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ROBOT FINGERTIP MODULE FOR MEASURING CONTACT FORCE AND LOCATION

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Abstract: This paper presents an exchangeable and inexpensive robot fingertip module for tactile sensing for the control of the robot hands. The developed module has real human fingertip scale and shape, and can detect contact force and location simultaneously. It has a thin-film type force sensor constructed with 37 unit cells as array, and it also includes a simple on-board chip for signal processing. The sensors are fabricated by using a simple screen printing technique. The whole fabrication process of the module including sensor and signal processing parts are suitable for mass production because of its very simple and low-cost process.

Keywords: Robot hand, Tactile sensor, Interaction, Mass production.

1. INTRODUCTION

Recently, as the field of robotics is continuously expanding to more various environments such as offices, hospitals, and homes, robots are required to perform increasingly human-like manipulation tasks [1]. To achieve advanced in-hand manipulation tasks, tactile sensing for robotic hands is mandatory. Many research groups are currently working with tactile sensors and tactile sensing systems which are suitable for integration into robotic hands. One of the representative solutions for tactile and force sensing in robotics is using a multi-axis force-torque sensor [2, 3]. It usually shows high sensitivity and stable performances such as hysteresis, linearity, and repeatability. However, it is very expensive and difficult to miniaturization. Moreover, it should need an analogue signal amplified system because of its low signal to noise ratio. On the other hand, many researches about the resistive, capacitive, piezoelectric, and optical distributed tactile sensors have been reported up to now [2-7]. Sugiuchi et al. are using a different design of a resistive tactile sensor matrix to measure a real two dimensional pressure profile over the fingers of their artificial hand [4]. The sensor is also implemented between two foils, so it is very thin and easy to integrate. Jockusch et al. are using a tactile sensor for position detection in their hydraulic three fingered hand [5]. It combines a resistive sensor and a piezoelectric PVDF film for slip detection. The PVDF film is mounted over the resistive sensor and is plated with an elastic nap cover. It converts slipping to a mechanical oscillation which can be measured via the PVDF film. However, the distributed tactile sensors don't provide good appearance because the sensor is attached to outer part of curved surface and has many signal lines. Some research groups try to blend the multi-axis force-torque sensor with the film type tactile sensor to sense higher accurate feedback force and position [2, 3]. One of the famous dexterous robotic hands, DLR Hand is equipped with a dual-soused tactile sensor system [2]. Each finger contains a highly miniaturized 6 DOF force-torque sensor and a tactile sensor based on a resistive principle is mounted over the finger tips. However, the construction of the sensor does only allow to measure single touch and it is very expensive. Therefore, we need a low-cost and durable tactile sensing module that can detect the location and force without direct attaching to curved surface.

This paper presents the design and fabrication of a robot fingertip module using tactile sensor which can sense touch force and location simultaneously, and suggests the simple and low-cost fabrication process for mass production. The developed module is evaluated by the calibration setup and LabVIEW™.

2. DESIGN AND FABRICATION OF MODULE

A schematic design of the robot fingertip module is shown in Fig. 1. The module is comprised of artificial skin part, born part, nail part, ring part, connecting part and sensor. The artificial skin part has human-like soft texture and two-axis curvature. The sensor is aligned into slots of the artificial skin base part and is covered with the artificial skin cover part. The skeleton part, ring part and finger-nail part fix not only artificial skin but each other parts. The connecting part connects our fingertip module to various robot hands and gripers. Its design and shape depends on the mother robot hand's shape. The using contact-resistance type tactile sensor is thin and flexible, so it is suitable to the fingertip module.

