iRing: Intelligent Ring Using Infrared Reflection

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ABSTRACT

We present the iRing, an intelligent input ring device developed for measuring finger gestures and external input. iRing recognizes rotation, finger bending, and external force via an infrared (IR) reflection sensor that leverages skin characteristics such as reflectance and softness. Furthermore, iRing allows using a push and stroke input method, which is popular in touch displays. The ring design has potential to be used as a wearable controller because its accessory shape is socially acceptable, easy to install, and safe, and iRing does not require extra devices. We present examples of iRing applications and discuss its validity as an inexpensive wearable interface and as a human sensing device.

Author Keywords

Multiple sensors; wearable computing; finger gesture; skin sensing; photo reflectivity;

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces. - Input devices and strategies.

INTRODUCTION

Along with advancing mobile computing, research on human sensing is being applied to understand human behavior and input control. However, finger input is still a primary method of user manipulation in the field of Human–Computer Interaction (HCI). Information on finger gesture and interaction with the hand provides special meaning and very specific information because the hand has high flexibility resulting from its several joints and agility, which helps reflect human intention [1]. Thus, there are many sensory techniques addressing finger and hand gestures using wearable devices or tracking systems. As an example wearable device, a data glove is an accurate method for sensing finger bending and distance between fingers. However, several expensive sensors are required and users are deprived of tactile sensitivity on the fingers.

Figure 1: iRing senses finger gestures. Bending, pressure, and rotation are shown on the visualizer.

iRing is an intelligent input device that recognizes finger gestures and external force. The sensing information only consists of skin infrared (IR) reflectance under an IR reflection sensor installed inside of iRing. Different reflectance for each gesture and situation is observed depending on the distance between the skin and the sensor, and skin protuberance. Using a reflection sensor guarantees safety and robustness against rough use in daily life. Four sensors are used to detect the finger, recognize the angles of iRing when worn, and identify the type of pressure applied internally or externally. After calibration, iRing recognizes the finger state, namely, straight, bent, bent backward, and clenched. If the finger bends, reflectance of all sensors increases, but if the finger bends backward, reflectance of the sensor on the palm of the hand decreases. Rotation is also recognized by calculating differences between values of the four sensors because finger skin has different reflectance on each side where the ring is located.

iRing is standalone, an accessory shape device, and the user does not have to wear extra devices. Further, it is suitable as a wearable interface and controller device. Being ring-shaped, iRing can be used by one hand for a few controls, but by using both hands more controls can be integrated when one of the hands touches the ring on the other hand. In this paper, we describe the principles and characteristics of finger skin that we leveraged in developing iRing, the calculation algorithm for recognizing finger gesture and external input, sensor reflectance for each situation,

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limitation of this work, and application in using input, controlling, and human sensing including rehabilitation.

RELATED WORK

To recognize hand gestures, Rekimoto et al. developed GestureWrist, a wrist device equipped with electrodes to measure conductivity [2]. Fukui et al. proposed a method of wearing a sensor device around the wrist to recognize hand gestures by using an array of infrared distance sensors [3]. Concerning gesture recognition, the purpose is similar to that of these developed devices, but our device iRing recognizes the absolute pressure applied to the finger and the extent of finger bending.Research on devices that can be worn only on the finger has revealed reduced difficulty in using these devices. Several ring-shaped devices are available, but not all can sense finger joint movements, and some require the user to wear them over the entire finger in order to be able to measure the finger's extent of bending; further, some other devices are expensive for consumer use and require extra pieces of equipment. Ubi-Finger is a gesture input device that uses a bending sensor over the entire finger [4]. Ring controllers are another invention in this field. For example, Ashbrook's Nenya is a small ring controller equipped with only a magnet [5]. The extra sensor on the wrist measures the strength of the magnetic field emitted from the ring's magnet. A jog dial and button input interface are obtained by rotating and shifting the ring. Although the ring contains an extra magnet sensor, iRing can support these interfaces using only the ring device. Finally, we mention other studies involving the use of IR sensors. Rhee et al. developed a medical ring device to sense a patient's pulse rate by measuring rays reflected from the inner skin [6]. Our method, however, measures reflectance at the skin surface to determine the distance between the device and the skin. Sugiura et al. proposed a method to measure cotton density [7]. By using an IR sensor, this method sensed the reflection of IR rays from cotton; in contrast, iRing senses the reflection from the skin. Mascaro et al. developed photoplethysmograph fingernail sensors to sense pressure when the finger touches an object [8]. Our method is obviously different from other such methods in this field because it is based on the principle of sensing finger bending movements and pressure accurately and externally by using an IR distance sensor.

