Fibratus tactile sensor using reflection on an optical lever

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Abstract

Among several tactile sensors in use currently, none can evaluate the sense of gentle touch. We have developed a fibratus tactile sensor that utilizes the property of reflection. This sensor enables to evaluate the sense of gentle touch. We propose a new interface device that employs this fibratus tactile sensor.

Keywords: tactile sensor, fiber, image sensor, optical measurement, optical lever

1 Introduction

In recent years, with the advancement in robotics, many tactile sensors have been developed in order to improve force sensation in robots. Several tactile sensors are commercially available in the market, for example, the 6-axis force/torque sensor that can measure the force at one point [BL AUTOTEC LTD]. There exists another sensor can measure the distribution of the contact state or the force distribution [Nitta Corporation].

The disadvantage of these distribution-type force sensors is their excessive wirings. Each sensor unit is arranged in close proximity of the measurement surface in order to allow a small sensor to be individually distributed, and the wiring that gathers information from a unit is also individually wired. Therefore, a sensor itself cannot prevent deterioration due to the stress of repeated measurements; further, the wiring assembly is complicated. Some optical sensors [Yamada et al. 2002; Kamiyama et al. 2005] such as the distribution-type optical tactile sensor have already been studied. In these sensors, the sensing units and the corresponding wiring from the measurement surface can be eliminated by using a camera. However, as these sensors measure the motion of the markers embedded in an elastic body, the sensor resolution, rather than the camera resolution, is determined by the markers. Therefore, the resolution of the camera is not completely utilized.

We have examined a sensor that uses an optical lever [Saga et al. 2006]. In the optical lever technique, the displacement is magnified by using reflection characteristics. We propose a sensor with a new system that exploits the optical lever and a flexible mirror surface and measures the reflection image. Due to the reflection image we can utilize the full-resolution of the camera. We propose a new type of optical tactile sensor that can detect the surface deformation with high precision by using the principle of an optical lever. Transparent silicone rubber is used as the flexible mirror surface.

If we can evaluate touch sensation information with respect to fibratus salience, the acquired information can be very useful for interactive devices. We then implant fibratus salience into the flexible mirror surface. From this salience, the end of the fibratus is considered to be the contact surface and the reflection characteristics are left. This salience indicates that the sensor functions as a fibratus tactile sensor.

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2 Fibratus tactile sensor

One tends to be kind when he strokes teddy bears or pets gently; in the same manner, one feels the tenderness of another's gentle stroking. Therefore, the sensations detected by the fibratus tactile sensor are capable of stimulating one's intuition. If we use these fibratus tactile feelings as interfaces, we can use the fibratus sensor as an input device in computers and evaluate its intuitional sense.

Figure 1: *Stroking a teddy gently& Stroked by mother gently: Left: A girl is stroking her teddy gently. Right: A girl's mother strokes her daughter gently*

Thus far, there exist some tangible interfaces that employ position sensors such as buttons, dials, joysticks, and touch panels; force sensors; and acceleration sensors. Many of these interfaces are the input devices that derive information from only one point, and acquired values are linked to symbolic information. In recent years some gaming interfaces have been using conventional sensors to obtain information on natural movements. However if we need to employ interfaces, the development of sensors with innovative concepts becomes imperative.

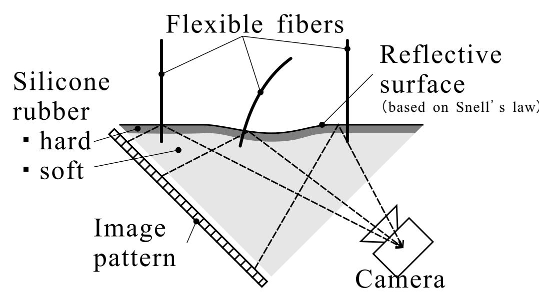

Figure 2: *Section of a sensor: Cross-section of the sensor. The surface of the sensor contains some fibers*

Our research focuses on distributed tactile sensors with soft tissues. Utilizing the principle of the sensor we propose a fibratus tactile sensor. By using this sensor, gentle touches can be evaluated and new interfaces can be developed. For example, by stroking fibers gently, one can create dynamic flows with one's fingers, and intuitional senses may be used as inputs for computers. If softer fibers are utilized, this sensor is capable of sensing even the blowing of wind. In the near future by employing this sensor in a robot, it will be possible to evaluate softer contact information than that detected by existing tactile sensors, thereby causing resulting in an increase in the use of robots in daily life.

