single fiber to capture both roughness and cold sensation. The cold sensing FBG is in contact with an object, and the roughness sensing FBG is at the point of deformation of the tube.

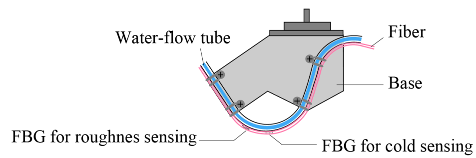

Fig. 1. Structure of tactile sensor

III. Results

A. Cold Sensation

Cold/warm sensation is recognized by differences in heat flux when in contact with a target[2]. In the measurement system, the sensor was vertically approached to a sample, pressed with a constant force, and measured temperature changes for 1 second. Five materials were used as samples: aluminum, acrylic, rubber, wood, and concrete, all kept at a room temperature of 24.3°C.

To examine the sensor's performance with and without constant temperature, measurements were taken 10 times for each sample under two conditions: sensor at room temperature and sensor at 36°C with a water flow of 45.0°C.

A support vector machine (SVM) model with a linear kernel and a regularization parameter of 1.0 was used. Using 5-fold cross-validation, the classification accuracy was calculated. The results showed 84.00% (std. dev. 4.9%) accuracy without water flow and 96.00% (std. dev. 8.0%) with water flow. This confirms that maintaining a constant sensor temperature improves cold sensation detection.

B. Roughness Sensation

Roughness sensation is recognized by the vibrations generated during contact. Using the same samples with Section A, a system was constructed to measure 1.5 seconds of vibration data when the sensor with water flow traced the sample surface. Measurements were taken 10 times for each sample. The same SVM model as Section A and 5-fold cross-validation method were used to calculate texture sensation accuracy, resulting in 94.00% (std. dev. 8.0%). This demonstrates that the tactile sensor can also accurately identify roughness sensations.

References

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