SenSkin: Adapting Skin as a Soft Interface

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ABSTRACT
We present a sensing technology and input method that uses skin deformation estimated through a thin band-type device attached to the human body, the appearance of which seems socially acceptable in daily life. An input interface usually requires feedback. SenSkin provides tactile feedback that enables users to know which part of the skin they are touching in order to issue commands. The user, having found an acceptable area before beginning the input operation, can continue to input commands without receiving explicit feedback. We developed an experimental device with two armbands to sense three-dimensional pressure applied to the skin. Sensing tangential force on uncovered skin without haptic obstacles has not previously been achieved. SenSkin is also novel in that quantitative tangential force applied to the skin, such as that of the forearm or fingers, is measured. An infrared (IR) reflective sensor is used since its durability and inexpensiveness make it suitable for everyday human sensing purposes. The multiple sensors located on the two armbands allow the tangential and normal force applied to the skin dimension to be sensed. The input command is learned and recognized using a Support Vector Machine (SVM). Finally, we show an application in which this input method is implemented.

Author Keywords
Skin deformation; soft interface; photo-reflectivity; bio-sensing; tactile feedback; tangential force.

ACM Classification Keywords
H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6): Input devices and strategies (e.g., mouse, touchscreen).

INTRODUCTION
Wearable interfaces, such as cheap and useful depth cameras and moduled sensors with easy-to-install microcontrollers for beginner user, and their related interactions are changing along with the new technologies.

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As described below, stable and durable sensors can be installed on wearable accessories [9]. After conducting two works on skin sensing technology [9, 6], our focus has progressed to utilizing skin as an interface. Ideas of using a user's body as a part of an input interface were already developed in the field of human-computer interaction [7, 10]. These designs provide tactile feedback to users through their own body. However, previous works have not considered direct input using skin as a surface, but only through camera-based tracking or distance sensors worn on the wrist. In contrast, our method measures the three-dimensional force applied to the skin's surface by a finger, so that the skin can be adapted as a soft interface. When touching their skin, users can feel the area of the skin being touched and can moderate the force they use when they touch it. People can gather information about the clothes they are wearing, whether they are leaning against a wall or a chair, and whether they are wearing a watch by using their tactile sense, without using their eyes. Socially, skin-to-skin contact improves human relationships, and it also offers a sense of reliability (sometimes people pinch themselves to make sure they are not dreaming). The challenge in this study was to establish a method for sensing information that is input using the skin as an interface and measuring the force applied to the skin quantitatively.

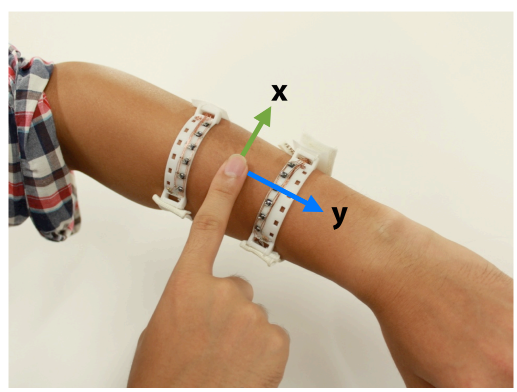

Figure 1. Image of the proposed input interface using skin deformation.

In this paper, we propose a novel method to measure the deformation of the skin surface as bio-information using an IR reflective sensor. This method can be adapted for use on skin on any part of the body. We chose to make our measurements on an arm, because this choice facilitated the sensing and the construction of the device. Only a few operations are required to perform three-dimensional force sensing: the user places the device that carries multiple sensors on his or her arm, and calibrates it. By modeling the tangential force and IR reflection, the force applied to the skin can be quantified. An advantage of the device design is that no devices or sensors cover either the area of the skin that is touched or the finger with which the user touches. Furthermore, the user receives tactile feedback from the skin that he touches when he performs input operations using his own finger and arm skin. This means that the user can control which place he touches and the amount of force that he applies. In short, the device realizes an interface that detects the interactions between the fingers and the skin on any part of the body. We focus on the aspect of the input interface, and show its applications.

RELATED WORKS

On-body Interaction

On-body interaction is becoming popular in HCI [7, 10] along with the progress and market growth of depth cameras and other sensors. Skinput [7] provides a method for turning the human body into an input interface using a bioacoustics microphone to sense the vibration that occurs when the body is tapped. A similar approach that uses a different material was proposed by Sugiura et al. [6], which leverages the photo-reflective sensor, using an elastic fabric as the deformable material. Sugiura et al. developed and investigated a soft interface using a stocking that can be attached to and cover any object. The implant approach [5] is another perspective for using skin as an interface, but requires a surgical process for attaching the device. The idea of SenSkin, which adapts the skin as an input interface, is related to the organic user interface [4], which provides the perspective of equality between function and form. This idea is adapted in this study, because SenSkin directly recognizes the user's finger function such as pull, push, and pinch.