PRINCIPLE

iRing leverages three characteristics of the skin. First, the finger has softness owing to its skin, muscle, and tendon, a factor that can be used to adjust IR reflectance. Second, skin absorption of IR light can be changed depending on situations such as stretching or pressing of skin. Last, the finger skin where the ring is located has different reflectances. We tested these characteristics from two dimensions listed below that are described in the experiment section.

Measurement of Distance and Softness

We found that the pressure on the finger device can be measured by a photoreflector that measures distance by detecting the emitted IR ray. In other words, skin reflectance can be used to measure the distance between the skin and the ring device. The pressure applied on iRing approximates the finger movement and the interaction with fingers. Hence, this method is suitable because of its high responsiveness, low power, and noninvasive nature.

Non-uniform Reflectance on Textures of Skin Surface

Human skin has an uneven surface texture, which is called the epidermis. IR radiation causes light to spread through reflection from the epidermis. Most of the incident light received by the phototransistor is reflected from the surface, and the surface texture determines the sensor reflectance. The finger has a different texture on the palm, back, and side, as described in Figure 2. The order of reflectance on the finger is as follows: top, side, and bottom. iRing exploits this property by capturing the absolute number of ring rotations.

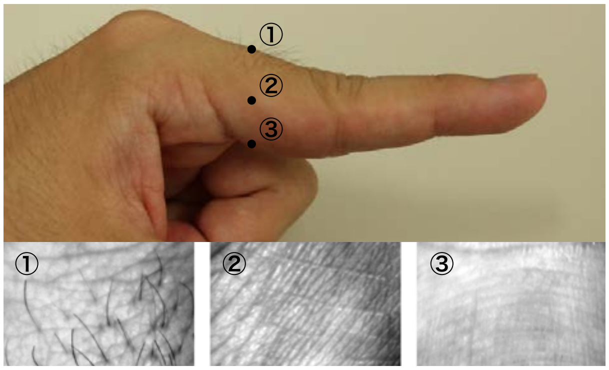

Figure 2. Surface texture has different reflectances.

CHARACTERISTIC EXPERIMENT

Experiment #1 (Reflectance with Pressure)

We inspected the relationship between pressure and reflectance acquired by the sensor that is shown in figure 3, using implemented iRing prototype. The maximum force is 920 g. The graph is approximately linear until about 7 N, but for higher values seems to curve along the upper line.

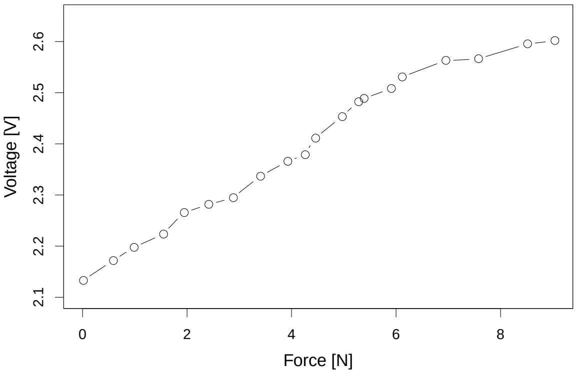

Figure 3. Voltage and applied force in Newtons.

Experiment #2 (Reflectance of Skin Surface)

We used one of the sensors installed in iRing to measure accurate reflectance when a user wears iRing. The subject is the first author of this paper who is originally Japanese; the sensing location is the root side of the left index finger. The interval was set to 10° and the start point is the palm side, going toward the thumb. Figure 4 illustrates the finger cross section and shows a photo that describes the measuring direction with a real finger.

In figure 5, there is a gap at around 150° that seems to be caused by a part that has different reflectance. However, this graph was estimated as a normal distribution by a one-sample Kolmogorov-Smirnov test (p = 0.1929).

