# Fibratus tactile sensor using reflection image

–The requirements of fibratus tactile sensor–

Satoshi Saga*
Tohoku University

Shinobu Kuroki†
Univ. of Tokyo

Susumu Tachi‡
Univ. of Tokyo

**Abstract**

In recent years, many tactile sensors have been developed with the advancement in robotics. For example, there are sensors that measure the distribution of the contact state or the force distribution. Among the several tactile sensors in use currently, none can evaluate the sense of gentle touch. We have developed a fibratus tactile sensor that uses the property of reflection. Using this sensor, it is possible to evaluate the feeling of gentle stroking that has never been evaluated. We propose a new interface device by utilizing this fibratus tactile sensor. We have developed a tactile sensor that utilizes the resolution of a camera to the maximum by using transparent silicone rubber as a deformable mirror surface. In this study, we examine the requirements of the hardness distribution of fibers and the base silicone rubber for fibratus sensors.

**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. There exists another sensor that can measure the distribution of the contact state or the force distribution.

*e-mail: saga@rm.is.tohoku.ac.jp
†e-mail: Shinobu_Kuroki@ipc.i.u-tokyo.ac.jp
‡e-mail: tachi@star.t.u-tokyo.ac.jp

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 [1, 3] 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 is determined by the resolution of the markers rather than the camera resolution. Therefore, the resolution of the camera is not completely utilized.

We have proposed a new type of optical tactile sensor that can detect the surface deformation with high precision by using the principle of an optical lever[5]. In the optical lever technique, the displacement is magnified by using reflection characteristics. Due to the reflection image we can utilize the full resolution of the camera. Transparent silicone rubber is used as the flexible mirror surface.

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 input devices that derive information from only one point, and the 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 using innovative concepts becomes imperative. In addition, in the field of sensing researches many distribution-type tactile sensors have been developed however, these sensors cannot measure small and fine details such as gentle touch.

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

One tends to be kind when gently stroking teddy bears or pets; 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 (Fig. 1). 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.

Additionally, realizing the fibratus tactile sensors can be used to develop an interface that can input spatial flows and at the same time can return some kinds of tactile sensation to the operator. For example, by stroking fibers gently, one can create distributed vector fields such as those created during the blowing of wind or the flowing of water with one's fingers, and intuitional senses may be used as inputs for computers. 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 resulting in an increase in the use of robots in daily life.

If we can evaluate touch sensation information with respect to fibratus salience, the acquired information can be very useful for interactive devices. We can 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 property remains unchanged.

# 2 Fibratus tactile sensor

We propose a new type of tactile sensor that combines the principle of an optical lever and a fibratus salience. To amplify the resolution of deformation, this sensor utilizes the principle of an optical lever and to employ the full resolution of the camera we utilize reflection images. Furthermore, to capture small forces, we use a fibratus salience at the same time.

By arranging the image pattern, camera, and the transparent silicone rubber as shown in Fig. 2, the light diffused from the image pattern is reflected from the silicone rubber boundary and captured by the camera. In additional this sensor employs silicone rubber layers and fibers. The fibers draw the 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 the fibratus salience can be evaluated on the basis of the distribution of the silicone rubber surface.

## 2.1 Comparison with other sensors

A tactile sensor with fibratus saliences has been developed [2]. This sensor uses plastic fibers as fibratus saliences and by utilizing microphones it measures the vibration of the polyethylene film that is connected to the fibers. The structure of human skin is shown in Fig. 3. The free

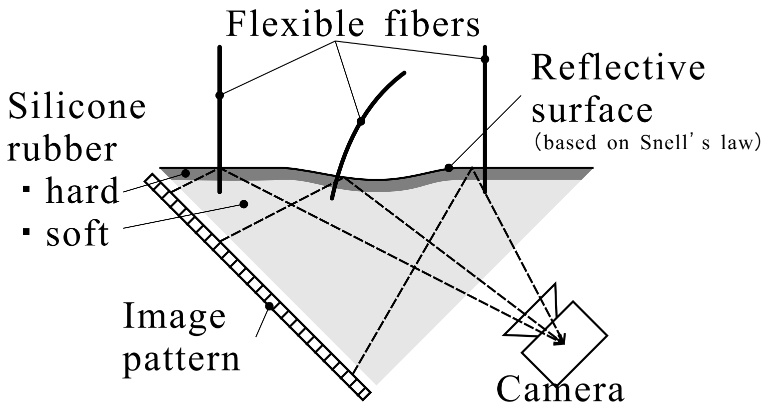


**Figure 2:** *Section of a sensor: Cross-section of the sensor. The surface of the sensor contains some fibers*

nerve endings detect each displacement of the fibers. The structure of the salience and the sensor resemble those of the previous sensor. However the distributed multiple sensors such as hairy skin receptors require microphones beneath the saliences. The number of the sensor units and the wiring can be drawbacks. This is a common problem for in distributed force sensors.

