Using Soft Fingertip Embedded with Micro Sensor in Textile's Texture Recognition

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Abstract—In this paper, we discuss an approach to developing a simple design of soft fingertip which is embedded with a micro sensor in textile manipulating. This sensor can detect three components of forces and moments, these are F_z, M_x, M_y. An FEA (Finite Element Analysis) simulation of fingertip's deformation is shortly mentioned to see the similarity in stress distribution between contact surface and the location of the sensor. Finally, we conduct experiments in handling some specimens of textile to show the potential of our design in recognizing quantitatively texture characteristics.

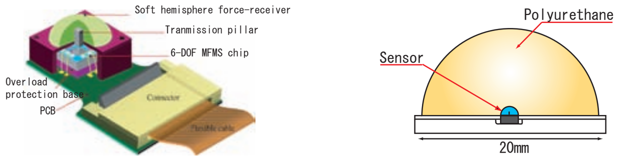
Key Words: Soft fingertip, tactile sensing, texture, micro sensor.

1. Introduction

Tactile perception has been a basic potential for robot arms which must operate contacting, or grasping object. Especially in textile manipulating, information about its texture such as thickness, softness, friction is important for proper, stable and flexible control. There has been many researches attempt to imitate the anatomy of human fingers in manipulative execution, which can be found in [1] and [2]. However, these imitations caused complications in design and implementation of tactile sensing models. Therefore, in this paper, we show our approach to development of a much simpler tactile model by using a soft fingertip which has a semispherical shape made of polyurethane rubber with diameter of 20 mm, and one 3 DOF (Degree of Freedom) micro force/moment sensor. In section 2, we discuss micro sensor and fabrication of a soft fingertip embedded with a sensor. Afterward, section 3 shows the results of experiments on textile manipulation which were carried out to show the ability of our model in tactile texture sensing.

2. The sensor and its placement inside the soft fingertip

In this study, we use a 3-DOF SCT (Soft Contact Tactile) sensor that has the configuration shown in Fig. 1(a). The core of the sensor is a 6-DOF MFMS (Micro Force Moment Sensing) chip which is described in [3]. It can detect three components of force (F_x, F_y, F_z) and three components of moment (M_x, M_y, M_z) independently. The MFMS chip is connected to soft contact element (a silicone rubber hemisphere) by a silicone transmission pillar. The overload protection base, made from Pyrex, is placed under MFMS to protect it from overloading. Connections between the chip and the printed circuit board are established by gold wire bonding. The chip and the protection base are covered by a ceramic case. A flexible cable directs the input voltage and output voltage. The overall dimensions of the package sensor are *Length* 11mm x *Width* 5 mm x *Thickness* 3.3 mm. There are 3 types of sensor which can output different signals. In this study, we only use sensor of type 1 which can produce F_z, M_x, M_y. As aforementioned, soft fingertip is a polyurethane rubber semisphere. The micro sensor is embedded inside the fingertip and at the center of rubber semisphere (Fig. 1(b)). Such a placement is also mentioned in [4] which shows that the sensor's responses when the soft fingertip slides on another surface or grasps object can reflect approximately basic mechanical phenomena on the contact surface. Fig. 2 shows the deformed shape of the soft fingertip when it makes contact and slides on a rigid surface. This process was simulated in ANSYS software by Nonlinear Finite Element Analysis (FEA). We can see from Fig. 2 that normal and tangential stress distributions on the contact surface are



(a)Configuration of sensor.　　(b)Scheme of soft singertip.

Fig.1 Sensor and soft fingertip

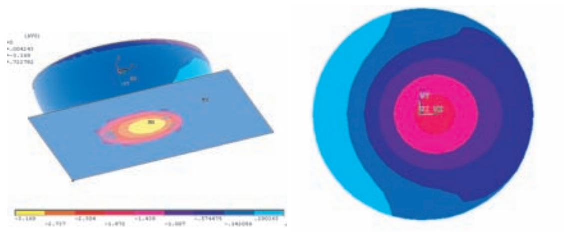


Fig.2 Stress distribution at contact surface and at surface on which sensor is located