We have proposed a new optical tactile sensor that can detect the surface deformation with high precision by using the principle of an optical lever. Transparent silicone rubber is used as the flexible mirror surface [Saga et al. 2006]. We implant fibratus salience, the hardness of which is a little greater than that of silicone rubber, into the flexible mirror surface. From this salience, the end of the fibratus is considered to be the contact surface and the reflection characteristics remain unchanged. This salience indicates that the sensor functions as a fibratus tactile sensor.

3 Principles

In order to realize sensing with regard to the movements of the fibratus salience, it becomes necessary to use some method detecting small angular shifts in surfaces such as that shown in figure 3. This sensor employs two silicone rubber layers and fibers. The outer layer is harder than the inner layer. Owing to this difference in the hardness, the fibers draw the harder silicone layer when they are moved. Therefore the distribution of the angle on the silicone rubber surface is changed by the movement of the fibers. In other words the movement of fibratus salience can be evaluated on the basis of the distribution of the silicone rubber surface.

Subsequently, we utilize the reflection method proposed in [Saga et al. 2006]. This reflection method employs an optical lever. Our

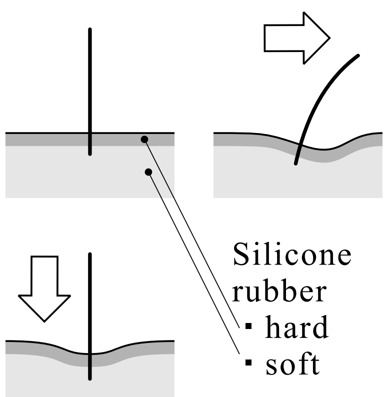

Figure 3: *Reaction of a fiber: Pressing the fiber along the vertical direction causes a symmetric shift of the silicone rubber. Pressing the fiber along the horizontal direction cause an asymmetric shift of the silicone rubber*

aim is to develop a flexible mirror surface by using this optical lever. The sensor detects the deformation of the surface by measuring the displacement via a reflection image from the mirror surface.

3.1 Reflection Condition

In this sensor, transparent silicone rubber is employed as the flexible mirror surface. With regard to the boundary between silicone rubber and air (figure 4), the refractive indices are denoted by n_r and n_a and the refraction angles by ϕ_r and ϕ_a. The notations "r" and "a" denote rubber and air, respectively. When the distribution of the refractive index at the boundary of silicone rubber and air satisfies equation 3, total internal reflection occurs; further, this boundary surface assumes the reflection characteristic of a mirror surface. We design a sensor with a flexible mirror surface by using the above-mentioned mirror surface reflection characteristic. By arranging the image pattern, camera, and the transparent silicone rubber as shown in figure 2, the light diffused from the image pattern is reflected from the silicone rubber boundary and captured by the camera.

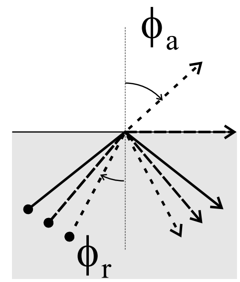

Figure 4: *Snell's law: Based on Snell's law, total internal reflection is achieved*

$$n_r \sin\phi_r = n_a \sin\phi_a \quad (1)$$
$$\phi_r = \arcsin(\frac{n_a}{n_r}\sin\phi_a) \quad (2)$$
$$\phi_r > \arcsin(\frac{n_a}{n_r}) \quad (3)$$

In this paper we employ this method for detecting the movement of the fiber attached to the surface of the sensor.