Fig. 2 presents the fabrication process of the contact-resistance force sensor using a silk screen printing technique. We use flexible printed circuits board (FPCB) as substrate of sensor based on polyimide film. The polyimide is well known for stable thermal, good chemical-resistance, and excellent mechanical properties. The FPCB is made of flexible copper clad laminate (FCCL) with the following specifications: the thickness of the polyimide film is 54 μm,

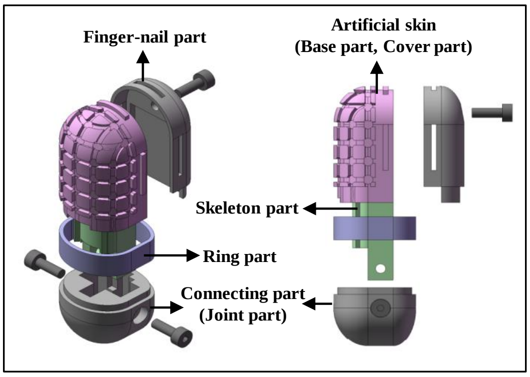

Fig. 1. A schematic design of the robot fingertip module.

while that of copper is 11 μm (Fig. 2(a)). The pattern of contact signal terminal line was made through the etching process (Fig. 2(b)). Conductive and resistive layers are coated by using the screen printing method. We use a high precision semi-automatic printing machine, the model LSP-6050L, by Linesystem Co., which uses a square-edge type squeegee. The squeegee is made of polyurethane material with shore hardness (Hs) of 70 durometer because it is necessary to spread paste onto the screen mask. A conductive layer (Fig. 2(c)) is formed on the film using a silver paste (CMI Co.), and a 300-mesh mask is used. The coated film must be leveled at room temperature for 10 minutes. It is then cured in an oven at 140℃ for 10 minutes. A resistive layer using carbon paste (CMI Co.) is coated (Fig. 2(d)); a 250-mesh mask is used. The carbon paste is cured in an oven at 150 ℃ for 60 minutes after being leveled at room temperature for 10 minutes. Finally, double-coated adhesive tape with thickness of 50 μm is used in the force sensor module to bond both the upper and lower surfaces of the printed film (Fig. 2(e)).

Fig. 3(a) presents the fabricated contact-resistance force sensor with signal processing system. The sensor has 37 unit sensing cell, each cell is 2 mm diameter. The tiny and cheap commercial signal processing chip is used for signal acquisition and A/D converting. Fig. 3(b) shows the assembled robot fingertip module and the picture with dummy hand. The module has 16.3 mm depth, 16.6 mm length, and 38 mm height. The every part such as sensor and signal processing part are perfectly packing into the module. The artificial skin part including tactile sensor has human-like soft texture and two-axis curvature. The fabrication processes are very simple and inexpensive, so it has advantage of the mass production.

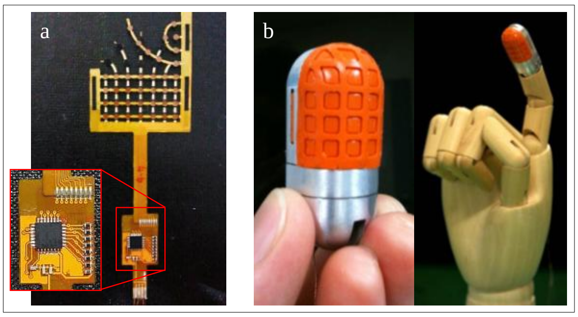

Fig. 3. Photograph of the tactile sensor(a) and the Module(b).

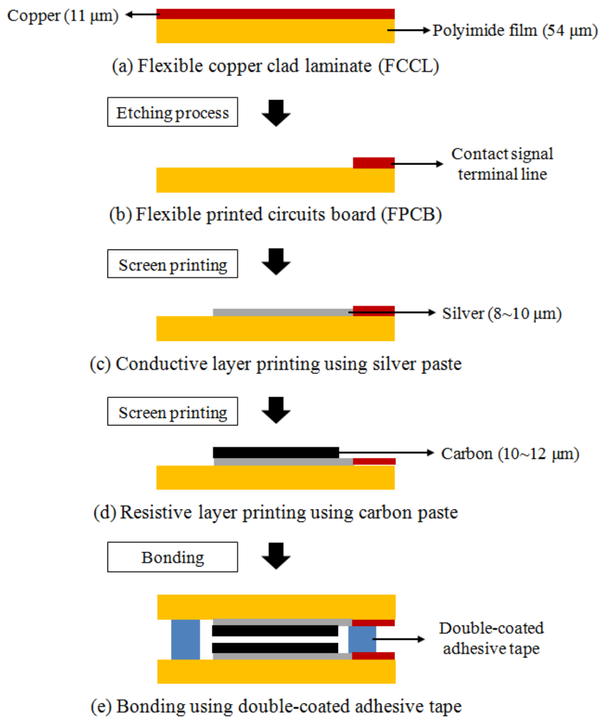

Fig. 2. A fabrication process of the contact-resistance tactile sensor using steps (a) to (e).

