Tangential Force Sensing System on Forearm

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ABSTRACT

In this paper, we propose a sensing system that can detect one dimensional tangential force on a forearm. There are some previous tactile sensors that can detect touch conditions when a user touches a human skin surface. Those sensors are usually attached on a fingernail, so therefore a user cannot touch the skin with two fingers or with their palm. In the field of cosmetics, for example, they want to measure contact forces when a customer puts their products onto their skin. In this case, it is preferable that the sensor can detect contact forces in many different contact ways. In this paper, we decided to restrict a target area to a forearm. Since the forearm has a cylindrical shape, its surface deformation propagates to neighboring areas around a wrist and an elbow. The deformation can be used to estimate tangential force on the forearm. Our system does not require any equipment for the active side (i.e. fingers or a palm). Thus a user can touch the forearm in arbitrary ways. We show basic numerical simulation and experimental results which indicate that the proposed system can detect tangential force on the forearm. Also we show some possible applications that use the forearm as a human-computer interface device.

Categories: H.5.2 [**User Interfaces**]: Haptic I/O

General Terms: Measurement

Keywords

Tactile Sensor, Tangential Force Sensing, Body Sensing, Human-machine Interface

1. INTRODUCTION

Previous tactile sensors can be categorized into following three groups when we focus on what contacting objects are. The tactile sensor which can detect contact conditions between 1) human and object, 2) object and object, and 3) human and human. The sensors in first category (human and object) are mainly used for human-machine interface device. A simple example of this category is a touch panel. The touch panel (object) can detect contact by a user. For the second category (object and object), the tactile sensors are often used in robotics. For example, the sensors are attached onto the robot hand for achieving a dexterous manipulation with something [1]. Also a robot can detect environmental objects such as a wall, a door, and furniture when it has tactile sensors on its body surface [2]. Both cases it is not so hard to set tactile sensors on the object side. In contrast, it becomes harder to detect contact conditions between human and human.

Some researchers have proposed finger-mounted tactile sensors. Each researcher detected contact conditions based on color changes of a fingernail [3], deformation of a fingertip [4], vibration on a fingernail [5] and emitted sound around a fingertip [6]. These sensors can detect contact information between not only 1) human and object, but also 3) human and human. This is because the user wearing this type of sensor can touch anything. The limitation of these sensors is that the user has to touch the object or the skin surface with their particular finger, on which the sensor is mounted. These sensors cannot work when the user touches with their other fingers or palm.

There is a requirement to measure the applied force to the skin surface in the field of cosmetics, for example. They want to know how strong a customer touches their skin surface when they use cosmetic products onto it. These contact information can be used to evaluate the usability of the products. When a user put a cosmetic on their skin, they sometime use two fingers at once or their palm. The previous finger-mounted sensors cannot be used for this purpose.

In this paper we show a sensing system that can detect one dimensional tangential force at a cylindrical body area such like a forearm. Figure 1 shows the representative photo of our sensing system. We put the two armbands with the photo reflective distance sensors on user's forearm. When the user touches the skin area in between the two sensors, the deformation of the forearm can be detected as the change of the height of the skin surface at the armbands especially when the skin moves laterally toward the sensor. Since the sensors were put on the passive side of human body, the user can touch there in any styles such like the single finger, two fingers and their palm. The proposed sensing principle can be used not only for 3) human and human contact but for 1) human and object interactions. For example, the user can touch the forearm with a mediate object, such like a towel.

This sensing system is also useful for an input interface. Recently many researches have tried to use human skin as an input surface. In these cases, user can use their own body as the input medium. Haptic information such like a relative position between the manipulation finger and the input skin surface, can help users for achieving better usability. As a result, users do no need to see the input area to input something. They can know how commands are inputted based on their tactile feelings. We show our first prototype which shows that the system can be used as an input interface to input 1 directional information.