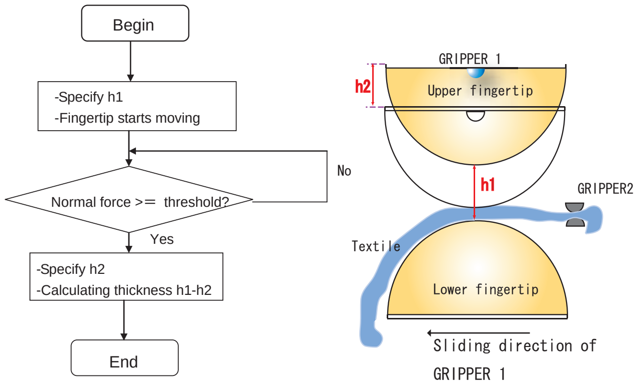


Fig.3 Thickness experiment description

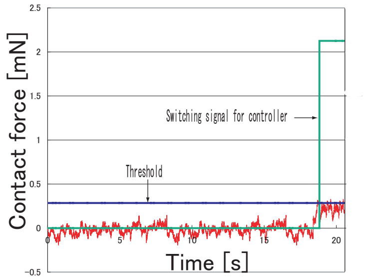


Fig.4 Response of contact force in thickness experiment

similar with that on the surface where sensor is located. Therefore, based on the changes of sensor's responses when the soft fingertip deforms, states of contact can be recognized.

3. Textile Texture Recognition

In textile manipulating, thickness, flexibility or roughness of a surface are highly considered variables. Being able to get that information approximately is necessary for constructing a control system that can handle textile, such as stretching or folding flexibly and intelligently. In the case of humans, if we want to know about particular features from an object, it is possible with only fingers by using some tactile procedures. For example, if we are interested in texture, just move fingertip on the surface and pay attention to tactile sensation from contact surface. In this study, we also follow that approach to recognize textile texture using a soft fingertip embedded with micro force/moment sensor.

3·1 Experiment setup

The apparati of the experiment can be realized with the following description:

1. A 2-DOF $X - Z$ linear stage which can move horizontally and vertically. It is controlled by computer with a motion resolution of 2 μ m.
2. Gripper 1 with two soft fingertips which have relative motion in vertical direction is mounted on the linear stage. The upper one has micro sensor implanted inside, while the lower one does not.
3. Gripper 2 is to hold fixed one corner of a textile sample for stretching work (Fig. 3).)
4. ADC (Analog-Digital Converter) card with sixteen inputs is employed for data acquisition from sensor. In addition, circuits for offset and amplifying signals from the sensor were designed.

3·2 Thickness experiment

In textile stretching work, the optimal gap between two fingertips which simultaneously contact with surface of textile specimen should be determined. If it is too small, the stretching work will be difficult because of friction force, while if it is too large, the textile will not be stretched properly. One of the criteria for determining optimal gap is the thickness of textile specimen. Experiments had showed that the optimal gap should be around the actual thickness of textile. Therefore, our approach is to build strategy for determining thickness of an arbitrary textile specimen. Fig.3 shows the flowchart of process. h_1 is gap between two fingertips at initial configuration, h_2 is displacement of upper soft fingertip. From initial configuration, the upper fingertip is moved toward surface of textile. When the detected contact force exceeds threshold M (Fig. 4), the fingertip is stopped and h_2 is determined. Based on h_1 and h_2, the controller can calculate the thickness of textile specimen that equals to h_1-h_2. The most considered problem is specifying the value of unique threshold M for any specimen. Moreover, fingertip has to stop right on the surface, so contact force is very low. Therefore, value of M should be small or it would affect the preciseness of result. Because of that, signal from sensor is afterwards filtered by FIR filter (Finite Impulse Response) to get the considerably fine and flat signal. Table 1 shows the experiments with three kinds of textile specimen. With each textile's specimen, measurements were repeated for at least 5 times. And the values quoted in second row of Table 1 are average ones with their coressponding threshold and tolerance. Based on that, we decided to choose M = 3 mV which corresponds to value of contact force of 0.255 mN (Fig. 4), and the average tolerance is 1%.