3. FEASIBILITY TEST AND RESULTS

The robot fingertip module is comprised of contact-resistance tactile sensor. All unit sensing cells of the sensor should show the same response on the same loading condition. Thus, each sensor is calibrated before applying it to the whole module. We use a calibration system to obtain calibration data for the force sensors. Fig. 5 shows the calibration setup that is composed of three-axis multi-component load cell, and three-axis linear stages. The multi-component load cell has a capacity of 100 N in three directions, which can measure the force response of the force sensor under static load. The z-axis linear stage among three-axis linear stages, having 1 μm resolution, was used to apply normal load to force sensor. The others, x-axis and y-axis linear stages were used to check the alignment between load cell's probe and sensor unit under loading and unloading conditions. Analogue amplifiers (In-strument Division Co., Model 2210) are used to amplify output signals of the load cell. We also used the PXI module (National InstrumentTM), which is comprised of PXI-8106 for data processing, PXI-7340 for motor controller, and PXI-6221 for signal acquisition of load cell. On the other hand, the signal data of the force sensor was transmitted by serial network within the signal processing board. The contact-resistance force sensor is a kind of variable resistor and its resistance varies from 50 Ω to 10 kΩ. Thus, resistance was measured using simple voltage divider circuit. The reference resistance was 500 Ω, while the input voltage is 3 V. The software, LabVIEW^{TM}, is used to control the linear stage and obtain the data of sensor and load cell. The force sensor was evaluated by vertical moving of z-axis linear stage of calibration setup. The z-axis stage moves at a speed of 5 mm/min until a load is reached to 5 N, the stage then remove the load. At the same time, the output data of force sensor is recorded under loading and unloading. Fig. 6 presents the force response of the force sensor ‘1’ under loading and unloading conditions during five repetitive cycles. The sensor has hysteresis error of 2.2 % and repeatability error of 0.6 % with respect to the full scale, 5 N, of the force sensor. Fig. 7 shows force response of the last cycle of three sensors. The deviation of three modules, uniformity error, has 3.0 % error. Calibration curves of sensors were obtained through the curve fitting of the evaluation results. The calibration curve fit functions of each sensor will be used for the whole module evaluation.

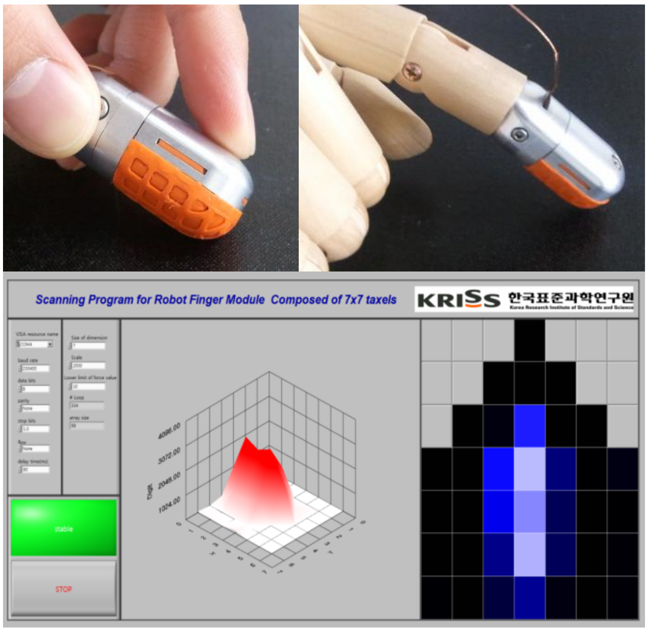

Fig. 4. A Feasibility test of the fingertip module using LabVIEW^{TM}.