3.2 Deformation of the Reflection Image

In some optical tactile sensors, a camera is used as the optical sensor [Begej 1984; Kamiyama et al. 2005]; the sensor detects the deformation by tracing a marker. However, the resolution of this sensor is limited because of the restriction due to the overlapping of markers. Further we propose a tactile sensor for the new system that makes use of a reflection image in order to utilize the resolution of the camera to the maximum possible extent by combining an optical lever and a flexible mirror surface and fibratus salience.

If the contact object touches the fiber, the silicone rubber boundary will be deformed (figure 3). Consequently, a deformation of the reflection surface occurs, thereby deforming the reflection image of the image pattern. The sensor measures the deformation of the reflection surface by solving an inverse problem using this deformation. Therefore, the entire reflection image contains information.

3.3 Geometrical Optics

We denote the deformed depth of point Q_1 on the reflection surface q by d, the depth displacement between the adjacent points Q_1 and Q_2 by Δd, the angle at each point on the surface by θ, and the angular displacement between the adjacent points Q_1 and Q_2 by $\Delta\theta$. Here, we express Δd by θ, and then express Δd with known values via $\Delta\alpha$. With some approximation we consequently obtain [Saga et al. 2006] the following:

$$\Delta d = \int_0^L \tan(\theta + \frac{\Theta}{L}l)dl \quad (4)$$

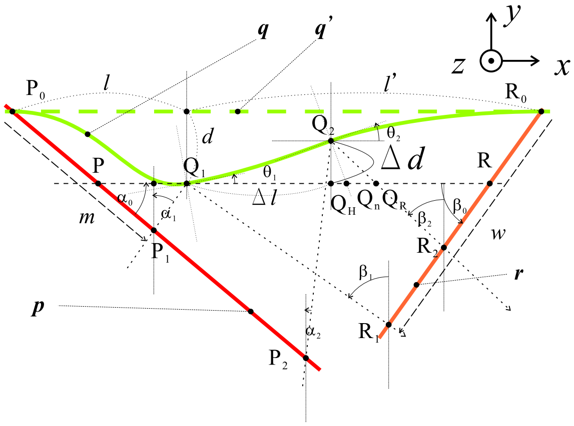

Figure 5: *Geometrical optics: We express Δd with known values via $\Delta\alpha$*

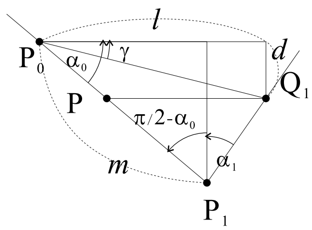

Figure 6: *Geometrical optics: This is a part of figure 5*

$$= \frac{L}{\Theta}\log(|\frac{\cos\theta}{\cos(\theta+\Theta)}|) \tag{5}$$

$$\alpha_1 = \beta_1 - 2\theta_1 \tag{6}$$

$$m = \sqrt{l^2+d^2}\frac{\cos(\alpha_1-\gamma)}{\cos(\alpha_1-\alpha_0)} \tag{7}$$

$$w = \sqrt{l'^2+d^2}\frac{\cos(\beta_1-\gamma')}{\cos(\beta_1-\beta_0)} \tag{8}$$

The sensor can measure m, w, β_1, and β_2 while L_0, α_0 and β_0 are known. The distribution of θ and d are the unknown quantities. The sensor can construct Δd if $\Delta\theta$ and Δl are known from equation 5; further, it can reconstruct θ and d if $\Delta\theta$ and Δd are known. However, because there are few equations, the unknown values in equations 7 and 8 cannot be solved if θ equals $\theta+\Delta\theta$ and l equals $l+\Delta l$. Here, we define

$$\Delta\alpha = \alpha_1 - \alpha_0 \tag{9}$$

From equation 7, we get

$$m^2\cos^2\Delta\alpha - (l^2+d^2)(\cos^2(\alpha_0+\Delta\alpha)) = 0 \tag{10}$$

