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Finger Ring Device for Tactile Sensing and Human Machine Interface

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Abstract: We propose a new tactile device which measures multi-DOF vibrations exerted on the proximal phalanx. In this paper, two kinds of applications for the device are discussed. One application is "virtual buttons" assigned on a finger. The idea is to estimate the location of contact on the user's finger by utilizing the features of multi-DOF vibrations measured at the root of the finger. The other application is to use the finger ring device as a pointing device. Our strategy for obtaining the position of the finger from the output of the accelerometer is to integrate the acceleration only when the finger is being rubbed on the textured surface to avoid error accumulation. As an experiment for "virtual buttons", the accelerations were exerted by tapping the distal and middle phalanx and the features of the obtained accelerations were examined. A preliminary experiment for the pointing device is also discussed.

Keywords: Tactile device, Human machine interface, Wearable computing

1. INTRODUCTION

Using a human finger as a part of tactile sensors is an attractive idea. Mascaro et al. have proposed a unique device which can estimate the fingertip touch forces and postures by measuring the coloration of the finger nails [1][2]. As they have pointed out, one of the merits of this sensor is that in using the device, it doesn't deteriorate the user's tactile feeling compared to placing force-sensing pads at the fingertips. The user can manipulate objects without haptic obstruction while the sensor can measure the equivalent information to the user's perception.

We propose a new tactile interface which measures vibrations of several different modes at the proximal phalanx. Unlike mechanoreceptors which reside just under the finger pad, it is difficult to directly measure the vibrations excited on the fingerpad without disturbing tactile perception. However, the induced vibrations propagate along the finger and they can be observed at distant positions from the fingerpad. Fig. 1 shows the device. The shape of the device is like a finger ring. The device measures the vibrations induced at the fingertip either by tapping or by rubbing textures on the fingerpad.

From the view point of wearable computing, such tactile sensors can also be used as human-machine interfaces. Fukumoto et al. [3][4] have proposed a device named "UbiButton." UbiButton can detect the vibration excited by finger tapping and interpret the rhythm and the number of tapping as input commands to the device. By measuring multi-DOF vibrations, our device can utilize not only the rhythm or the number of the taps but also the estimated location of contact. That means the device can assign "virtual buttons" located along the finger.

The other application is to use it as a pointing device. Currently, touch screens[5] or touchpads are widely available and used. A drawback of such devices is that users must touch a specified region. If the motion of a finger rubbing an object can be measured without any restrictions on locations of touched surfaces, even a mere desktop surface, wall, or the user's lap can function as touchpads.

In this paper, the two kinds of applications mentioned above are discussed. In Section 2, the specification of the device is briefly explained. In Section 3, we discuss one of the applications "virtual buttons". In Section 4, the details of the application as a pointing device is explained and related preliminary experiments are shown.

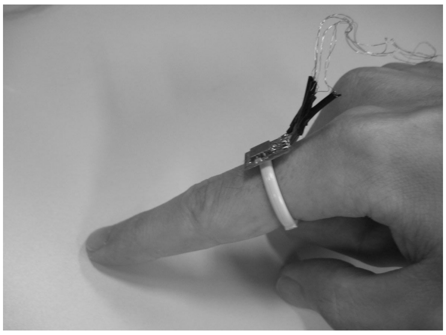

Fig. 1 The finger ring device

2. DEVICE

In order to measure the vibrations at the root of the finger, a tri-axis accelerometer (HOKURIKU, HAAM-313B) was used. The bandwidth of the accelerometer was DC to 500 Hz. The outputs of the accelerometer were amplified with instrumentation amplifiers (AD623, Analog Devices) and sampled with AD board (ADA16-8/2(CB)L, CONTEC).

The accelerometer was attached on a ring made of plastic. The users wore the ring on their index fingers.
The x- and z-axes of the accelerometer are shown in Fig.

2 (Left).

3. APPLICATION I

3.1 Overview

In this section, one of the applications "virtual buttons" is discussed. As the first stage of the development, we measured vibrations along two different directions on the backside of the proximal phalanx when the user tapped his index finger with his thumb. The purpose of the experiment was to confirm the difference between the observed vibrations exerted by tapping on the distal phalanx and on the middle phalanx. The methods and results of preliminary experiments are described in the following section.