Table 1 Calculated thickness of various specimens

	Felt	Denim	Cotton
Average measured thickness [mm]	1.8	1.17	0.9
Actual thickness [mm]	1.78	1.179	0.81
Threshold [mV]	3	3.1	3
Tolerance [%]	1.1	0.8	1.1

Table 2 Calculated hardness of various specimens

	Felt	Cotton	Denim
F_1 [mN]	0.255	0.255	0.255
F_2 [mN]	0.4	0.4	0.4
D [mm]	0.46	0.27	0.12
H [N/m]	0.3	0.53	1.23

3·3 Hardness Experiment

It is possible to derive quantitatively the hardness of a textile's surface from essential calculations based on sensor's output when soft fingertip contacts with it. First, upper fingertip moves into contact with textile in the similarway with the previous process of thickness experiment. At this phase, contact force F_1=0.255 mN and position of fingertip are recorded. After that, soft fingertip slowly moves ahead increasing the contact force until it reaches threshold of F_2=0.4 mN. It stops again and new coordinate is sent to computer. Based on that information, controller computes the displacement of upper fingertip during the mentioned pushing process. Because two soft fingertips are used, both sides of textile's surface are deformed identically; two soft fingertips deform as well.

The hardness of the textile's surface can be calculated as :

$$H = \frac{F_2 - F_1}{D}$$

where H is the so-called textile's hardness, F_1 and F_2 are thresholds of phases, D is the displacement of upper soft fingertip between two phases. Table 2 shows that, with the soft specimen like Felt, H is relatively small, while with Denim, it is much larger. Therefore, the parameter H can reflect the hardness of textile surface quantitatively.

3·4 Friction Experiment

As aforementioned, simulation showed that when soft fingertip slides on a surface, normal and tangential stress on the contact surface are similar with those on cross-sectional surface where the sensor is located. Therefore, responses from the sensor can reflect status of contact. However, being able to calculate accurately the actual friction force is complicated. Because, there are many factors that affect friction force evaluation, such as polyurethane rubber's nonlinear elasticity, boundary and constraint conditions, etc. However, in this textile stretching task, it does not require precise friction force. In short, we just approximately investigate status of contact friction by considering tangential signal from sensor(Mx, My).

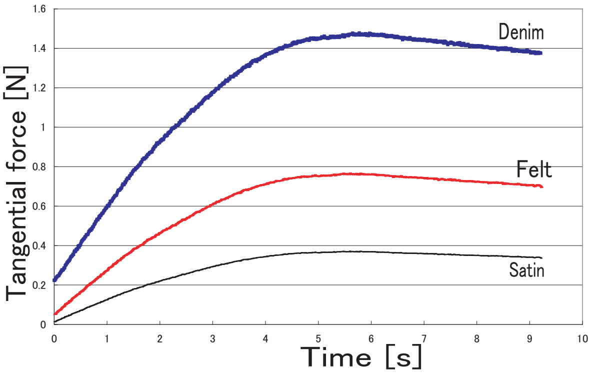


Fig.5 Tangential force signals of sensor when soft fingertip slides

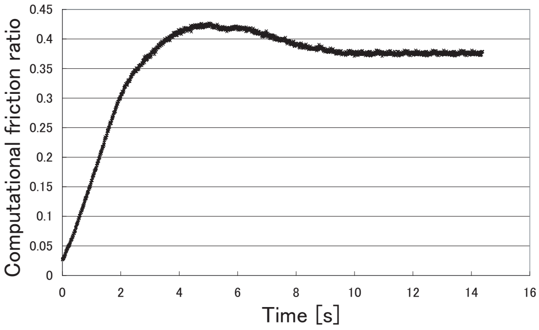


Fig.6 Computational friction ratio based on responses of sensor when soft fingertip slides

Upper soft fingertip is controlled to slide on the surface of textile specimens toward X-axis; therefore output signal M_y of sensor will reflect friction force. As illustrated in Fig. 5, tangential forces which were computed from M_y during sliding motions on various textile specimens bring knowledge of resistive characteristic of each specimen's surface. Materials like Felt or Satin generate smaller tangential force while Denim (material for jeans) shows much higher value because of its high roughness.