Photo-Reflectivity

Photo-reflective sensing is used in the broad fields of not only environmental measurement but also human sensing. Research studies have been conducted on measuring the biological information of a human body using a nail sensor for measuring pressure applied on a finger [11]. Our previous works are [9, 13, 6]. A similar approach proposed by Sugiura et al. [13] leverages the photo-reflective sensor, using an elastic fabric as the deformable material. They developed a soft interface using a stocking that can be attached to and cover any object. The iRing, which leverages a photo-reflective sensor to detect the gestures of the finger on which the ring is worn, is proposed in [9]. The next step in the approach for adapting IR sensing for the purpose of biological sensing is to apply it for sensing the tangential force of the skin, as done by Makino et al. [6]. They used skin deformation sensing to find the relationship between the sensor's distance from the skin and the tangential force that is applied parallel to the arm bone. In this study, we measured the three-dimensional force applied by a finger to the skin using the same multiple sensors as were used in our previous study, and used SVM learning to train an input interface to recognize finger gestures made on the skin.

Haptic and Force Sensing

Our study focused on a model for measuring the three-dimensional force that is applied when the skin is touched by a finger by sensing the skin deformation. The method requires that sensor bands be attached somewhere on the user's body. However, since no sensor is attached to the finger, and the skin that is touched is not covered by a sensor, users can touch their skin freely and are not aware of the device in everyday use. Nakatani et al.'s method [8] recognizes pressure applied by a finger to the palm without haptic obstacles by measuring finger pad deformation. Yoshimoto et al. [11] developed a skin pressure sensor using electrodes and capacitive sensing. SenSkin realizes the sensing force in an interaction between two skins without haptic obstacle or skin-like material.

SENSKIN

Senskin is a method and technology that uses multiple IR reflective sensors implanted in an armband to allow the skin to be used as a soft input interface. We compared the actual force and the sensor values using an elastic model of the human skin. Our previous work studied the relationship between a one-dimensional force and the values recorded by two photo-reflective sensors. In this study, we found the relationship between a three-dimensional force model and the output of multiple sensors through two lines. In addition, by training an SVM on patterns of skin deformation, the recognition of finger gestures made on skin was achieved.

Principle and Method

Senskin leverages the principle of skin softness and deformation. In fact, the skin deformation when a three-dimensional force is applied is sensed. Skin has folds and wrinkles when the limb that it covers is not extended, and the subcutaneous fat works as a defense when the skin is subjected to an external force. The inner force generated by muscle movement affects the deformation of the skin surface and the extension of the skin. This research also provides a method for measuring the three-dimensional force applied to the skin, which is experimentally verified.

A computational model of skin, including fold and wrinkle deformation, was already studied in [6], according to which the skin can be represented as an elastic membrane, and the principal stresses can be computed using Hooke's law. Skin has three layers: the epidermis, dermis, and subcutaneous tissue. These layers are stretched when a force is applied to the skin surface.

Measurement

A one-dimensional tangential force model was already proposed in a previous work [6]. In this experiment, two IR reflective sensors identified as Sensor 1 and Sensor 2 were used. We measured the difference between the normalized Sensor 1 and Sensor 2 sensor values, and found that the value monotonically increases. By placing sensors along the armband, other tangential forces could be measured. When the finger moves in the right (or left) direction parallel to the armband, the sensors on the right (or left) side of the armband become closer to the finger than those on the other side. In addition, the normal force can also be predicted using this method by comparing the difference between the values recorded by sensors on two armbands. Therefore, using the methods of measuring tangential force that were presented in previous studies, the three-dimensional force applied by a finger to the skin can now be measured.

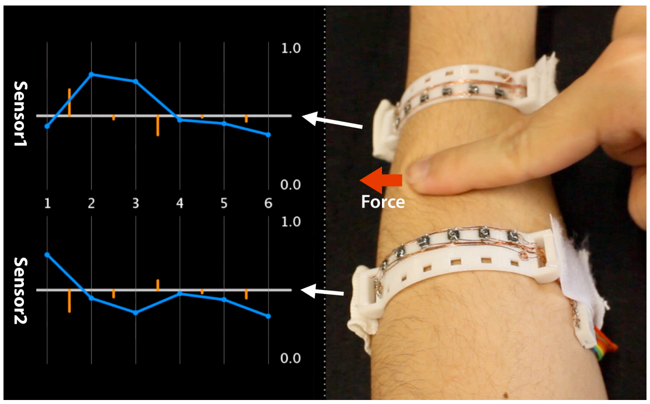

Figure 2. Measurement with multiple sensors.

