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Touch Interface for Sensing Fingertip Force in Mobile Device Using Electromyogram

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***Abstract*— The aim of this study is to develop a three-dimensional touch interface for mobile devices, specifically a touch interface for detecting fingertip force. This interface consists of a conventional touch interface and an electromyogram (EMG) amplifier. The fingertip force during manipulation of the touch interface is estimated from the EMG measurement. We develop a method for obtaining fingertip force information using an EMG, while the two-dimensional position of the finger is measured using the conventional touch interface found in mobile devices. Further, we evaluate the validity of our newly developed interface by comparing the fingertip force estimated using our proposed method with the fingertip force measured using a force sensor. Lastly, we develop an application using our interface.**

I. Introduction

Mobile devices are rapidly becoming the most useful interfaces for accessing network resources and various applications [1], [2]. For example, a biomedical application based on a mobile device was used a device monitoring for a subject's kinematic and physiological parameters [3]. Touch interfaces are useful for measuring biomedical parameters because they provide a simple interface for the input of kinematic data into a mobile device [4]. Touch interfaces can sense the finger positions of users on the touch screens of mobile devices. Conventional interfaces are used to determine the location of the fingertip on the screen of mobile device and to recognize the two-dimensional location of the fingertip.

The aim of the current study is to increase the degrees of freedom for conventional touch interfaces installed in mobile devices. We determine the force of the fingertip on the touch-screen for this purpose. A common method for the measurement of finger force involves the use of a force sensor attached to the fingertip. However, a suitable force sensor is not available for this purpose because most sensors are likely to disturb the smoothness of finger movements on a touch screen. We also suggest that the tactility of the fingertip is important when operating a touch interface.

Thus, we need to estimate the fingertip force without attaching a force sensor to the fingertip. The finger force applied during isometric muscle contraction can be estimated using an electromyogram (EMG) of the unconstrained finger muscle [4]. Thus, we attempt to use an EMG to estimate the fingertip force, to prevent any interference with the fingertip tactility during the operation of a mobile device. The system we developed comprises an EMG amplifier and a conventional touch interface installed on a mobile device. The EMG signal is measured using a device-specific A/D converter, which is implemented to record the user's voice. The fingertip force is estimated using the EMG measurements. We confirm the validity of the depth information estimated by the EMG. Finally, we develop the prototype system of an application using the interface.

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II. Methods and Materials

A. Setup of the touch interface system

Figure 1 shows an outline of the system setup for our novel touch interface. The system comprised an EMG amplifier and a commercial mobile device equipped with a touch interface. The EMG was measured with the mobile device via the microphone jack. In addition to measuring the two-dimensional finger position on the touch-screen, we attempted to determine the depth of the finger force, i.e., how much force the user exerted on the screen with their fingertip. We assumed that touching the screen with the thumb was due to an isometric contraction associated with thumb movement. We estimated the fingertip force using the EMG signal measurement while the user was operating the touch interface. The EMG signal was measured using the A/D converter of the microphone installed in the mobile device.

B. EMG amplifier

We estimated the fingertip force from a single channel EMG signal, which was measured using the mobile device. We developed an EMG measurement device for this purpose. The total amplitude of the EMG amplifier was 1000 times.

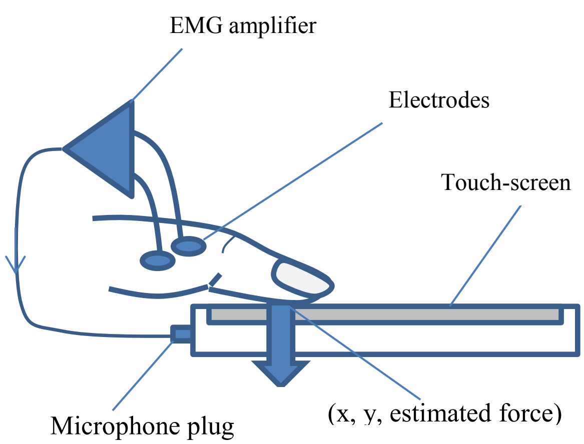

Figure 1. Three-dimensional touch interface based on EMG.

We applied band-pass filtering with a cut-off frequency of 0.048 and 3.00 kHz to process the EMG signal. Skin surface electrodes with a 10 mm diameter were attached to the thumb.