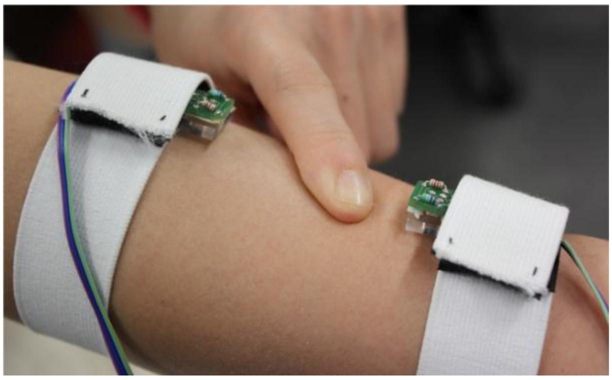

Figure 1. The belt type sensor that enables to measure the tangential force generated onto skin surface.

2. RELATED WORKS

2.1 Tangential Force Sensing

Strain gauges are commonly used to measure the tangential force on hard objects. Herot and Weinzapfel presented an interface that can measure, via strain gauges, the force vector applied to a screen [7]. Since the voltage change in the gauges is small, an operational amplifier must be used, resulting in complex circuitry. Also, strain gauges are rigid instruments. Since it requires solid attachment to the material, the material's stiffness can change. Our technique allows us to customize the sensor's position and sensing area according to the target location of body because it only requires sensor allocation without any special tool and complex manner.

Camera-based method has been proposed for measuring tangential forces applied to soft material. Kamiyama et al. developed the Gelforce sensor, which could measure six-degrees of freedom forces by capturing the deformation of color markers embedded in an elastic material [8]. While camera-based method works well in a limited environment, a certain amount of space is required between the surface and sensor.

There are several attempts to measure slipping movement on a soft surface by using same optical sensor as that user in an optical mouse [9] [10]. These methods measure the material's relative translational displacement, which leads to cumulative errors. Our sensing method measures the absolute stretch of skin, thus it is not prone to such errors.

2.2 Finger-Mounted Tactile Sensors

Recently some researches have proposed finger-mounted tactile sensors to detect human to human contact condition. Mascaro et al. proposed camera based tactile sensor which detected contact force based on color change of a fingernail [3]. Nakatani et al. proposed normal force sensor by attaching strain gauges on sides of user's fingertip [4]. When the user touches object, normal deformation of the fingertip changes the width of the finger. The sensor can detect the change at the side of the fingertip, user can touch the surface without putting any sensors between the finger and the object. Makino et al. attached piezoelectric vibration sensor on a fingernail to detect contact related vibration [5]. They used those vibration data for achieving a lifelog system. Tanaka et al. proposed a sound-based sensor system [6]. The sensor can detect tactile related sounds to estimate roughness of the contact object. Based on these sensors, users can touch any surface. However they cannot touch the body with another finger or their palm. Our method allows users to touch the skin surface in arbitrary way.

2.3 Human Body as Input Surface

There are several attempts to use human body as an input surface. Harrison et al. propose the method named "Skinput" to detect the location of the finger taps on the body, especially on the arm by analyzing mechanical vibrations that propagate through the body [11]. Harrison et al. also proposed "Omni touch" system [12]. It enables a user to use an arbitrary surface as an input area based on depth-based sensing and projection. Nakatsuma et al. have developed wristband-shaped touch input device that enables the back of the hand to be a canvas for finger gesture recognition [13]. The finger position is captured by IR reflection emitted by photo reflective sensor array. Approach to measure the finger position using ultra-sonic sensor has been presented by Lin [14]. Many researchers have focused on developing sensors that can detect touch (binary sensing) or measure touch pressure (force in the normal direction) as well as identify the touch points. We focus the interaction via skin that involves not only touching and pressing but also pinching, pulling, releasing, twisting, and caressing, thereby creating different tangential forces.

3. PRINCIPLE

Basic configuration of our proposed system is shown in Fig. 2. The system uses two armbands. A photo reflective sensor, which detects a gap distance to the skin surface d, is attached on the armband. The photo reflective sensor emits infrared light to the skin surface and detects its reflected light intensity. As the intensity of the reflected light depends on the distance to the skin, the system can measure the gap distance d to the skin surface.