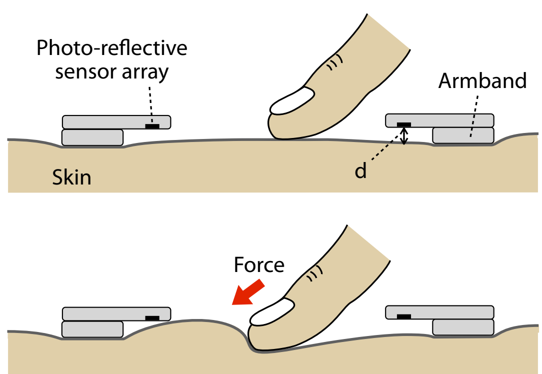

Figure 3. Section image of armband.

Hardware Design

Because of the structure of the skin and its elastic model, a relatively vast area of skin is pulled when force is applied. For example, if the skin is pinched and pulled, the skin on the opposite side of the limb moves. We designed an armband that stops the skin from sliding out from the sensing area, that is, the area between the two armbands. To maintain a distance from the skin, the sensor part of the armband is raised above the level of the surface that is in contact with the skin. By stopping the skin from sliding between the armbands, the skin deformation can be measured quantitatively as the change in its distance from the edge of armband.

The armband device has six IR reflective sensors on each band and an elastic tape with hook-and-eye fasteners to allow easy attachment. The sensors are placed at 10 mm intervals on the band, and each sensor has four pins, all of which are connected to a power supply and an analog–digital converter. The polycarbonate parts on which the six sensors are mounted project over the skin area between the bands at a height of 2 mm.

We selected the SG-105 Photointerrupter [Kodenshi Corp.] as the IR reflective sensor. The sensor consists of an IR LED and IR transistor. We chose a 75 Ohm resistor for the LED and a 30 K Ohm resistor for the transistor to transmit the sensor output to an A/D converter. The 75 Ohm resistor is connected by lines to all six sensor LEDs. The A/D converter is an Arduino Pro Mini (3.3 V) and it is connected to a Bluetooth module to transmit sensing data to a PC.

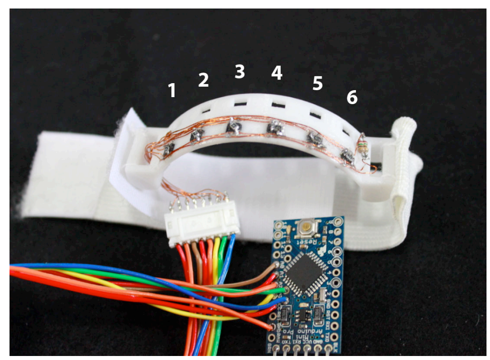

Figure 4. Prototype. (Armband and A/D converter)

Calibration

The main purpose of the calibration is to set a baseline of the sensor value when skin is in normal state, as well as to terminate the range of possible sensor values when it deforms. The procedure is:

- (1) Set the baseline value;
- (2) Put the finger between the two armbands and move it randomly;
- (3) Make sure that all sensors are measured and the upper and lower thresholds were set. At the same time, it is recommended to push the area near the armband and pull the skin toward the armband.
- (4) Set the baseline again in case the skin was moved during the previous processes.

All sensor values are calculated as relative values. The values vary the lowest and highest value determined by calibration with a range from 0.0 to 1.0. The baseline of the relative values is 0.5, because skin deformation is affected by wrinkles, and the levels of pull toward and backward is not equal.

MEASUREMENT

Bearing in mind a related work [6], we tested two types of measurement: the relationship of the horizontal tangential force and the sensor value; and the relationship of normal force applied to the skin surface and the sensor value.

Horizontal Tangential Force

Before presenting the calculation of the sensor values, we describe the index numbers of the sensors on the armbands. The user wears two armbands; the armband near the wrist is called A, and the other is called B. The sensors are given index numbers from 1 to 6 from the left side. Thus, for example, the sensor identified as S_{A1} is the leftmost edge sensor on armband A. The formula for obtaining the horizontal component *X* is calculated as

$$X_A = \sum_{i=1}^{3}(S_{A(i)} - S_{A(i+3)}), X_B = \sum_{i=1}^{3}(S_{B(i)} - S_{B(i+3)})$$

$$X = \frac{X_A - X_B}{2}$$

Component Y, which is the vertical tangential force, is calculated as

$$Y_A = \sum_{i=1}^{6} S_{A(i)}, Y_B = \sum_{i=1}^{6} S_{B(i)}, Y = \frac{Y_A - Y_B}{2}$$