C. *Software implementation*

We implemented a prototype EMG real-time viewer on a mobile device. We used a multithreading algorithm in the user interface environment to observe the EMG waveform. Figure 2 shows a flow chart of the EMG data processing. Two threads were generated by an event when pushing a button. These threads were executed independently when the user started running the software. Initially, the thread began recording of EMG signal. The second thread was then generated to draw the EMG waveform when the buffer was full. Initially, the touch interface installed in the mobile device sensed a contact with the user's finger, which was required to trigger the touch interface to reduce detection errors. Fingertip estimation was carried out only when a touch event occurred. Finger touch detection was accompanied by the thread recording the EMG waveform. The EMG waveform acquired by the recording thread was drawn on the screen by the waveform drawing thread. For the data analysis, the EMG data was stored as a text file in the SD card installed inside the device when the user stopped viewing the signal.

D. *EMG acquisition*

The EMG data was acquired via a microphone plug because the EMG signal was in the frequency range of human hearing. During EMG recording, we used the A/D converter installed in a mobile device for processing the user's voice. The EMG data was sampled at a sampling frequency of 8 kHz. The data format was pulse code modulation (PCM) with 16 bits per sample, which was guaranteed to be supported by Android devices. The application ran on an Android mobile phone operating system, which was a Linux-based operating system designed primarily for touch screen mobile devices such as smartphones and tablets.

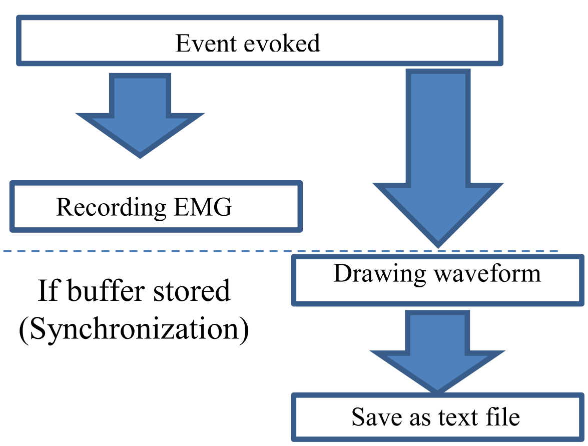

Figure 2. Flow chart of EMG data processing.

E. *Estimation of fingertip force*

The thumb, which comprises a proximal phalange and a distal phalange, can be modeled as a single-link manipulator. Two or more channels of EMG data were needed to analyze its kinematics precisely. In this study, a thumb was simplified as a single link rigid body around the metacarpophalangeal (MP) joint. Phalanges were modeled as a homogeneous cylinder. Because of this limitation, the directional force initiated by the torque generated around the MP joint was only that perpendicular to the surface of the touch screen.

We attempted to estimate the fingertip force based on the EMG signal measured in the abductor pollicis brevis muscle (APB muscle). The EMG signal was corrected and the integrated EMG (iEMG) was calculated for a predefined time window. The value of the iEMG was normalized against the maximal voluntary contraction (MVC) value. We verified the accuracy of the fingertip force estimated using the single-channel EMG data.

III. Experiment for Evaluation of the Developed System

A. *Experimental setup*

We confirmed whether the EMG signal was measure correctly using the mobile device. To verify the system accuracy, we examined the validity using a mobile device emulator for an Android Virtual Device (AVD) on a PC. The experimental setup is shown in Figure 3. A flexible force sensor (NITTA Corporation, Japan) attached to a carbon board was used to measure the fingertip force. The output of this sensor was sampled using an A/D converter (CONTEC Inc., Japan) with a sampling frequency of 1 kHz and the data was stored. We measured the iEMG and the fingertip force at the same time. The fingertip force was estimated based on the iEMG measurements and we confirmed the relationship between the estimated and measured fingertip force values.