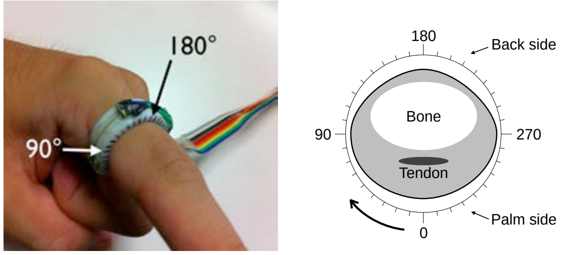

Figure 4. Measuring reflectance using iRing marked with a blue line that expresses angles by 10°.

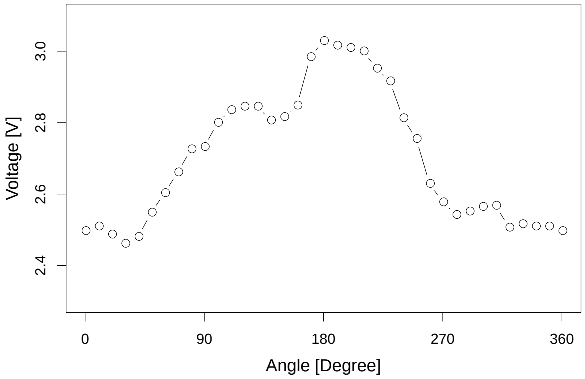

Figure 5. Reflectance of the first author's finger skin at 10° intervals expressed by voltage.

Experiment #3 (Reflectance of many people)

To gather more reliable data from a large group of people, we acquired finger skin reflectance of 22 subjects when using the ring-shaped rigid device. Subjects are Japanese undergraduate and graduate students including one Nordic and one black. Subjects were tested using two types of ring. One is the same device described in the implementation section and the other one is a device that was made for people with slim fingers. Data in figure 6 show the sensed values at 8 points. As the top and bottom reflectance in each point is different for each person because of the finger size, color of skin, and level of wrinkles, all data are normalized in figure 7. Although 20 out of 22 are Asian subjects, we also included non-Asian people who work at the laboratory. Data of the black and Nordic subjects are 1.47 and 0.36 times against the average of the 22 subjects, respectively. Though these data show that a multiethnic group has uneven skin reflectance that seems to be caused by melanin, the distribution is along the average data.

As compared to the result in experiment #2, the value at 180° is lower than the nearby value, because the back of the finger is not round but almost flat. However, the standard deviation in figure 7 shows that the reflectance of each point can be distinguished even if we consider the deviation that is expressed as a line that does not cover to the other point on the y axis. This graph is also estimated as following a normal distribution (p = 0.8748).

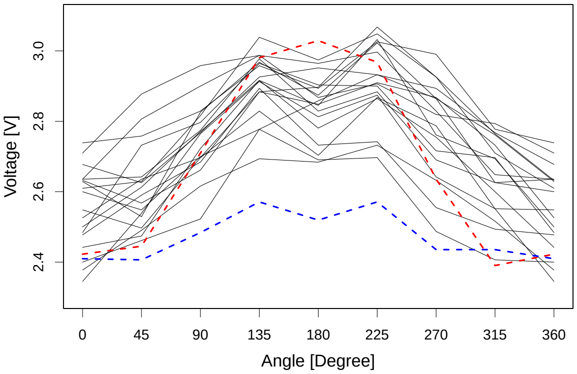

Figure 6. Raw data from A/D converter of 22 skin reflectances from 22 subjects, with 8 points by 45°. The value at 360° is the same as that at 0°. The red line denotes the data for black people while the blue line denotes Nordic ethnicity.

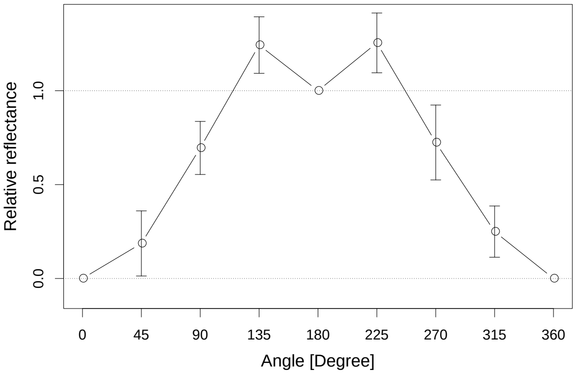

Figure 7. Average and standard deviation of figure 6. As the baseline of raw data is scattered, data are normalized with values of zero° and 180° corresponding to 0.0 and 1.0 on the y axis, respectively. Hence, there is no standard deviation at 0°, 180°, and 360°.