Component Z, which is the normal force, that is the axis perpendicular to the skin surface, is calculated as

$$Z_A = \sum_{i=1}^{6} S_{A(i)}, Z_B = \sum_{i=1}^{6} S_{B(i)}, Z = \frac{Z_A + Z_B}{2}$$

The measurement of the tangential force of component *X* was conducted as shown in Figure 5. The measuring direction must remain tangential to the skin surface. The instruments used to take the measurements were a force gauge (A&D Company, Limited; AD-4932A-50N; resolution: 0.01N) and a plastic plate glued to skin. The results are shown in Figure 5. The sensor value is a relative value that varies between the lowest and highest value determined by calibration. The plot shows the linear relationship up to almost 5 N (510 g).

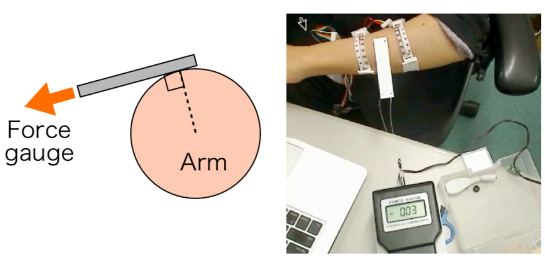

Figure 5. Measuring direction and experimental setup.

Figure 6 shows the data produced with our experimental setting. The first section between zero force and the next force point is relatively smooth, and can be thought of as the slack of rope. The plots rise to near 8N, with an elastic model after 6N. This measurement was done with one participant (author) after two trials: the first was stopped because the device peeled away from the skin because of weak adhesiveness; the second showed the same tendency of elasticity. The plots in Figure 6 terminate at the point when the plate glued to the arm peeled off.

Normal Force

Normal force is the 3rd axis of this system and is the pressure added perpendicularly to the skin surface. This force is estimated from each pair of armband sensors across the sensing area. When the finger touches the skin, the skin deforms along the force level from the finger, and the difference in the value between the pair of armband sensors increases. By sensing these changes, the point on the skin that is touched and the force is calculated.

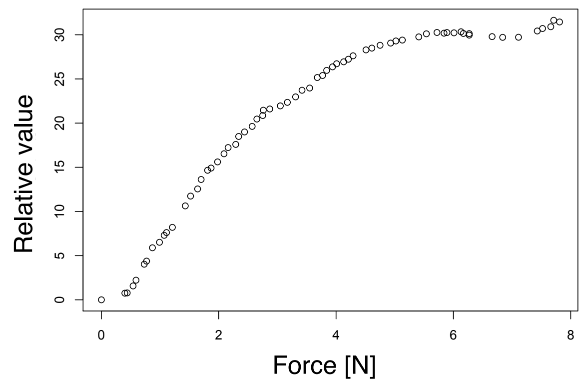

Figure 6. Relationship between sensor value and tangential force (horizontal axis).

RECOGNITION

Recognition of the input command from 12 sensors is first learned using SVM. We tested using three classes: (1) raw data of 12 sensors; (2) ***$Diff_A$(i), $Diff_B$(i)***: the differences between the values of each sensor, that is, 5 differences for each armband, yielding 10 data; and (3) ***Cross(i)***: 12 raw data and 6 cross difference data of each indexed sensor. The variables were

$$Diff_A(i) = S_{A(i+1)} - S_{A(i)}, i = 1 \sim 5$$

$$Diff_B(i) = S_{B(i+1)} - S_{B(i)}, i = 1 \sim 5$$

$$Cross(i) = S_{A(i)} - S_{B(i)}, i = 1 \sim 6$$

We prepared seven command modes for input: normal, push, pinch, pull-up, pull-down, pull-right, and pull-left. The SVM model was constructed using 145 plots of sensor data including all the command classifications. The recognition rates for these commands for the three classes were: (1) 98.11%, (2) 91.82%, and (3) 98.74% of prediction collection.

DISCUSSION

The recognition rate is sufficient to identify the input command, and it is clear that the SVM model using cross differences (3) is better than that using only 12 sensor data (1). The cross difference component yields better results because skin is considered an elastic model, and the relationship between the sensor data of the two armbands is considered. On the other hand, (2) does not contribute to improving the results. The difference between the values of adjacent sensors is also an important element for recognition, because it represents the differential calculus of the skin deformation shape.