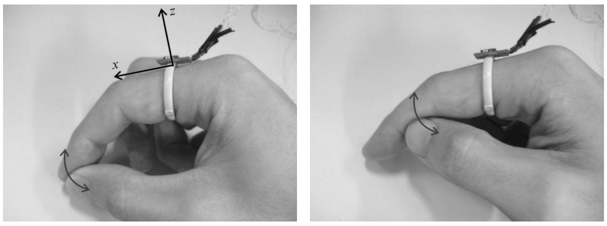

Fig. 2 DP tap (Left) and MP tap (Right). The axes shown in the left figure represents the x- and z-axis of the accelerometer.

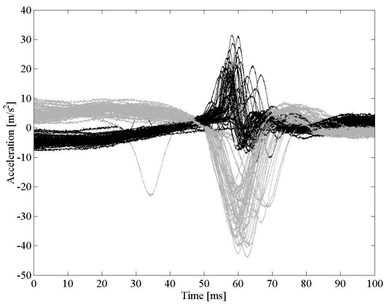

Fig. 3 The observed accelerations for Subject 1 induced by DP tap. The black line is the acceleration of z-axis. The gray line is the acceleration of x-axis. Fifty results are overlaid.

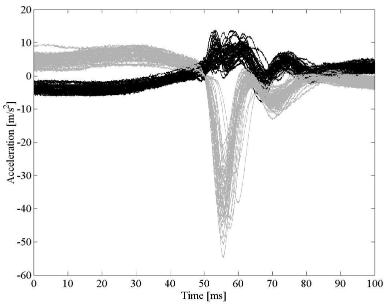

Fig. 4 The observed accelerations for Subject 1 induced by MP tap. The black line is the acceleration of z-axis. The gray line is the acceleration of x-axis. Fifty results are overlaid.

3.2 Experiment

The experiment was designed to confirm that by measuring 2 DOF vibrations, the location of the contact position can be identified. The subjects were asked to tap their palm side of the distal phalanx (Fig.2 Left) or of the middle phalanx (Fig.2 Right) with their thumbs. In this paper, we call tapping on the distal phalanx "DP tap" and the middle phalanx "MP tap".

The subjects were 22 – 30 years old. All the four subjects were men. The subjects wore the device on their index fingers. After brief instructions on how to tap, they were asked to tap their distal phalanxes and middle phalanxes with their thumbs.

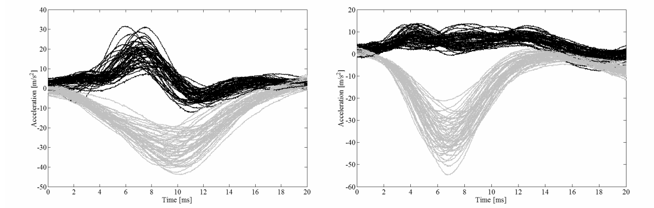

Fig. 5 The observed accelerations for Subject 1 induced by DP tap(Left) and MP tap(Right). These graphs are cropped from Figs. 3 and 4.

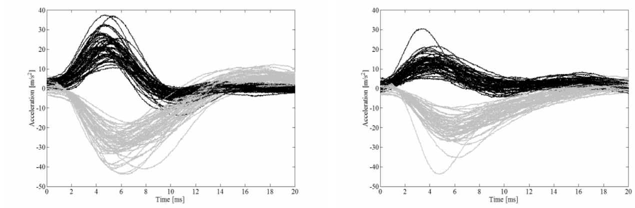

Fig. 6 The observed accelerations for Subject 2 induced by DP tap(Left) and MP tap(Right).

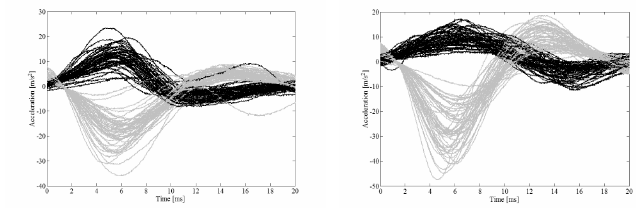

Fig. 7 The observed accelerations for Subject 3 induced by DP tap(Left) and MP tap(Right).

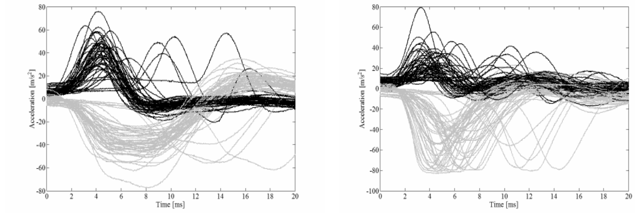

Fig. 8 The observed accelerations for Subject 4 induced by DP tap(Left) and MP tap(Right).