When the skin surface between the two sensors moves tangentially the gap becomes larger at one side and it becomes smaller at the other side as shown in Fig. 2. As a result the difference of the two gap distances corresponds to the applied tangential force.

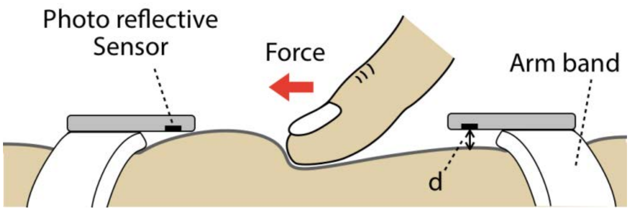

Figure 2. Armband type sensor that enables to measure tangential force given to skin surface.

3.1 Simulation model

This deformation characteristic was experimentally confirmed by using the Finite Element Method (FEM) analysis. Figure 3 shows our simulation model by ANSYS. We modeled a forearm as the simple cylinder with the bone. The dimensions and boundary conditions are given in Table 1. The force was given at the center of the forearm model as shown in the figure. The y-directional deformations, which correspond to the output of the photo reflective sensors, were simulated at the position A and B.

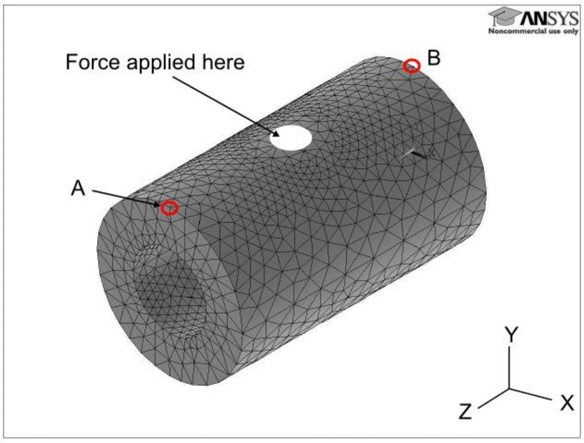

Figure 3. FEM simulation model.

Table 1. Simulation model conditions.

Dimensions	Forearm length	100 mm
	Forearm radius	30 mm
	Bone radius	15 mm
	Force area radius	5 mm
Physical parameters	Young's module	10^5 Pa
	Poisson's ratio	0.49
Constraints	On bone surface	Fixed XY motion
	At the sides	Fixed Z motion

3.2 Simulation results

Figure 4 shows the simulation result which shows y-directional displacement as a color differences when the skin surface moves tangentially. It is clear that the skin surface at the measurement points *A* and *B* moves in opposite way. The skin surface at the point *A* moves upward (positive y-direction) while the other side *B* moves downward (negative y-direction) when the tangential force was given to the z-direction.

Figure 5 shows the displacement value at the two positions (*A* and *B*) with the tangential deformation to the z-direction. Only the tangential force was applied at the center in between two measurement points. No normal force was given in this case. No slip occurs in the simulation. In this case, the displacements at both sides seem opposite. The height of the skin changes linearly.

Figure 6 shows how the graph changes depending on offset normal force. The normal force was given to the negative y-direction at the same position. When the offset normal force increases, each plot goes upward in the graph. That means, normal force can be detected as the "in-phase" deformation at the measurement points while the tangential force is detected as the "anti-phase" deformation. Based on the graph, the gap increases 0.1 mm when the tangential force increases from 1 N to 3 N. On the other hand, it increases 0.02 mm when the normal force increases from 0 N to 2N. The sensitivity to the tangential force is 5 times larger than that to the normal force. Theoretically, the system can detect both the tangential and the normal force respectively. However, the change of displacement by the normal force is too small to be detected accurately. We only estimate the tangential force in this research.