Possible Applications

Because Senskin recognizes finger gestures made on the skin though the skin's deformation, it can be used as a controller for other wearable computers, such as those incorporated in eyeglasses or wearable game devices. However, the device cannot easily be used in a sports situation or on a body part that is at a significant distance from the hand. It can, however, be used in other fields, including the medical and cosmetic, because it senses skin interaction without interfering with the user's activity. In Figure 7, we show an application to cursor and desktop icons using SenSkin as an input controller. Figure 8 depicts a situation where SenSkin is used.

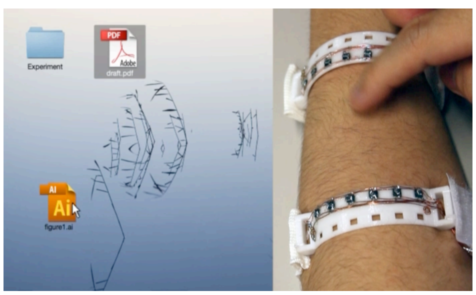

Figure 7. Using Senskin as an input controller.

Limitation

Skin deformation can be caused by joint and muscle movement. To obtain precise data from the sensor data for input recognition, Senskin should be used in conjunction with an accelerometer to detect the joint status to eliminate sensor output chattering. In normal use of the device in normal situations, the IR reflection does not present a problem. However, very strong IR rays emitted by the armband sensors may cause skin disorders in people whose skin is sensitive. Our experiment was done with one participant (author); an experiment with more than two participants may find other limitations or characteristics. Finally, almost all wrinkled skin has lost some subcutaneous tissue, so that it would be difficult for people with very wrinkled skin to use the Senskin device.

CONCLUSION

In this paper, we proposed and described the idea of Senskin, which is a technique for sensing skin deformation, allowing the skin to be used as an input interface. The contributions of this research study are fourfold. (1) An organic interface was proposed that uses soft skin, and provides feedback to the user through his or her own skin. (2) A sensing method and a device design for measuring the tangential force and normal force applied to the skin's surface were presented. (3) The results for command recognition by SVM learning were sufficiently accurate to show that the skin can be used as an input interface. (4) A skin input interface with possible applications was proposed.

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REFERENCES

1. Argyros, Antonis A., Lourakis, Manolis I.A. Vision-based interpretation of hand gestures for remote control of a computer mouse. *Computer Vision in Human-Computer Interaction, Lecture Notes in Computer Science* (2006), 40-51.
2. Erol, A., Bebis, G., Nicolescu, M., Boyle, R. D., Twombly, X. Vision-based hand pose estimation: A review, *Computer Vision and Image Understanding 108*, 1-2 (2007), 52-73.
3. Harrison, C., Tan, D., Morris, D. Skinput: appropriating the body as an input surface. In *Proc.CHI 2010*, ACM Press (2010), 453-462.
4. Holman, D., Vertegaal, R. Organic user interfaces: designing computers in any way, shape, or form. *Communications of the ACM 51,* 6 (2008), 26-30.
5. Holz, C., Grossman, T., Fitzmaurice, G., Agur, A. Implanted user interfaces. In *Proc. CHI 2012*, ACM Press, 503-512.
6. Makino, Y., Sugiura, Y., Ogata, M., Inami, M. Tangential force sensing system on forearm. In *Proc. of AH 2013*, ACM Press, 29-34.
7. Mascaro, S., Asada, H. Photoplethysmograph fingernail sensors for measuring finger forces without haptic obstruction. *IEEE Transactions on Robotics and Automation 17*, 5 (2001), 698-708.
8. Nakatani, M., Kawasoe, T. Shiojima, K., Koketsu, K., Kinoshita, S., Wada, J. Wearable contact force sensor system based on fingerpad deformation, *World Haptics Conference,* (2011), 323-328.
9. Ogata, M., Sugiura, Y., Osawa, H., Imai, M. iRing: intelligent ring using infrared reflection. In *Proc. of UIST 2012*, 131-136.
10. Saponas, T.S., Tan, D.S., Morris, D., Balakrishnan, R., Turner, J., Landay, J.A. Enabling always-available input with muscle-computer interfaces. In *Proc. UIST '09*, 167-176.
11. Yoshimoto, S., Kuroda, Y., Imura, M., Oshiro, O. Superimposed skin pressure sensor. In *SIGGRAPH Asia 2012 Emerging Technologies,* SA 2012. 4 pages.
12. Sturman, D.J., Zeltzer, D. A survey of glove-based input. *IEEE Computer Graphics and Applications 14,* 1 (1994), 30-39.
13. Sugiura, Y., Inami, M., Igarashi, T. A thin stretchable interface for tangential force measurement. In *Proc. of UIST '12*, 529-536.