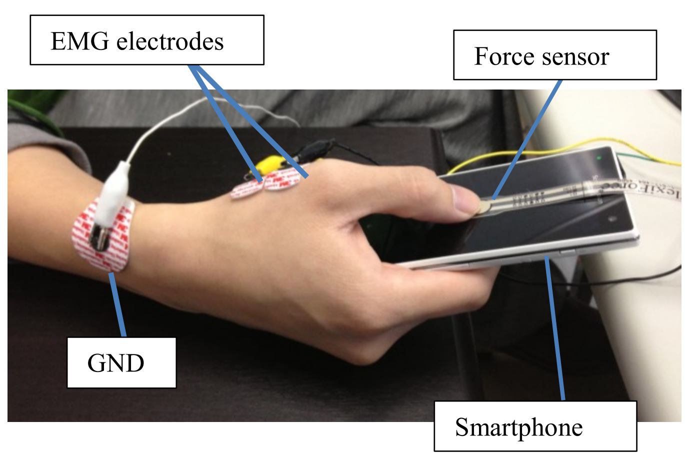

Figure 3. Experimental setup used to measure the fingertip force with a force sensor and EMG electrodes.

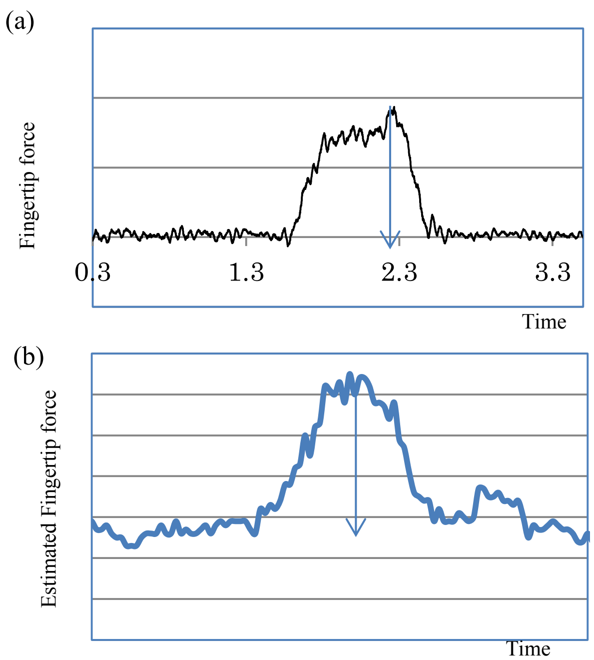

Figure 4. Waveforms of the actual fingertip force (a) and the estimated fingertip force measured by our system (b).

The fingertip force was measured using the MVC at the start of the experiment. A subject was asked to push the force sensor on the board as hard as possible using their thumb. We calculated the iEMG as the strength of the MVC. The subject then pushed the screen repeatedly with different strengths of thumb force. All of the data were normalized against the peak value. There were 15 trials.

B. Relationship between the estimated and measured force

Figure 4 shows a set of measurement results for the actual and estimated fingertip forces measured for one subject in a single trial. We verified that the system functioned successfully and that the iEMG approximated the applied fingertip force.

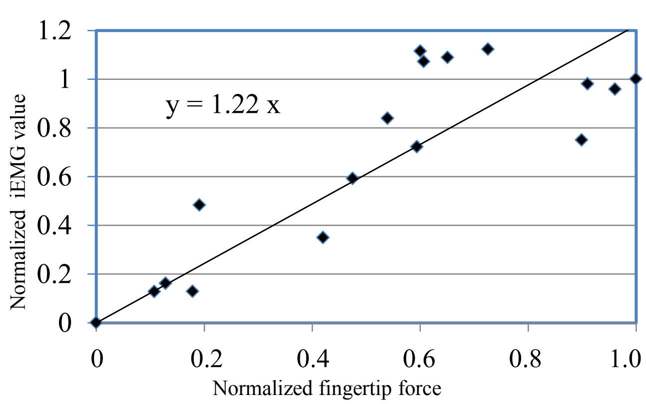

Figure 5. Estimated and measured fingertip force using our system.

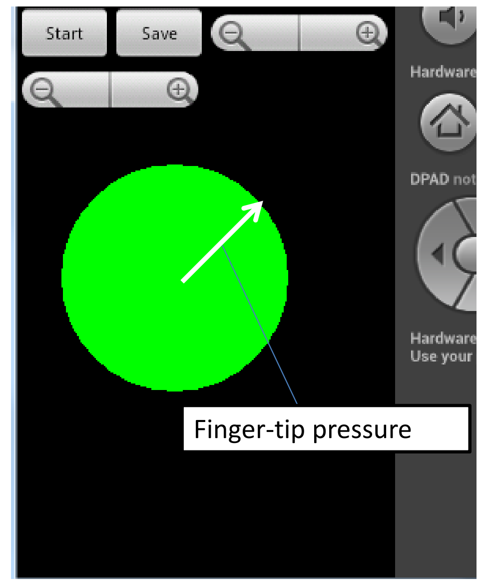

Figure 6. Screen capture of the Android emulator running the image resize application.