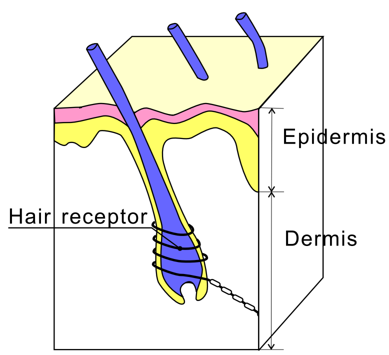


**Figure 3:** *Section of human hairy skin*

## 2.2 Requirements of fibratus tactile sensor

Here we consider about the requirements of sensors that detect the deformation of fibratus saliences like the hairy skin receptors of humans. The fibratus salience is projected at an angle almost perpendicular to the implanting surface. The salience is sustained by the contact between the implanted part of the salience and the implanting surface. Taking the structure into account, to transmit the deformation of the salience the hardness of the salience should be harder than that

**Table 1:** *Young's modulus on hairy skin [4, 6]*

| Tissue | Young's modulus |
|---|---|
| Dermis | 0.136 [MPa] |
| Epidermis | 0.08 [MPa] |
| Subcutaneous tissue | 0.034 [MPa] |
| Beard hair | 3.50 [GPa] |

of the implanting surface. Otherwise the deformation of the salience cause the folding of the salience at the implanting point, and the deformation cannot be transmitted under the surface (Fig. 4). In fact, the distribution of Young's modulus on hairy skin is as follows (Table 1)[4, 6].

Because of the distribution of the hardness the salience can work as a "lever" whose supporting point is near the implantation point, therefore the deformation of the implanted part becomes smaller and the stress change of the implanted part becomes larger (Fig. 5). In human skin the free nerve ending is wrapping around the end of the salience. Taking the "lever" movement into account, it is possible that the nerve ending detects this large stress change.

Based on the previous discussion, we should detect the stress caused by each salience individually. However employing the sensor in order to detect each stress individually is a complex procedure. This is why we do not detect the stress but the deformation itself. To not only avoid

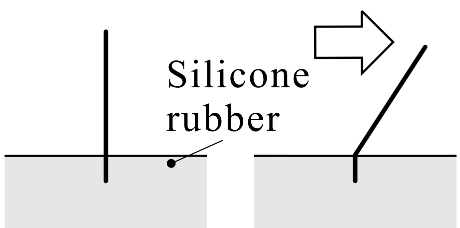


**Figure 4:** *Reaction of a salience with small Young's modulus*

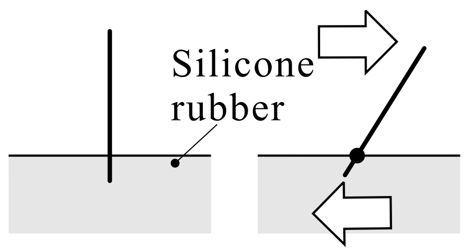


**Figure 5:** *Reaction of a salience with large Young's modulus*

the complexity of the sensor units and wirings, but also to enlarge the deformation we use our sensing method – a method of flexible distribution-type tactile sensing [5].

## 2.3 Detecting the deformation

This tactile sensor utilizes 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 was 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 a flexible mirror surface. In this sensor, transparent silicone rubber is employed as the flexible mirror surface. With regard to the boundary between silicone rubber and air (Fig. 6), the refractive indices are denoted by $n_r$ and $n_a$ and the refraction angles by $\phi_r$ and $\phi_a$. The notations "$r$" and "$a$" denote rubber and air, respectively. Based on Snell's law, when the distribution of the refractive index at the boundary of silicone rubber and air satisfies Eq. 3, total internal reflection occurs; further, this boundary surface assumes the reflection property of a mirror surface.

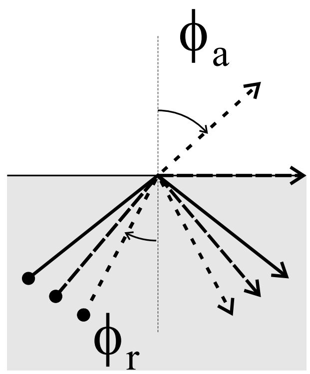


**Figure 6:** *Snell's law: Based on Snell's law, total internal reflection is achieved*

$$\begin{aligned} n_r \sin\phi_r &= n_a \sin\phi_a & (1)\\ \phi_r &= \arcsin(\frac{n_a}{n_r}\sin\phi_a) & (2)\\ \phi_r &> \arcsin(\frac{n_a}{n_r}) & (3) \end{aligned}$$

Further, we implant a 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 property remains unchanged. Thus, the sensor functions as a fibratus tactile sensor.

