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# Development of a Flexible Optics-based Tactile Sensor System

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**Abstract - Many robots require tactile sensors – the ability to give a robot the "sense of touch" and optics-based tactile sensors are often employed. Most of them utilize a camera to detect deformation of a sensor pad [1][2], which results in higher power consumption and computational complexity. Additionally, cameras also increase the overall size of the devices due to required focal lengths. We propose a flexible, optics-based tactile sensor system using photo-voltaic sensors instead of cameras. Our system can detect not only pressure distribution but also the shape of the target object. In order to improve the usability of the sensor, we focused on decreasing the overall device thickness and enhancing its precision resulting in a sensor that is lighter, requires fewer cables, uses less energy consumption, and is easier to produce as compared to camera-based approaches.**

## 1. Introduction

To detect and display tactile information, many researchers tried to develop various types of sensors that use CCD cameras. These sensors are mainly focused on contact force detection between sensor surface and the object. By using a camera, they can capture the surface deformation and calculate the force by deformation differences. For example, in [1] and [2], although the sensors can sense force, several components such as camera, lens, rubber dome, heavy casing and a computer are needed to run the calculation. These types of sensors also tend to be heavy and expensive. And because the payload of every robot is limited, these sensors are difficult to implement in a real working situation. [3] is also a research of a skin sensor, it focuses on the deformation of an elastic membrane. Although the skin itself is thin and light, it is very difficult to produce. Moreover, additional equipment is needed to observe the deformation of the polymeric optical fiber. Here we proposed a new concept of sensor, based on sensing the light intensity that changes with the distance from LED chips to photo cells. The weight of sensor is light, sensitive and by using simple principle, the fabrication is easy and not expensive.

## 2. Sensor system design

Fig.1 shows a schematic view of the sensor. It consists of 5 layers, first layer is a 2mm-thick opaque elastic membrane that covers the other layers, so that the internal light is not affected by external light. The second layer is a 4 X 4 array of LED chips (0.04 cd of luminance, model: OSYL1608). These LED chips are connected with 3.3V power by soft copper cables to a PCB board. The third layer is a 30mm-thick transparent elastic membrane, which lets the LED light easily reach the photocells at the bottom. There is a fourth layer of 4 X 4 array of photocells (10MOHM type, model:GL5549), whose inner resistance will change when exposed to light, which in turn will induce a voltage change. These photocells are connected to a fifth layer of that includes a custom-made PCB board that outputs the signals to an Arduino. We can get the readout from the Arduino which convert voltage into 1024 units reading value. With this combination, when the light intensity changes, means that some object is in contact with the sensor. By this design, we can implement our tactile sensor.

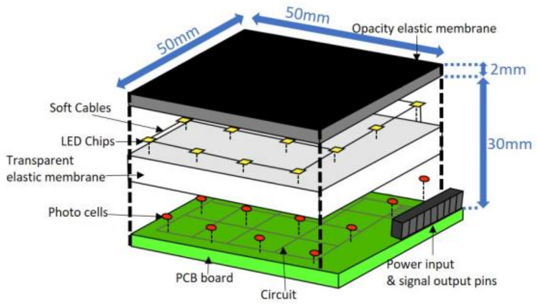



Fig.1 Schematic view of sensor

## 3. Proposed elastic tactile sensing principle

In this paper, the proposed concept of the optics-based tactile sensor consists of multiple photocells, LED chips with elastic material which covers the elements. Fig.2 shows the principle of operation, which is mainly to detect the different intensities of light on the photocells. By the equation of linear light source intensity, the relationship between distance and light source is represented as:

(I). $I = (C/d^2) \cdot \cos\theta$

Where, $I$ is the light intensity (lux), C is luminance of the LED, d is the distance (meter) from the light source and $\theta$ is the angle of the light vector. As the equation shows, when distance get shorter, the light intensity will increase, and then the photocell's resistance value will increase and induce an alteration in the output voltage. Before the object makes contact with the sensor, every photocell remains stable receiving the same amount of light. By the readout value, we can convert the value to voltage($V$) and resistance(*Photocell[KΩ]*) of photocells with the formula:

(II). $V = \frac{Photocell[K\Omega]}{R[K\Omega]+Photocell[K\Omega]} \cdot V_0$

By the voltage and resistance value of the photocells, we know that if inner light intensity increased, voltage and resistance will raise and vice versa. Fig.2 shows that after the object made contact and caused deformation of the elastic membrane, the distance between photocells and LED chips get shorter. Photocell R2 and R3 are now receiving more light than R1 and R4. So, by the voltage and resistance value's difference of each photocells, we can tell that the object made contact between positions R2 and R3. From the amount of deformation, we can also know the weight of object or the force with which the sensor is being pushed.