RING DESIGN

Similar to an accessory, iRing consists of a rigid body made from polycarbonate that works with four sensors to guarantee valid sensing when pressure is applied. The relation between the finger skin and the ring can be classified into two states. First, distance exists between iRing and the finger skin that can be detected by the IR reflection sensor when inner or external pressure is weak. Second, there is no distance between the ring and the finger skin, but the sensor cannot measure how strong the applied pressure is. Considering the sensor characteristics, the ring size should fit the finger to measure accurate reflectance. If the ring is tight, reflectance becomes higher than in the normal state and is near to the pressured state. After soldering, iRing is coated by acrylic resin (Figure 8).

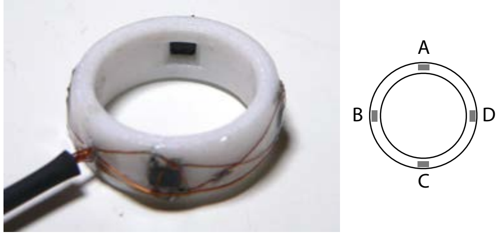

Figure 8. Rigid body of iRing and photoreflector. The four sensors are named A, B, C, and D.

Hole inside the iRing

If pressure is applied, a small part of the finger skin goes into the hole because skin is soft and wrinkled, as described in Figure 9. Even in the straight finger state, the distance between the skin and the sensor will be zero if the sensor touches the skin when the user wears the device. Making a hole on the inner ring allows measuring strong pressure even when the distance between the skin and the ring is zero. The hole height is 1.0 mm, an optimized distance between the skin and the photoreflector. This design allows sensing the protuberance of finger skin when the user bends the finger and also when he/she clenches his/her fist, because this movement generates inner pressure on the finger. Furthermore, when the fist is clenched, the device can sense the power level, which cannot otherwise be measured by a bend sensor.

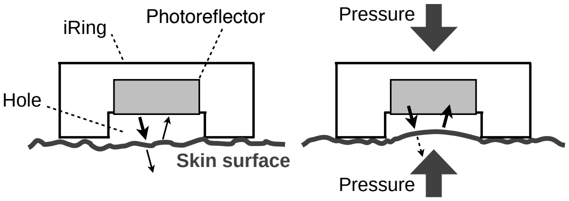

Figure 9. Cross section of iRing. Reflectance of skin changes when force is applied because of smaller distance to the sensor and less skin absorption.

Multiple sensors

As mentioned above, the combinations of various principles provide a ring device with several functions. We describe the functions with respect to sensor position on iRing, as in figure 8. The finger surfaces, named top, side, bottom, and side, correspond to sensor positions named A, B, C, and D, respectively. Concerning the number of sensors, four is the smallest number of formations that guarantees stable sensing of movement, rotation, and external pressure. First, all sensor values are low when the user is not wearing the device. However, once the user wears the device on the finger, the sensor values increase and installation is detected.

IMPLEMENTATION

We selected a small standalone distance sensor, but it can detect IR reflectance. IR light is selected for less interference than visible light for the purpose of distance measurement. This sensor, called photoreflector, combines an IR LED with a phototransistor. The sensor type is GENIXTEK Corp.'s TPR-105. As the sensor gain is controlled to a sufficient level to measure finger skin changes, 470 and 30k Ohm resistor are used for the LED and transistor, respectively. As the maximum number of grasping motions is 5/s, we set a sufficient sensing rate of 20 Hz. iRing recognizes finger clenching, which can also be detected by a pressure sensor. However, compared to conventional pressure sensors, photoreflectors are low-cost, compact, fast, robust, and they do not require an amplifier because they are not attached to the skin.

An Arduino Pro mini microcontroller (based on AT-mega328) was used for reading data from the IR sensor. It has a 10-bit A/D converter that allows photoreflector outputs from 0 to 1023. The power supply was selected as 3.3 V so that graphs and results in this paper shown below have a maximum voltage of sensor gain, which was set to 3.3 V. The hardware used is shown in figure 10.