Moreover, in the sliding process of soft fingertip from still position to gross sliding, there is almost a linear increase in value of tangential force until the maximum value is reached, after that it keeps constant (Fig. 5). These can be explained by contact mechanism. First, when the slip has not happened, static coefficient rises linearly and causes the friction force to increase. When static coefficient reaches its maximum, the slip happens. After that incipient slip, fingertip slides constantly; friction coefficient is now a dynamic friction coefficient which is smaller than the static one, therefore friction force remains unchanged [5]. Fig. 6 shows the friction coefficient (relatively) which is calculated in real time based on normal and tangential force's signals of sensor during sliding motion of soft fingertip on textile's surface.

3·5 Roughness Experiment

The roughness of textile's surface not only can be realized by observing friction force exerted on contact surface, but also be examined by analyzing power

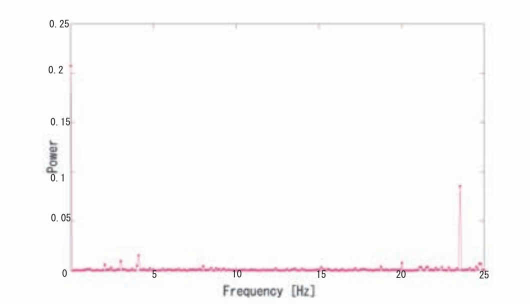


Fig.7 Frequency content of contact force when soft fingertip slides on Denim's surface

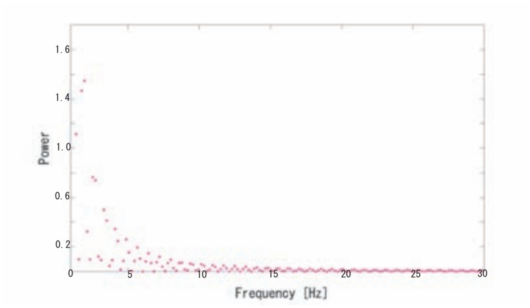


Fig.8 PSD of contact force when soft fingertip slides on Felt's surface

spectral density (PSD) of contact force. Most of textiles are knitted by fabric causing ridges which are distributed widely on textile's surface. Therefore, when soft fingertip slides on textile's surface, responses from sensor contain information about density of those ridges, as well as roughness of surface. If fingertips slide with a constant velocity v, distance between two continuous ridges (wavelength) d, then frequency of periodic signal will be $f = v/d$ [6]. By analyzing power spectrum of sensor's signals we can determine main frequency f, afterward d will be specified. It is clear that the value of f must not be zero, because value of f around zero corresponds with the real signal of actual contact force (fingertips slide with unchanged speed). Therefore, signals which have frequency other than zero could be considered as noises. The signal containing the information of textile surface's roughness will have higher power than other noises (but it is still a noise). This leads to essential consideration when designing digital low-pass filter so that it does not lose information of that required signal.

We programmed fingertips to slide on the surface of Denim specimen. On that textile specimen, there are ridges distributed continuously with d=0.7 mm. The fingertips slide with velocity v= 15 mm/s resulting the main frequency in power spectrum to be 21.5 Hz. Fig. 7 shows that signal's frequency, at which the highest power is detected, is 24 Hz. This result has a small deviation compared with actual wavelength. It can be explained that contact of soft fingertip and surface is surface-contact. At the same time, there are many contact points between soft fingertip with ridges. If space between two ridges is large enough so that the contact of fingertip and textile's surface can be considered as point-contact, the received PSD will be finer and it will be easier to realize main signal's frequency which discloses wavelength d .

When roughness experiment is carried out on Felt which has many small bunches of cotton fiber instead of ridges, the obtained PSD shows that there is no specified main frequency, other than zero. As a substitute, there are many signals that have the same small power, it is not clear to specify the main signal (Fig. 8). In this case, it can be concluded that the surface of Felt material does not have uniform distribution of fiber or the sensor's ability of detection is not high enough.

4. Conclusion

In this paper, we showed our approach in developing a simple design of soft fingertip that can detect textile's texture efficiently. Based on this ability, we design flexible control system for handling textile such as pinching, stretching, folding, etc.

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