Figure 5 shows the relationship between the finger force and iEMG in 15 trials. The horizontal and vertical axes indicated the finger force measured using a force sensor on the screen and the iEMG value, respectively. The normalized EMG value agreed with the actual fingertip force measured using the force sensor.

IV. Example Application of Our Proposed Method with Three-Dimensional Information

Touch interfaces are common devices used during human-computer interactions. The interface proposed in this study may improve the accessibility and usability of mobile devices because it allows greater interaction with mobile devices. Figure 6 shows an example of an application using our proposed interface. The interface can detect the finger force without the need for a force sensor on the fingertip.

The degrees of freedom for the touch interface were extended to three dimensions. We developed an image resize application using our proposed interface. A circle was drawn on the touch screen, as shown in Fig. 6. A touch contact was recognized by the application and the image was resized according to changes in the fingertip force. The diameter of the circle corresponded to the estimated force.

A specific graphical user interface (GUI) is normally required in conventional methods used for image resizing, i.e., symbols for “+” or “-.” However, a GUI is not required for image resizing when using our system. Thus, our system allows greater interaction with the mobile device.

V. Discussion

A. Estimation of fingertip force

We developed a three-dimensional touch interface for mobile devices using an EMG amplifier and we confirmed the validity of our proposed system. We also implemented an example application using our proposed system.

We assumed that the thumb could be simplified as a rigid model with the MP joint. Based on this assumption, we attempted to estimate the fingertip force using the iEMG. This rule seemed to affect the accuracy of the estimation. As shown in Fig. 5, we confirmed that the fingertip force could be estimated from the calculated iEMG (correlation ratio R = 0.834). Akazawa *et al.* showed that a fingertip force waveform could be approximated as a smoothed EMG waveform [4]. In our system, we used a similar approach to estimate the fingertip force. We determined the interval to calculate the integrated EMG. We verified that the fingertip force estimated based on the iEMG agreed well with the actual fingertip force.

B. Advanced flexibility and usability

Our proposed interface extended the degrees of freedom for a conventional touch interface on mobile devices. Our novel interface has several benefits compared with a conventional touch interface.

In Android 2.0 and later versions, multi-touch refers to the touch sensing surface's ability to recognize the presence of two or more points in contact with the surface. The multi-touch function allows innovative interactions with computers. For example, a user can pinch the object displayed on a screen using two fingers.

Pinching is a finger gesture used on a touch screen interface where two or more fingers move relative to each other to zoom in and out. Pinching is also referred to as a semantic zoom. Two-fingered pinching is required if the user wants to change the resolution of an image. Image resizing is achieved by finger pinching after calculating the distance between the two fingers. However, pinching appears to lack the desired usability and there may be some difficulties when adjusting the size of an object appropriately. By contrast, our interface provides greater interaction when zooming in or out of an object. We described an example application using our system. Our proposed system could change the object size displayed on the touch screen. With our system, zooming in and out could be performed with only one finger. Thus, our interface allows greater interaction with an object.

C. Application possibilities

There are many possible applications of our novel system, e.g., the device could assist motor rehabilitation [5], [7]. Our current setup provides context only through haptic means but we are also considering adding some degree of haptic feedback. Some studies have demonstrated the possibility of robot manipulation using a smartphone or tablet PC. Touch interfaces are available for the controller during virtual reality robot manipulation [6]. Our system may allow greater interaction between computers and humans for this purpose.

VI. Conclusion

In this study, we developed a touch interface for sensing the fingertip force on a mobile device. A conventional touch interface was used in conjunction with an EMG amplifier. Our proposed system estimated the fingertip force when a subject touched the screen of a mobile device without any need for a force sensor. Our system did not require an external A/D converter or a microprocessor for signal processing. This interface can easily extend the degrees of freedom when using conventional touch interfaces.

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