Based on these simulation results, the tangential force F_t is proportional to the subtraction of the two displacements.

$$F_t \propto d_1 - d_2 \qquad (1)$$

Here d_1 and d_2 are the gap distance measured with the photo reflective sensors.

Based on the simulation result, it is clear that the y-directional displacement is larger if the measurement point is closer to the center (i.e. the interval between the two sensors is smaller). That means the interval between the two armbands is better to be small for achieving sensitive measurement. The sensitivity of the system decreases when the interval of the two sensors is farther. It is also clear that the y-directional deformation occurs on the line connecting two measurement points *A* and *B*. The width of the deformation is approximately 20 mm in the simulation. That means, the contact area has to be within $\pm$ 10 mm in x-direction.

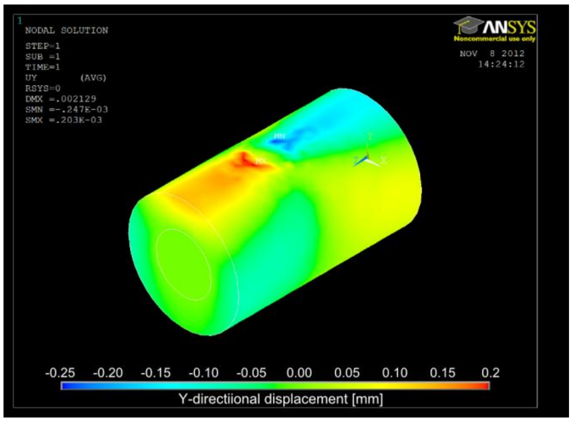

Figure 4. Simulation result of y-directional displacement with 3 N tangential force.

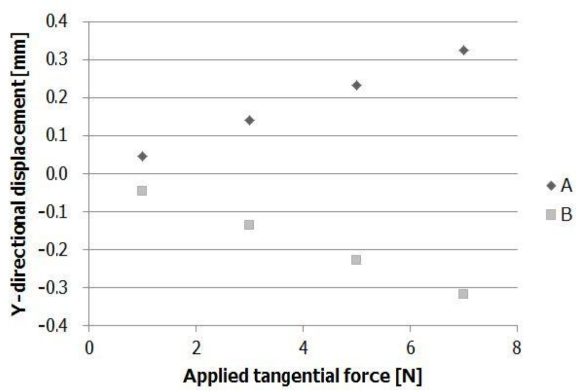

Figure 5. Y-directional displacement with tangential force at the measurement points A and B.

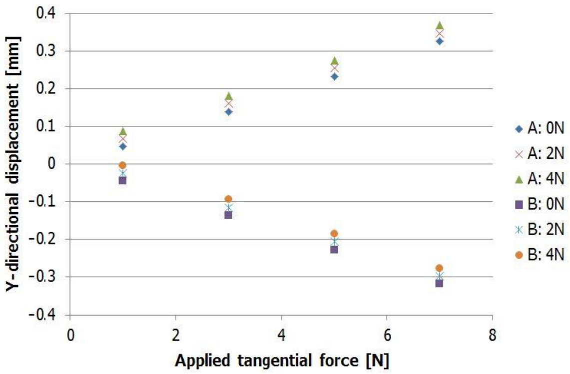

Figure 6. Y-directional displacement with tangential force by changing the offset normal force.

Our other simulation results, which are not shown here, demonstrated that the gap displacements do not change with the same manner when the contact position is closer to one side than the other (i.e. the contact position is far from the center). The changes of the gaps depend on the contact position on the forearm. This can be calibrated by measuring the finger position, however in this paper, we assumed that the finger moves around the center area (approximately $\pm$ 5 mm in z-direction).

4. PROTOTYPE SYSTEM

We constructed a prototype sensor module that can be easily attached to human body, especially on the arm part (as shown in Fig. 1). It consists of a photo reflective sensor that is attached to an acrylic base, a flexible band to fix the photo reflective sensor on the forearm and microcontroller. The sensor has a thickness of 6mm and a weight of 20g. The ATmega328 microcontroller has a 10-bit A/D converter, so the photo reflective sensor outputs a value of 0 to 1023.