3.3 Result

Figures 3 and 4 show the observed acceleration when the DP and MP of Subject 1 were tapped, respectively. The horizontal axis represents time [ms]. The vertical axis represents the acceleration [m/s^2]. The black and gray lines are the acceleration along the z and x axis, respectively. The accelerometer output of the z axis (the black line) was used as the trigger source. The curves are fifty results overlaid.

One apparent feature seen in Figs. 3 and 4 is that the amplitude of the acceleration seen before tapping is smaller and the frequency of that is lower compared to the vibrations occurred after tapping. This concludes that the accelerations caused by the swing of the finger and that caused by the tapping are distinguishable. Another feature is the frequency of the observed accelerations. Especially, the frequency of the accelerations in x-direction is different comparing Fig. 3 with Fig. 4.

Figure 5 is the acceleration data cropped from Figs. 3 and 4. The data was cut based on a particular threshold of the acceleration in z-direction. Figures 6, 7, and 8 are the acceleration data for the rest of the subjects. The features described above can also be seen in Figs. 6, 7, and 8. Except the results shown in Fig. 8, the acceleration for each subject was relatively stable.

Fig. 9 Application as a pointing device. The user wearing the finger ring device is controlling a cursor by rubbing the surface of a desk.

4. APPLICATION II

4.1 Overview

In this section, the details of an application as a pointing device are discussed. Theoretically, the position of a point is calculated if the acceleration is integrated to obtain the velocity and then the velocity is integrated again to obtain the position. However this procedure usually does not function in practical situations because of error accumulation.

Sagawa et al.[6] have proposed a method to measure horizontal walking distance from the output of a tri-axis accelerometer and a MEMS gyro attached on the user's toe. In their method, in order to avoid long-term integration, the user's walking phase was categorized into swing phase (i.e. the user's foot was swung) and stance phase (i.e. the user's foot was in contact with the floor) based on the output of the gyro, and then the horizontal acceleration was integrated only when the walking phase was categorized as the swing phase.

We propose a similar algorithm to the one proposed by Sagawa to obtain the incremental position of the finger. The motion of a finger during in the course of being rubbed on textured surfaces is quite different from the motion of a foot during walking. However, by utilizing a part of tactile information, it is possible to determine whether the user is rubbing the finger on textured surfaces and to integrate the acceleration only in the course of rubbing.

4.2 Principle

As described in the previous section, our strategy for obtaining the position from the output of the accelerometer is to integrate the acceleration only when the finger is being rubbed on textured surfaces. In addition, we assume that the motion of the accelerometer is limited to translation in the course of rubbing.

Under these conditions, the position vector $x(t)$ during Nth rubbing is expressed as,

$$x(t) = x_N(t) + x_0 + \sum_{i=1}^{N-1} x_i(T_i), \quad (1)$$

$$x_i(t) = \int_{t_{init\_i}}^{t_{init\_i}+t} v_i(\tau)\, d\tau, \quad (2)$$

$$v_i(t) = \int_{t_{init\_i}}^{t_{init\_i}+t} a(\tau)\, d\tau + v_{init\_i}, \quad (3)$$

where x_0 is the initial position of the finger, t_{init_i} is the starting time of the ith rubbing, T_i is the period between the start and the end of the ith rubbing, $a(\tau)$ is the acceleration of the finger, v_{init_i} is the velocity of the finger at t_{init_i}.

According to eq. (1), eq. (2), and eq.(3), t_{init_i}, T_i and v_{init_i} are required to calculate the position in addition to the acceleration. These parameters are obtained based on the typical features of the acceleration in the course of rubbing. Figure 10 shows an example of the observed acceleration when the user of the device rubbed his index finger against a desktop in positive x-direction. The graph exhibits the following features. First, impulsive acceleration occurs at the moment the finger contacts with the desktop. Second, high frequency vibrations are observed during the finger is in contact with the desktop and is being rubbed on the desktop. Third, even before the moment of contact, positive acceleration can be seen because the finger has already started to move. These three features correspond to the three parameters: t_{init_i} corresponds to the moment the impulsive acceleration is observed. T_i is equivalent to the period in which the high frequency vibrations are observed. v_{init_i} is calculated by integrating the acceleration data ranging from about 0.1 ms before t_{init_i}, to t_{init_i}.

The output of the accelerometer $a_o(t)$ contains gravity vector. We assume that the posture of the finger does not change during rubbing. Under this assumption, the acceleration $a(t)$ in eq. (3) is expressed as

$$a(t) = a_o(t) - g_{init\_i}\,, \tag{4}$$

where g_{init_i} is the gravity vector obtained before the beginning of the ith rubbing. g_{init_i} is the output of the accelerometer when the finger is not moving, and is updated if no fluctuations are detected for about 0.2s.