# 3 Simulations

To detect the deformation of the fibratus salience, we need a method to detect the small displacement of the surface angle. The sensor used is made of transparent silicone rubber and a fibratus salience. In order to utilize the principle of an optical lever, the construction of silicone rubber developed should be sensitive to the deformation of the surface which is induced by the movement of the fibratus salience. Then we compare the development of single-layered silicone rubber and multi-layered silicone rubber by simulation. The simulator is Femlab 3.0.

Cond. 1: Silicone rubber with softer single layer A

A : Young's modulus, 0.08 [MPa]; Poisson's ratio, 0.33

Cond. 2: Silicone rubber with softer layer A (downside) and harder layer B (upper side)

A : Young's modulus, 0.08 [MPa]; Poisson's ratio, 0.33

B : Young's modulus, 1.6 [MPa]; Poisson's ratio, 0.33

Cond. 3: Silicone rubber with harder single layer B

B : Young's modulus, 1.6 [MPa]; Poisson's ratio, 0.33

In each condition we have simulated a situation in which a fiber with a Young's modulus of 1.0 [MPa], width of 0.5 [mm], and length of 50 [mm], is implanted into the surface with a depth of 10 [mm], and a force in the right direction force is applied to the upper-endpoint of the fiber. Each Young's modulus is based on the actual measurement value of the the two types of silicone rubber. The results are shown in Figs. 7,8, and 9. The color bar shows vertical stress in the x-direction.

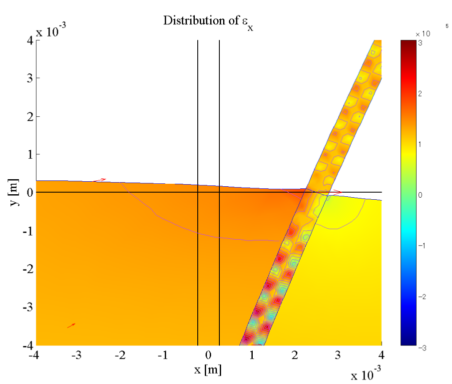


**Figure 7:** *Stress distribution & change of surface shape (Cond. 1)*

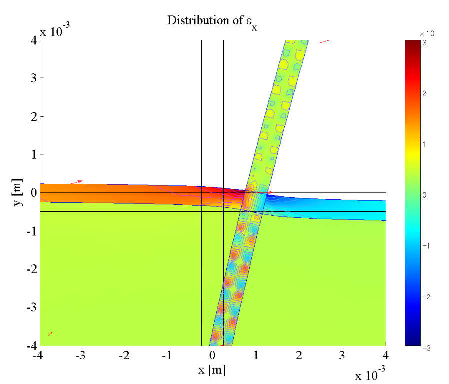


**Figure 8:** *Stress distribution & change of surface shape (Cond. 2)*

Compared with Figs. 7 and 8 Fig. 9 shows little deformation of the surface in the case of a harder single layer. Comparing Fig. 7 with Fig. 8, although the vertical deformation of the surface is almost the same, the deformation of the surface is widely distributed in Cond. 1. With our sensor using an optical lever, the displacement of the surface angle is greater than the

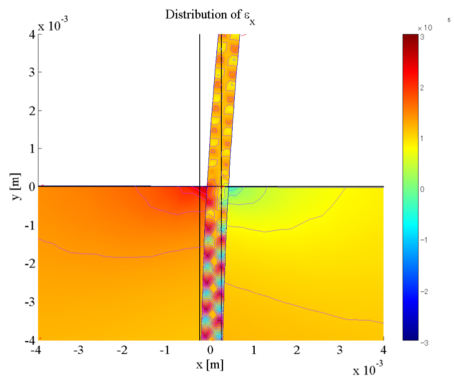


**Figure 9:** *Stress distribution & change of surface shape (Cond. 3)*

deformation. As a consequence, the construction of Cond. 2 is more suitable for the sensing method. Therefore we develop a silicone rubber that has two layers similar to Cond. 2.

# 4 Implementation

Based on the discussion in the previous section, we use two-layered silicone rubber (Fig. 10).