When $\Delta\alpha$ is expressed as $\gamma = 0$ and $\Delta\alpha \simeq 0$ from the second Taylor series expansion, then $\Delta\alpha$ can be expressed as follows:

$$\Delta\alpha = \frac{\left(\begin{array}{l} -(d^2+l^2)\cos\alpha_0\sin\alpha_0 \\ \pm\sqrt{\begin{array}{l}(d^2+l^2)^2\cos^2\alpha_0\sin^2\alpha_0 \\ -(m^2-(d^2+l^2)\cos^2\alpha_0) \\ \times((-m^2)+(d^2+l^2)(\cos^2\alpha_0-\sin^2\alpha_0))\end{array}}\end{array}\right)}{(-m^2)+(d^2+l^2)(\cos^2\alpha_0-\sin^2\alpha_0)} \tag{11}$$

From equations 6, 9, and 11, we can express θ_1 with the known parameters and measured values.

By defining Q_1 in equation 5 as the n^{th} characteristic point and defining Δd as Δd_n from the continuation property of a boundary surface, we can assume that

$$\Delta d_n \simeq \Delta d_{n+1} \tag{12}$$

Based on this assumption, we can express equation 5 as follows:

$$\Delta d_{n+1} = \frac{\Delta l_n}{\Delta\theta_n}\log(|\frac{\cos\theta_n}{\cos(\theta_n+\Delta\theta_n)}|) \tag{13}$$

Since we assume that $d = 0$ at $l = 0$ and $l = L_0$, we obtain l_n and θ_n from equation 7. We obtain $\Delta\theta_n$ from the given value of θ_n and calculate Δd_{n+1} in equation 13. We obtain α_n, d_n, and the distribution of α and d by performing a step-by-step iteration of this calculation.

4 Implementation

The sensor developed in this study uses the addition-polymerization-type silicone rubber (KE109A, B and KE1052A, B [Shin-Etsu Chemical Co., Ltd.]). We fabricate a triangular pole-shaped flask with transparent acryl, pour silicone rubber into it and perform a lap reaction. Here, we use two types of silicone rubbers. The surface of the sensor is made of a harder type of silicone rubber, KE109, and the sensor contents are made of a softer silicone rubber, KE1052. Then we put fibers to the surface of the sensor. The fibers are made of polystyrene.

Depending on the difference in hardness the fibers draw the harder silicone layer when the fibers are moved. Thus the angle distribution of the fibers on the silicone surface changes due to the movements. After the lap reaction, we perform exfoliation using an acryl board and prepare the reflection surface. One of the remaining acryl surfaces functions as the pattern surface and the other one functions as the captured surface.

In this case, we use a lattice-patterned paper as the pattern surface. In this manner, we prepare a sensor with a flexible mirror surface (figure 7). We install a camera to adequately capture the flexible mirror surface (figure 8).

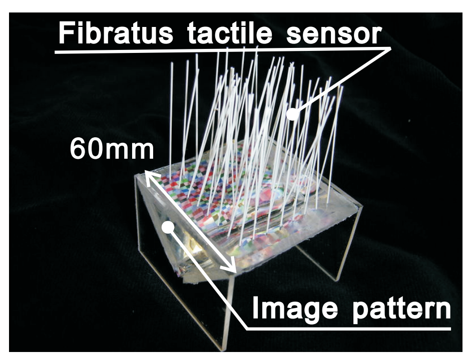

Figure 7: *Silicone rubber with a lattice pattern: the rubber is transparent and the pattern can be seen. The sensor is almost cube shaped with a side length of 60 [mm]*

Here we confirm whether or not the fiber movement induces a deformation of the surface shape. Figure 9 shows the image before fiber movement, and figure 9 shows the image after fiber movement.