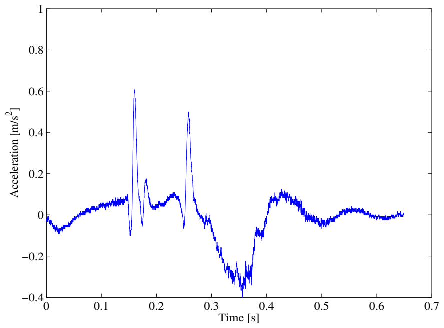

Fig. 10 Observed acceleration during the user is rubbing the finger on a desktop

4.3 Implementation

The acceleration data is sampled at 10 kHz and stored in a FIFO memory after compensating the gravity vector. Figure 11 shows the diagram of the stored data. The FIFO stores each 1280 sampling points for the accelerations in x-, y-, and z-direction. At each time 128 x 3 points are refreshed, the 256-point FFT of the acceleration in z-direction a_z is calculated. The obtained frequency components of a_z is used to detect 1. impulsive acceleration, 2. high frequency vibration, 3. low frequency fluctuation. If the impulsive acceleration is detected, v_{init_i} is calculated using the stored 1280 samples and the integration of the acceleration data starts. The summation of the frequency components ranging from 78 to 510 Hz is used to determine if the user is rubbing the finger or not. If the lowest frequency component (up to 40Hz) is not detected for 0.2 s, the gravity vector g_{init_i} is updated.

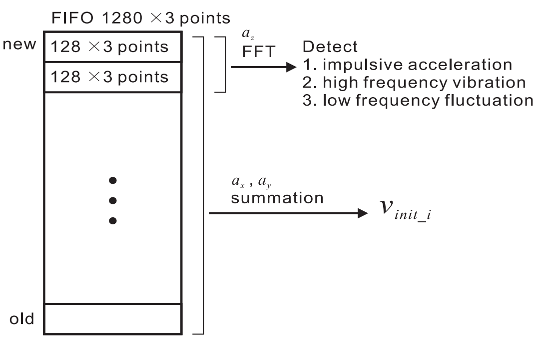

Fig. 11 A diagram of the acceleration data in a FIFO.

4.4 Preliminary experiment

Preliminary experiment was conducted to confirm the feasibility of the algorithm. The subject wore the finger ring device on his right index finger and was asked to rub the fingerpad from left to right on a desktop. The desktop was made of a melamine plate and slightly textured. A scale was placed on the desktop to indicate the length to move the finger. The subject's finger was moved 5 cm. The observed acceleration is shown in Fig. 10 and the calculated position using the acceleration data is shown in Fig. 12.

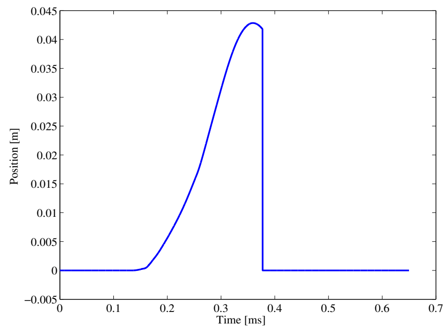

Fig. 12 Calculated position of the finger. The horizontal axis represents time. The vertical axis represents the position. The results were calculated based on the proposed algorithm with the acceleration data shown in Fig. 10.

5. DISCUSSION

In this paper, two applications of the finger ring device were proposed and examined. As to the application as "virtual buttons," we could confirm the difference of the accelerations when the distal and middle phalanx were tapped. For further research, it is necessary to develop appropriate analysis methods to stably distinguish the two states.

As to the application as a pointing device, though the accuracy of the position was sufficient as to the data in Fig. 12, several improvements are required. One of the required improvements is the dependence of the calculated position on the initial velocity v_{init_i}. In proposed algorithm, v_{init_i} was calculated using fixed number of data points. However, depending on the motion of the finger, the number was not sufficient to acquire appropriate initial velocity.

Another problem is the effect of the gravity on the accelerometer. Though we assumed that the posture of the finger does not change during rubbing, in practical situations, the tilt of the accelerometer should be compensated. In addition to the accelerometer, MEMS gyro sensors should be implemented.

6. CONCLUSION

In this paper, we proposed a new tactile interface and two kinds of its application. Though the experimental results were sufficient for exhibiting the idea and potential of the finger ring device, further evaluations and improvements on both hardwares and analysis methods were required.

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