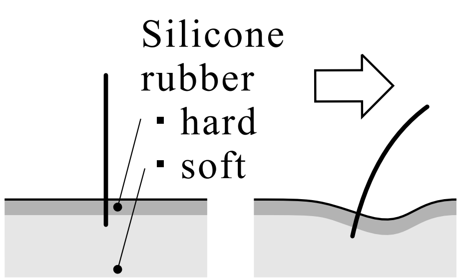


**Figure 10:** *Two-layered base & reaction of a fiber*

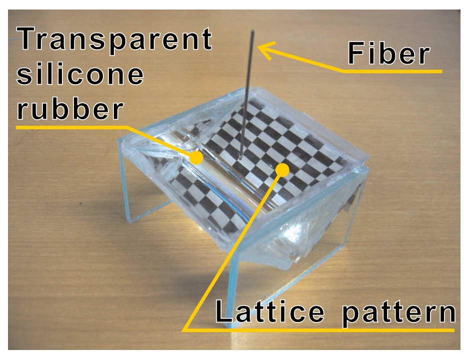


**Figure 11:** *Sensor Overview*

Using this prototype sensor (Fig. 11) we validate the behavior of the sensor. By applying a force to the endpoint of the fiber we acquire the deformed reflection image. Fig. 12 and 13 show the acquired images. These figures show that the sensor can detect a small deformation by using a deformed reflection image. By using this reflection image we can reconstruct the deformation of the surface [5]. Based on the assumption that the fibratus salience stands almost vertical to the surface, we can reconstruct the posture of the fibratus salience after reconstruction of the shape of the surface.

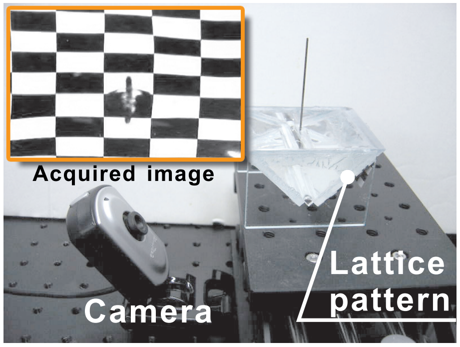


**Figure 12:** *Before deformation*

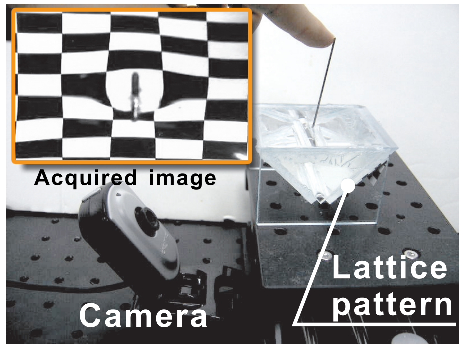


**Figure 13:** *After deformation*

# 5 Conclusions

In this paper, we have proposed a tactile sensor that employs the principle of an optical lever, a flexible reflection surface, and fibratus salience. We have discussed about the structural property that is needed for the fibratus tactile sensor and have clarified that our proposed reflection sensing method is suitable for the fibratus sensing. In addition, we have also discussed about the surface condition required to achieve the deformation caused by the fibratus salience with this reflection sensor. We found that , the two-layered sensor can enlarge the displacement of the surface angle to a greater externt than a single-layered sensor. Based on the simulation of the design of the sensor, we have created a prototype fibratus tactile sensor, and have confirmed that the deformation of the surface can be acquired from the deformation of the reflection image.

As a future work we are planning to compare the reconstruction of the surface shape from the acquired reflection image and the simulated shape, and validate the error between the real deformation of the fibratus sensor and the simulated one. Additionally, we will discuss about the reconstruction of the surface shape using sensors with multiple fibratus saliences and determine the method to estimate the applied force toward the saliences; further we aim to establish the usage of the sensor as an interface device.

# References


[1] Stefan Begej. An optical tactile array sensor. *SPIE Intelligent Robotics and Computer Vision*, 521:271–280, 1984.

[2] Yui Ishizaka, Marika Hayashi, Shigeru Kanzaki, Kei Okada, Ikuo Mizuuchi, Tetsunari Inamura, and Masayuki Inaba:. Development of touchy-feely friendly robot and animal suits embedded fibratus tactile sensor,. In *Proceedings of ROBOMEC06*, 2006. 1P1-E05.

[3] Kazuto Kamiyama, Kevin Vlack, Hiroyuki Kajimoto, Naoki Kawakami, and Susumu Tachi. Vision-based sensor for real-time measuring of surface traction fields. *IEEE Computer Graphics & Applications Magazine*, 25(1):68–75, 2005.

[4] Takashi Maeno, Kazumi Kobayashi, and Nobutoshi Yamazaki. Relationship between structure of finger tissue and location of tactile receptors. *JSME International Journal*, 63(607-C):881–888, 1997.

[5] Satoshi Saga, Hiroyuki Kajimoto, and Susumu Tachi. High-resolution tactile sensor using the deformation of a reflection image. *Sensor Review*, 27:35–42, 2006.

[6] S. M. Thozhur, A. D. Crocombe, and P. A. Smith. Structural characteristics and mechanical behaviour of beard hair. *Journal of Materials Science*, 41:1090–1121, 2006.