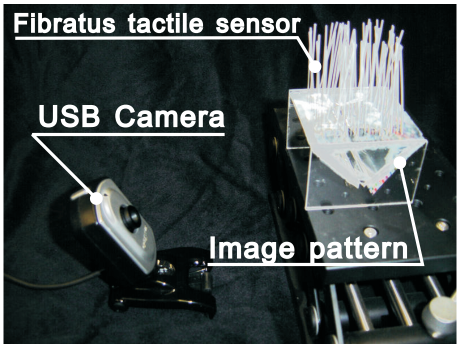

Figure 8: *Overview of the sensor: The optic axis of the camera is located perpendicular to the captured surface*

These two figures show that the fibers can induce a deformation in the surface shape. We can reconstruct the surface shape by using these images and equation 13. According to the surface shape the fibers movements can be estimated.

5 User Experience

We have already developed a simple reflection sensor. This system requires one computer. By using this system the concept of our sensor can be experienced and comprehended. Additionally we will create two fibratus-type sensor systems. Each of these systems also requires with one computer. We plan to activate these sensor systems by using LCDs and show interactive demonstrations so that attendees can comprehend the performance of our sensor. Furthermore, two or three people can simultaneously touch the sensor. Further we plan to display a description video of the sensor on a large screen by means of a projector.

6 Conclusions and Future Work

In this paper, we have proposed a tactile sensor that employs the principle of an optical lever and a flexible reflection surface. We have designed a tactile sensor that takes advantage of the reflection image whose deformation can be detected with high precision using an optical lever; the sensor also takes sufficient advantage of the resolution of a camera by using transparent silicone rubber as the flexible mirror surface. Further we have developed a prototype made of silicone rubber with fibers and have confirmed that the fibers can induce shape deformation of the surface and a change in the reflection image can be captured.

The proposed fibratus tactile sensor employs the full-reflection based on the distribution of the refractive index. Thus variable soft fibratus salience and silicone rubber can be used as the sensor material. Sensing by means of dense distribution of soft fibratus and sensing by a sparse distribution of hard fibratus can be realized. According to this property, the sensor can not only be a conventional tactile sensor but also a more sensitive tactile sensor that can even sense the blowing of wind. Thus, the sensor can not only realize the possibility of a novel interface but also makes the robots to be spread in daily life.

In addition the simplicity of the sensor facilitates not only the use of fibratus sensors but also its use in a variety of variable applications.

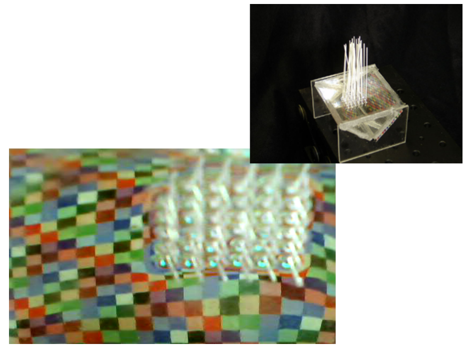

Figure 9: *Before deformation: White objects on the right side of the image are the end of the implanted fibers*

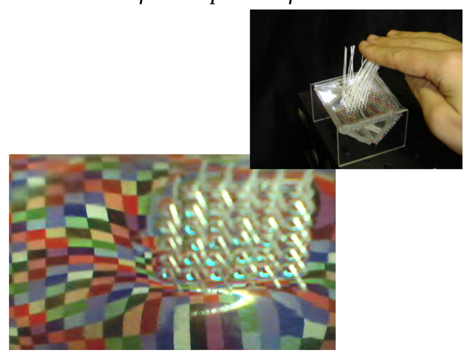

Figure 10: *After deformation: Acquired image is deformed by the touch toward the fibers*

For example, (1) multi sensing, contact-less sensing, interactive devices; (2) sensing by means of active patterns; and (3) thin device and rapid sensing can be realized by using this sensor. Our future work involves the extensive use of these sensing devices and utilizing each of their properties [Saga et al. 2006].

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