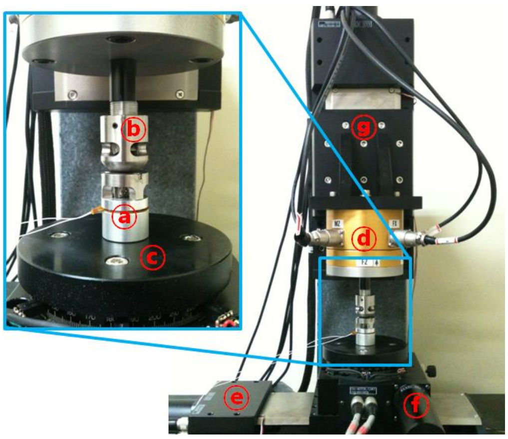

Fig. 5. Calibration setup to evaluate the characteristic of the contact-resistance force sensor : ⓐ force sensor; ⓑ sensor unit; ⓒ stage; ⓓ three-axis load cell; ⓔ x-axis linear stage; ⓕ y-axis linear stage; and ⓖ z-axis linear stage.

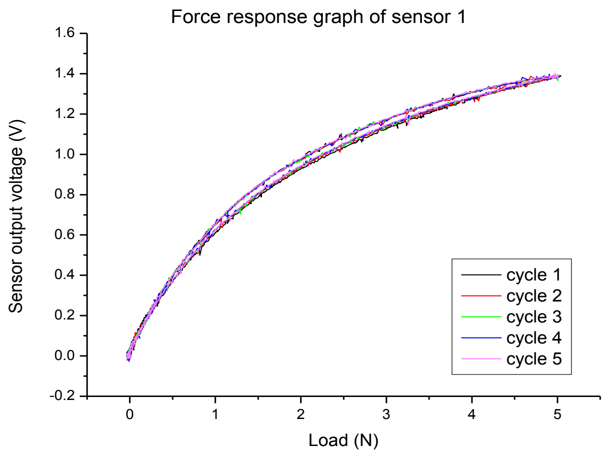

Fig. 6. Output signal of force sensor ‘1’ obtained from loading and unloading during five repetitive cycles.

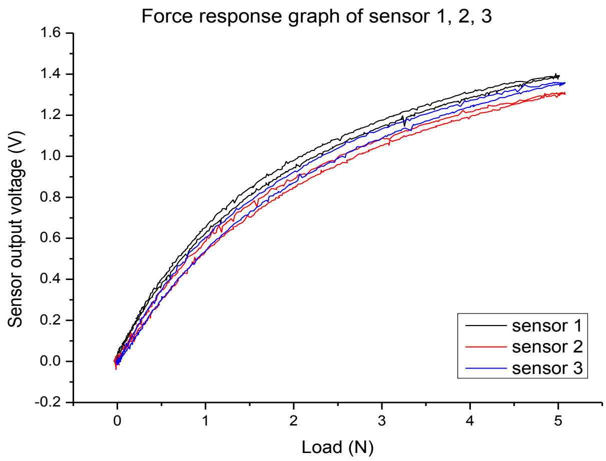

Fig. 7. Output signals of force sensor 1, 2, and 3 during fifth cycle.

4. CONCLUTIONS

This paper presents an exchangeable and inexpensive robot fingertip module for tactile sensing for the control of the robot hands. The developed module has real human fingertip scale and shape, and can detect contact force and location simultaneously. It has a thin-film type force sensor constructed with 37 unit cells as array, each cell is 2 mm diameter. The tiny and cheap commercial signal processing chip is used for signal acquisition and A/D converting. The module has 16.3 mm depth, 16.6 mm length, and 38 mm height. The every part such as sensor and signal processing part are perfectly packing into the module. The artificial skin part including tactile sensor has human-like soft texture and two-axis curvature. The fabrication processes are very simple and inexpensive, so it has advantage of the mass production. The unit sensing cells of the tactile sensor were evaluated by the calibration setup. It showed hysteresis error of 2.2 % and repeatability error of 0.6 % with respect to the full scale, 5 N. The deviation of three units, uniformity error, had 3.0 % error. This study shows feasibility of the developed sensor and module adaptable to the dexterous robot hands and simple gripper.

5. ACKNOWLEDGENT

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