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Development and evaluation of a two-axial shearing force sensor consisting of an optical sensor chip and elastic gum frame

Toshihiro Takeshita [a,*], Kota Harisaki [a], Hideyuki Ando [b], Eiji Higurashi [c], Hirofumi Nogami [d], Renshi Sawada [d]

[a] Graduate School of Systems Life Sciences, Kyushu University, 744 Motooka, Nishi-Ku, Fukuoka 819-0395, Japan
[b] Fuzzy Logic Systems Institute, 1-5 Hibikino, Wakamatsu-ku, Kitakyushu 808-0135, Japan
[c] Department of Dermatology, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-Ku, Fukuoka 812-0054, Japan
[d] Research Center for Advanced Science and Technology, University of Tokyo, 4-6-1 Komaba, Meguro, Tokyo 153-8904, Japan

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ABSTRACT

We developed a promising shearing force sensor that is small in size and can measure shearing force along two axes independently. This sensor consists of an elastic gum frame and an optical sensor chip (6 mm × 6 mm × 8 mm). From the experimental results, the resolutions of the sensor along the *x*- and *y*-axes are found to be 0.070 N and 0.063 N. We also experimentally demonstrated that the sensor can separately measure shearing force along two axes. Finally, we demonstrated that the scale factor which correspond to resolution and linear portion which correspond to measuring range of the signals can be changed easily by using three types of elastic gum frame. This sensor can be embedded in the finger of a robot hand and use it to not only measure shearing force but also detect the slip phenomenon.

1. Introduction

A force sensor is an important device in fields such as robotics, and the development of medical equipment and automobiles. Force sensors are classified into two types: pressure sensors for measuring the force vertical to the measuring surface and shearing force sensors for measuring the force parallel to the measuring surface. Unlike pressure sensors, shearing force sensors have not been sufficiently developed, although they find wide application owing to their ability to provide information on not only shearing force but also the slip phenomenon. An example of the application of a shearing force sensor is in industrial field robots such as nursing care robots. When the robot hand grabs a soft object such as a human body, it must be able to perform the sensitive grasping motion with minimum pressure and without slip. While a pressure sensor can measure the contact force exerted by the object, it cannot detect slipping. Such minute motion can be realized by embedding a combination of a shearing force sensor and a pressure sensor into the robot's fingers [1]. Recently, shearing force sensors using a piezoelectric element [2–4], a strain gauge [5–7], electro static [8,9] and an optical element [10–12] have been developed. For embedding the sensor in a robot hand, in particular, an optical sensor is superior compared to other types in terms of the response speed. However, optical sensor tends to be large and complex in structure [13,14].

We developed a shearing force sensor that comprises an optical sensor chip and a metal frame [15]. The optical sensor chip is composed of a VCSEL (vertical cavity surface emitting laser) and a Si chip on which PDs (photo diodes) are integrated [16–18]. However, this sensor has disadvantages including only being able to measure the shearing force in a single axial direction and it is large owing to its trapezoidal metal frame with a size of 14 mm × 6 mm × 3.4 mm. Therefore, in this study, we developed a new shearing force sensor that is smaller in size and can measure shear force along two axial directions. This sensor is comprised of an optical sensor chip, which allows measurement of the force in two axial directions, and an elastic gum frame of size 6 mm × 6 mm. Moreover, the novelty of this sensor is that the elastic gum frame component, on which the shearing force is applied, and the optical sensor chip, which is the shearing force sensing component, are physically separated and possible to replace. In general, the force sensing component of a sensor is integrated with the force-receiving components such as that reported in [2–11]. However, the optical sensor chip in our sensor, which is small, high-precision, and delicate, is not influenced by any shearing power in the measuring range. This feature facilitates high endurance toward stress on the sensor. In case of any damage to the elastic gum frame, the sensor can be revived by replacing the frame with a new one. A.H. Dietzel et al. reported the tactile sensor which is the sensing component and the

* Corresponding author. Tel.: +81 92 802 3241.
E-mail address: takeshita.nanomicro416@gmail.com (T. Takeshita).