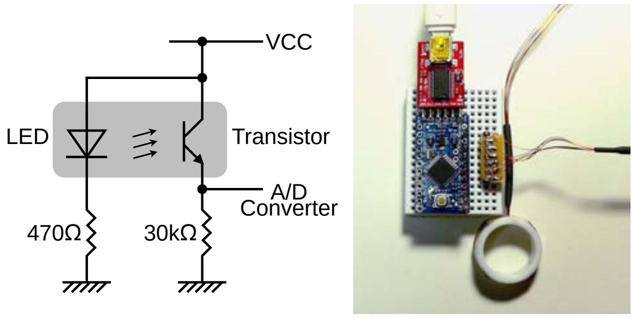

Figure 10. Circuit configuration implemented on iRing shown in the photo with an A/D converter.

RECOGNITION ALGORITHM

All gestures can be distinguished because they give unique sensor values. For example, as bending increases the total sensor value, bending and other functions (including rotation) can be distinguished.

We used four *variables*, S_A to S_D, as values of each sensor A, B, C, and D identified in figure 8. S_{AVE}, the average of S_A to S_D, is useful to roughly evaluate which state finger such as worn and inner pressure occurred.

$$S_{AVE} = (S_A + S_B + S_C + S_D) / 4$$

By calibrating, the *baseline* $B_{X\ (X=A,\ B,\ C,\ D)}$ is set as the sensor value for the straight finger state, and G is set as the distance from baseline when the finger is bent. If the finger is bent, inner pressure occurs, changing all the sensor values. All S_X become higher than B_X so that finger bending can be detected by considering S_{AVE}.

Bending/Inner Pressure

Finger bending can be described as the below equation. R is a ratio that sets the level of recognition (R < 1.0).

$$S_{AVE} > B_{AVE} + R \cdot G_{AVE}$$

However, backward finger bending derives a different relationship shown below. X refers to the sensor on the back of the finger (position of 180° in figure 8), while Y refers to the other sensors. The Y value does not change, but X changes because of bulged skin on the back of the finger.

$$S_X > B_X + R \cdot G_X \cap S_Y < B_Y + R \cdot G_Y$$

Rotation and Degree

According to experiments #2 and #3, the finger has non-uniform reflectance, but it is approximately normally distributed. Supplementing the lack of a maximum at 180° in figure 5, finger reflectance can also be thought as a sine curve distribution. This characteristic brings a uniform value of S_{AVE} in all the angles. Even if S_{AVE} changes, its value is maintained under *threshold* T (T can be defined as G with a constant ratio). A_A is an *angle* position of sensor A defined in the experiment section.

$$\begin{aligned} &When\ S_{AVE} < B_{AVE} + T \\ &A_A \approx 0°: \quad S_A < S_B \approx S_D < S_C \\ &0° < A_A < 90°: \quad S_A < S_B,\ S_D < S_C \end{aligned}$$

External Pressure

Because of the rigid body of iRing, external pressure relatively keeps the same sensor state to normal. It means that the opposite side of the pressed side is distanced from the finger, so that S_{SUM} does not change beyond *threshold T*.

$$S_X > B_X + T \cap S_Y < B_Y - T \ (Y\ is\ opposite\ to\ X)$$

In this operation, the rotation parameter can be affected because the relationship among sensors will be changed. To separate two commands, the recognition of external pressure has priority over rotation.

Calibration

The skin reflectance is stable for finger bending and rotation. However, calibration is required for setting the threshold to recognize commands. iRing requires individual calibration. It first records both states of the bending gesture: straight and bent finger. The system then configures the steps to identify to what extent the finger is bent. Other gestures are also calibrated in this way.

1. Putting on finger with sensor position on the right angle.
2. Demanding system to determine the *baseline* of the straight state.
3. Bending finger completely, but not clenching.
4. Demanding system to determine the *gap* of the bent state.
5. Bending finger straight.
6. Rotating the ring and demanding the system to store reflectance data on each point by 90°. The purpose is to standardize for uneven photoreflector sensor characteristics by recording reflectance at four points. The user should perform this task only thrice; the first point is already sensed.