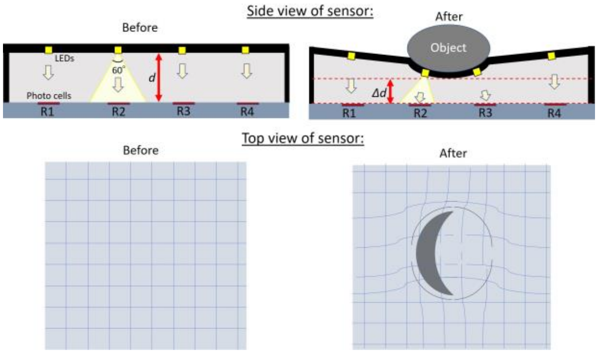



Fig.2 Sensing concept

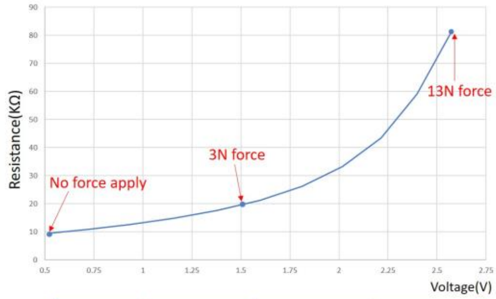
## 4. Evaluation experiments and results

### 4-1. Experiment of force sensing measurement accuracy

The experiment is set on a push platform, a linear motor generates a step force with 60-sec interval that increases from 3N to a maximum of 13N of force. We measured the voltage and resistances of the photocells by the sensor readout as the force applied on the sensor changes over time. Fig.3 shows the relationship between resistance and voltage. Before loading force, the minimum resistance is 9.46K$\Omega$ and the voltage is 0.52V. With loading forces between 3N to 13N force, we see the output signal rising from 20.7 to 80.4 K$\Omega$, verifying the concept of the sensor.

### 4-2. Force sensing resolution

In order to examine the force sensing resolution of single or multiple photocells against an unknown object, we installed tips with areas 5*5mm2, 10*10mm2 and 15*15mm2 that push onto the sensor and run two experiments. on①10N continuous force directly on photocell[C11] and ②10N continuous force in the center of sensor (not on top of a single photo cell) with the three different tips. Fig.4 shows the displacement result of the experiment with measured resistance of the photocells. ①With these three results, photocell[C11] shows higher resistance values, because it is receiving more light. Comparing to surrounding photocells, we see that because of the deformation of the membranes, photocells C6, C7, C8, C10, C12, C14, C15 and C16 are most impacted by the applied force. ②In the experiment of applying 10N force on multiple photocells in the center of the sensor. As the graph shows, the loading force applied in between photocells when the 5*5$mm^2$ tip is applied can be differentiated from the 10N force applied on C6, C7, C10 and C11, which is similar to 10*10$mm^2$ tip case. In the case of the 15*15$mm^2$ tip, the affected area is too wide for the current prototype, so almost every photocell in the sensor is activated; however, as the result shows, the center where the force was applied can be easily found. In these experiments, we see that the sensitivity of this sensor is promising for robotic applications such as detecting object sizes or sensing force.




| | No force apply | 3 N | 13 N |
|---|---|---|---|
| Resistance | 9.46 KΩ | 20.7 KΩ | 80.4 KΩ |
| Voltage | 0.52 V | 1.21 V | 2.57 V |

Fig.3 Photocell resistance & voltage relationship

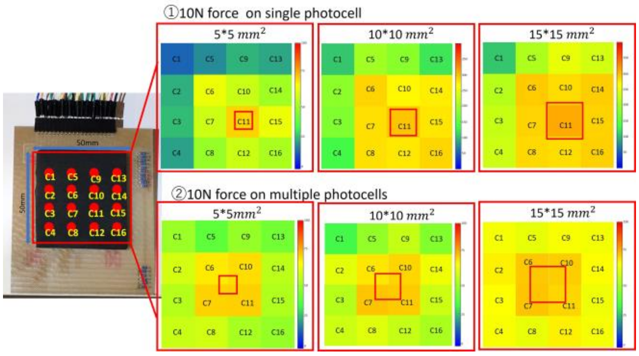



Fig.4 Result of three object position sensing ability

## 5. Conclusion and future worksx

An optics-based tactile sensor with soft elastic membrane was proposed. The experiments ran on the prototype sensor show a promising ability of force sensing and object position detection. In future works, we plan to implement more photocells in to the sensor pad and try to stabilize the sensing ability. We also plan to experiment grasping different kind of objects with the sensor.

**Reference**

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