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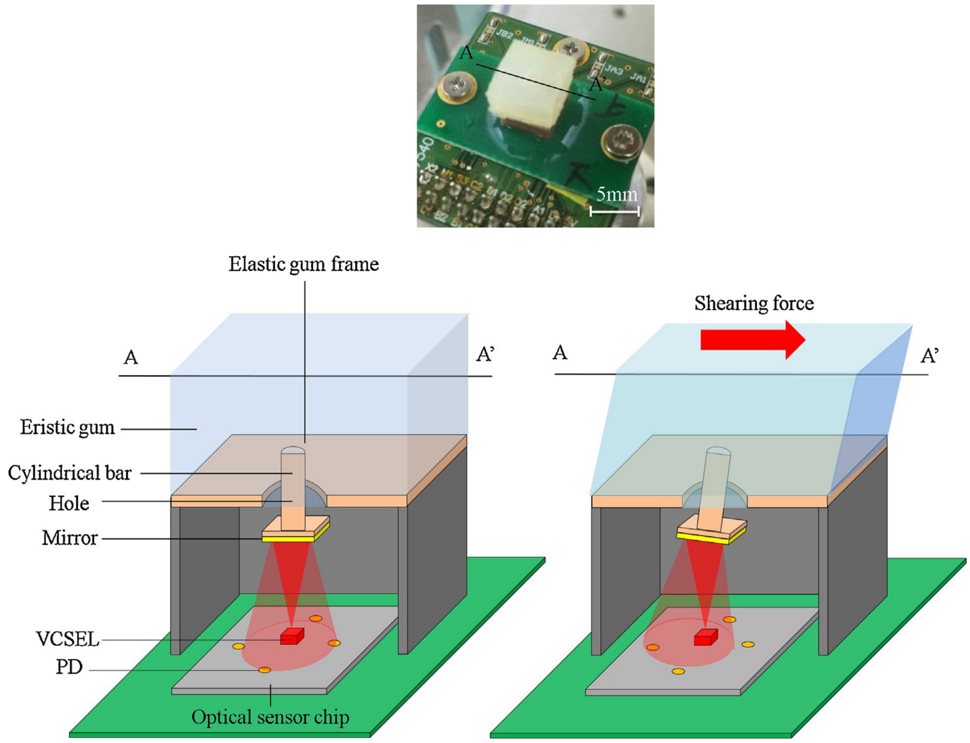

Fig. 1. Structure and principle of the proposed shearing force sensor.

force-receiving component are separated [12]. However, with this sensor, the force-receiving component is impossible to replace. In contrast, with our sensor, the force-receiving component is possible to replace, easily. By varying only the shape and material of the elastic gum, the performance of the shearing force sensor can be easily customized as required. Also, G. Palli et al. reported tactile sensor which measured force and torque from liner displacement and angular displacement of the external mirror which is attached on external frame [19]. Their sensor can measure 6-axis force and torque using three sensor chip. The principle and structure is similar to our sensor and the number of measuring axes is more than our sensor. However they did not discussed about material and structure of external frame. Also, the size of the external frame is so big that the sensor is unsuited for embedding robot hand. Structure and the material of external frame are important factors to decide the performance of the tactile sensor. We devised the structure of the external frame which was fabricated by 3D printer and surveyed the influence of materials of external flame. As a result, we hereby succeeded in the downsizing and high functionality of our sensor.

In this paper, we describe the two-axial shearing force sensor we developed. First, we describe the optical sensor chip and elastic gum frame used in the sensor. We present the experimental results to demonstrate that the performance of the sensor can be changed by using three types of elastic gum frame. Finally, we present the discussions of the results and conclude the paper.

2. Shearing force sensor

Fig. 1 shows the cross-sectional view of the shearing force sensor. The sensor consists of an optical sensor chip and a frame. Four PDs are integrated on optical sensor chip, and a VCSEL is placed on the optical sensor chip. The frame is covered by an elastic gum, and a mirror is attached to the frame's ceiling. Hereafter, we refer to this component as the elastic gum frame. When a shearing force is applied on the surface of the elastic gum frame, the elastic gum deforms and the cylindrical bar inside the elastic gum tilts around the hole on the center of frame. As a result, the mirror attached at the edge of the cylindrical bar tilts. The tilt angle depends on the magnitude of shearing force applied. Using the optical sensor chip, the sensor measures the tilting angle of the mirror. First, we mention about optical sensor chip and elastic gum frame, respectively.

2.1. Optical sensor chip

Fig. 2 shows the structure of the optical sensor chip, which can measure the rotation angle of the mirror attached to a subject to be measured in two axes. The VCSEL chip is bonded to the center of the silicon wafer. The VCSEL is small, has low power consumption, and

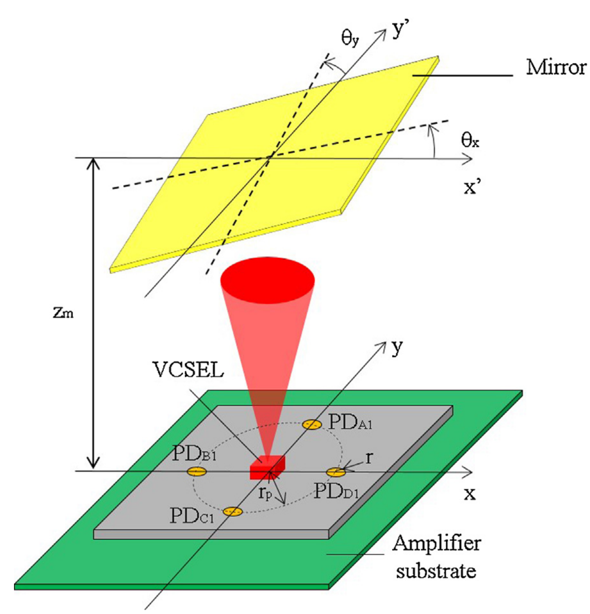

Fig. 2. Structure and design of the optical sensor chip.