4.1 Experimental Set Up

We conducted an experiment to investigate the relationship between the photo reflectivity and the amount of tangential force. We prepared the experiment tool that can pull the skin. The frame in the tool which contacted on the surface slide in parallel to the skin, thus the normal force to the surface is constant during experiment. The contact part was connected to a force gauge (A&D Company, Limited; AD-4932A-50N; resolution: 0.01N). The tool pulled the skin in a step-by-step manner. A KODENSHI SG-105 photo reflective sensor was located as shown in Fig. 7.

Participant wound two photo reflective sensors on his forearm (Fig. 7). The photo reflective sensor values were recorded using an Atmel ATmega328 microcontroller. The photo reflective sensors were included in the voltage-divider circuit so that the measured output voltage would be inversely proportional to the light reflected on the sensor.

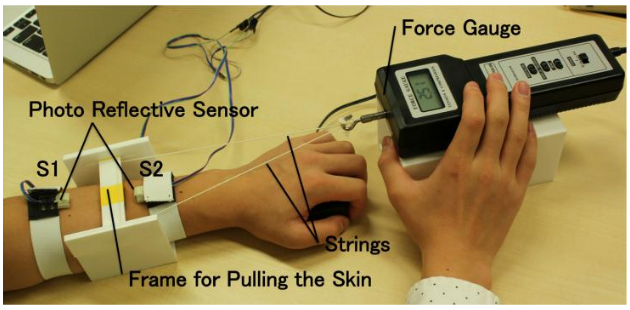

Figure 7. Experimental tool for applying tangential force in a step-by-step manner. Digital force gauge measures pulling force.

4.2 Procedure

1. Place the force gauge in direction end of the hand.
2. Adjust initial force to be at its minimum.
3. Record photo reflective sensor output at 1Hz for 10s.
4. Pull the skin to S2 direction in steps of 0.5N.
5. Repeat steps 3 and 4 until the force reaches 6N.
6. Force gauge placed at the opposite side.
7. Record the photo reflective sensor output at 1Hz for 10s.
8. Pull the skin to S1 direction in steps of -0.5N as well.
9. Repeat steps 7 and 8 until the force reaches -6N.

4.3 Result

Figure 8 shows a graph of the sensor's value against the force. The sensor's values were initialized with the first value. Both sensor values have changed continuously according to the lateral force on the forearm. The trend seems similar to the simulation result as shown in Fig. 5. According to the graph in Fig. 8, the dynamic ranges of sensor values depend on the location of the sensor. The range of S1 is 118.6mV and S2 is 71.9mV. The reason is thought that the amount of deformation range of the skin is different from the boundary conditions such like a thickness of the skin.

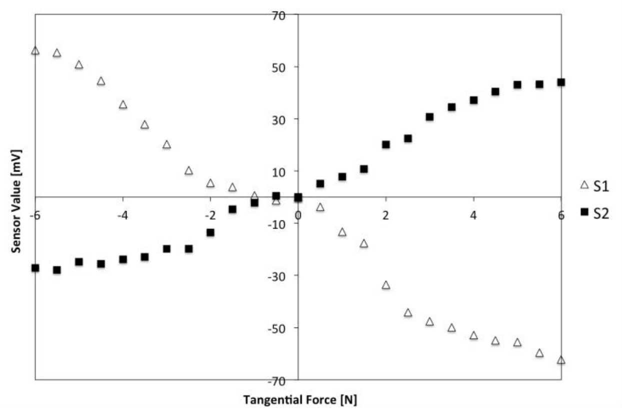

Figure 8. Average measured voltage against tangential force of skin.