Limitation

As shown in experiments #2 and #3, iRing has a limitation in sensing the entire finger skin equally because of the variety in finger sizes and shapes. However, these problems can be solved by choosing a size fit for each person and using many sensors instead of the current product implementation.

Although the recognition of finger state is described with an equation, the ideal state is achieved when the iRing's sensor is set on the right angle position. It is difficult to sense other states during the intent to do other gestures. For example, iRing cannot detect rotation when the finger is bent because the sensor value relationship can be complicated.

As the photoreflector can detect minute distances from an object, sensing data from different sensors are not even because of the physical gap of the installation. In this paper, the recognition equation premises an even condition of sensor data to simplify calculation. The sample application normalizes the small lag among sensors.

FUNCTIONS

Bending Extent as Input

iRing detects bent finger and the level of bending by calculating *baseline* value and *gap* that can be detected when the hand is clenched. The bending measurement is not linear to the bending angle, but it is linear to pressure.

Inner Pressure Measurement

When the hand is clenched, pressure is exerted on the palm without a visible change on the outside. When the ring is worn, this inner pressure can be sensed during finger bending. Calibrating in advance allows the ring to distinguish the states of the hand—with and without inner pressure—even when the hand is clenched.

Degree and Direction of Rotation

This measurement provides the absolute degree of rotation when the ring is worn. Therefore, the ring can be used as an interface, e.g., as a volume controller or jog dial. The equation described in this paper guarantees constant resolution of 45˚ (eighth of 360˚).

Touch Sensor (Pointing and Flipping Actions and Omnidirectional Movement)

The external operation of a device usually requires a switch. The ring detects the direction of the outer pressure by using the finger skin as the medium that reflects the IR ray. This method allows pointing from the top, bottom, and diagonal directions. Furthermore, values of multiple sensors allow calculation of the time span, direction, and force, which would be useful in understanding user operations such as flipping and tracing. The user can provide a 180° input by holding the ring, which means that it can be omnidirectional, like a joystick.

APPLICATIONS

Music Controller

We used iRing as a music controller to (a) rewind and fast-forward, (b) change the channel, and (c) increase or decrease the volume. The stroke (two directions, right and left), pressure (two sides, top and bottom), and rotation functions are connected to operations (a), (b), and (c), respectively. Therefore, if the ring is used as a jog dial and push button, there is no need for an extra controller for the music player.

Cursor Controller and Wearable Mouse

The user can manipulate a cursor by using iRing in two ways. The first way is to use two rings, on the thumb and index finger, and consider them as horizontal and vertical inputs, respectively. The second way is to use the ring as an omnidirectional input device, e.g., a joystick, by holding and moving it in 2D directions. With this device, users only have to use the ring, which has a socially acceptable shape, unlike other human interface devices.

Enhancement of Tablet Computer

We designed an application that uses finger bending on a tablet computer to control functions such as dragging and turning an object on the display. In this example, a straight finger drags and a bent finger rotates a 3D object. We show the possibility of enhancing existing interfaces in wearable computers.

Rehabilitation Support

iRing can be used as a rehabilitation instrument to visualize improvement in movement at a clinic. According to reports of medical staff, it is difficult to quantify improvement in rehabilitation, and clinicians usually have to perform a qualitative evaluation of some disorders. For example, a quantitative test for a patient with apoplexy is to draw a line along a printed spiral line; the severity of the disease is determined by calculating the difference between the two lines. However, devices available presently for measuring surface electromyograms of patients are expensive, with difficulties in movement of the hand and fingers. iRing not only provides the patient motivation to practice but also helps medical staff monitor improvement over time.

FUTURE WORK

In the future, iRing is expected to be suitable as a wearable controller that can be manufactured on a commercial scale. Conventional user interfaces such as a mouse and keyboard are too large to be carried around and too complicated to be used while walking. If users can operate a device through only finger movements, they can control next-generation devices such as glass computers without additional processing (for example, hand image recognition).

CONCLUSION

We proposed a highly functional, wearable input device that uses infrared reflectance as a basis for sensing pressure. We presented examples of application of this interface device as a controller interface and in human sensing systems.

ACKNOWLEDGEMENTS

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