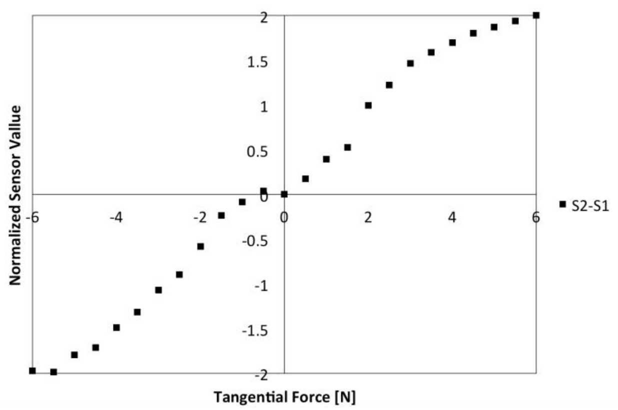

Figure 9. Difference between normalized S1 and normalized S2 against tangential force of skin.

Subtraction of the normalized S1 and S2 sensor value is shown in Fig. 9. We found that the value monotonically increases according to the tangential force. Sensor values in the region of a small force, there is a disturbance. We suppose the mechanism that pulled the skin did not provide tangential force smoothly in the region.

We confirmed that our prototype system can detect tangential force with a single finger, two fingers and a palm. However in the case of using the palm, the interval between two sensor units was too close to move the palm freely.

5. DISCUSSIONS

5.1 Possible Applications

To illustrate the utility of sensing system, we have developed two applications. One is simple music controller used to change the track and volume by stroking and flicking the skin. This application will be useful when the user is doing something else such like jogging. As other application, we developed the pong game using the same interactions as shown in Fig. 10.

In order to know the absolute value of a given tangential force, we have to calibrate each sensor as is shown in section 4.2 to obtain the graph as shown in Fig. 9. This will be a time-consuming task. However, when they require not absolute but relative value of the tangential force, we do not need cumbersome procedure. The system requires the gain of each sensor and their offset voltage. We confirmed that the simple music controller or the pong game did not require a strict calibration procedure.

Although our current system can only detect tangential force in a single direction, it can be two dimensional by using multiple photo reflective sensors. We show that our current system can be used on a cylindrical area. Also we can say that the sensing principle can be applied to non-cylindrical area such like a face. Deformation of the facial skin propagates to the neighboring area as a change of height of the surface. This can be applied any soft body parts by attaching the device on clothes and accessories such as glasses, watches and so on..

Some of intended application is medical field; continuous skin condition monitoring for bedsores which sometimes happen to bedridden person. Because our device is able to be attached to not only forearms, but also other body parts such as thigh and back, and convert them into detectable surfaces, it might be used to measure the posture of a person sitting on the chair, especially slipping and visualize it to encourage good postural balance.

Figure 10. Pong game application with our system.

5.2 Current Limitation

There is a limitation in the current device. The sensor values will change when user apply a force to the muscles of the arm or move the fingers dynamically. Thus, in current phase, the devices require to fix the arm as much as possible for stable measurement. In the future, we will improve the device to cancel this effect by detecting these body motions.

6. CONCLUSION

In this paper, we proposed a one dimensional tangential force measurement sensor system on the forearm. With this system we can measure the force between human and human. A user can touch the skin surface with arbitrary ways such like a single finger, two fingers and their palm or with some mediated objects like a towel.

The system uses two photo reflective sensors attached on the forearm. It detects the displacement of the skin surface. Since the forearm has a cylindrical shape, the surface deformation propagates to neighboring areas around a wrist and an elbow. The sensors can detect such change of the skin surface.

We evaluated our proposed system by using a simple Finite Element Method (FEM) analysis. The result indicated that the skin surface actually moves vertically with the tangential force. One important thing was that the displacements differed depending on the sides. One side went upward while the other side went downward. This change was relatively larger than the change caused by a normal force.

We showed our prototype system. We confirmed that the sensor outputs of the system were monotonically changed depending on the applied tangential force as was expected. This can be used not only for evaluating cosmetics and other skin related products but also as an input interface for controlling some electric devices.

7. ACKNOWLEDGMENTS

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