UBI-FINGER: A SIMPLE GESTURE INPUT DEVICE FOR MOBILE AND UBIQUITOUS ENVIRONMENT

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Abstract. We propose a novel interface in mobile environment called "Ubi-Finger" that realizes sensuous operations for PDAs and information appliances using gestures of fingers. In this paper, first, we propose the concept of Ubi-Finger. This concept enables users to sensuously control various devices in the real world. Since gestures are usual methods of nonverbal communications and enables sensuous operations for users, many researches on them carried out especially in the field of Virtual Reality. In the meanwhile, the uses of computers have rapidly extended to the daily life, such as mobile computing and ubiquitous computing.Ubi-Finger is a gesture-input device, which is simple, compact, and optimized for the new computing environment. Second, we develop prototype systems based on the concept that can control real-world devices with simple and natural gestures. Third, we develop some applications to control devices in the real world. Using our systems, a user can detect a target device by pointing with her/his index finger, then control it flexibly by performing natural gestures of fingers. Finally, we evaluate how effective our approach works.

Key words. Gesture Recognition, Information Appliances, Home Electronics, Ubiquitous Computing, Wearable Computing.

1. Introduction. As the computers became more downsized and powerful recently, the uses of them have extended to the daily life. With that, the concern with new human interfaces that focus on the various uses in real world has been growing.

As the popularity of personal digital assistants (PDAs) and cellular phones has increased rapidly in recent years, more and more computers are used in mobile environment. In such situations, the user interfaces should be compact and easy to use, compared to conventional computers in office or school environments.

In the meanwhile, Mark Weiser proposed a vision of a future computing environment called "Ubiquitous Computing" in which many various computers work in harmony [18]. Now, his vision is going to be realized as the diffusion of information appliances: more and more computers and networks are expected to spread into households in near future, and various kinds of home electronics become information appliances connected to the networks. Although many appliances become more high-performance and multifunctional in such an environment, control methods of them tend to become more complicated, and the difficulty for users to master enormous control methods is rapidly increased. Therefore, new interfaces that can control various information appliances with simple and friendly operation are desirable [11].

We focus on human gestures of fingers to solve the above problems of mobile computing and operations of information appliances. We propose a novel wearable interface called "Ubi-Finger" that realizes sensuous operations for mobile computers and information appliances using gestures of fingers.

1.1. Gesture Input Method. Generally, in the communication of human emotions or wills, the nonverbal means are more important than verbal means [12]. Human gestures are typical examples of nonverbal communication, and help people communicate smoothly [9]. Human gestures are used not only in the communication between foreigners or language-disabled, but also actively used in the usual communication.

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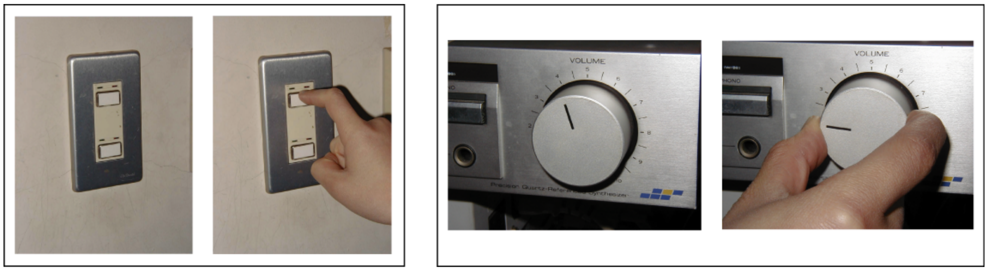

Fig. 1. *Affordance of the real-world devices. Left: "Push" a switch of a room light. Right: "Turn" a volume knob of an audio amplifier.*

In this way, human gestures are very useful communication means, and naturally used by everyone. For these reasons, many researches applied gesture input systems especially for immersive systems such as Artificial Reality [10, 19]. Moreover, some researches have appeared in recent years that focus on compact and multipurpose gesture input systems [1, 2, 6, 13]. In the meanwhile, our approach focuses on daily use of mobile computers and home electronics. We discuss each research on Chapter §6.

2. Ubi-Finger. Ubi-Finger is a compact gesture input device attached on fingers. It realizes sensuous operations of various devices in real world with gestures of fingers. The main concepts of Ubi-Finger are as follows.

1. Sensuous operations with gestures of fingers.
2. Wearable interface optimized for mobile use.
3. Multiple uses with a single interface.

We describe details of these concepts, discuss the problems, and propose the approach of development.

2.1. Control of Real-world Devices with Gestures. Ubi-Finger realizes operations of real-world devices with gestures of fingers. The benefits of applying the gesture input method to operations of real-world devices are as follows: (1) easy-to-understand mappings of operations with existing metaphor, (2) active use of corporeality. The former benefit means that we proposed easy-to-understand control techniques using existing methods to control devices in real world. Real-world devices naturally offer their properties by providing their own affordance [5]. For example a volume knob of an audio amplifier makes people feel like "turning" it (Figure 1). Since many users are familiar with these control methods, they should easily control various appliances using these metaphor. The latter benefit means that the gesture input method should be one of the most suited methods to make good uses of corporeality. Corporeality is considered as a significant factor in Ubiquitous Computing [14] because of its features such as memorability. For example, the operation method learned by moving one's body is more memorable than the method learned by pushing many buttons in order. Therefore, corporeality will be useful for the operations of real-world devices.

2.2. Wearable Interface. Fukumoto [3] said that there are three factors required for wearable interfaces: portability, operationality, and constancy. That is, wearable interfaces must be compact and light weight, easy to use despite of downsizing, and always ready to interact with users. Most of the existing gesture input systems, however, have focused on varieties of gestures, and apply the approach to attach sensors to all fingers. Although this approach excels in versatility, it makes it difficult to satisfy the factors of wearable interfaces such as portability and operationality.

Therefore, we focus on simple gesture input method that excels in portability. We apply a method to detect (1) bending of a thumb and an index finger, and (2)tilt angles of a wrist. By concentrating all sensors around an index finger, our approach can reduce user's load on wearing compared with the existing approach.

Reduction of Unexpected Inputs. Since wearable interfaces should be always ready to use, the methods to differ intended user inputs from unexpected ones are very important. However, most of the existing gesture input systems didn't care about the above problem, and didn't provide features to reduce unexpected inputs.

In Ubi-Finger, we have attached touch sensors on the side of an index finger, and proposed a new method to start and stop the gesture recognition by pushing touch sensors with a thumb. By providing the clear trigger mechanism, we could succeed at reducing unexpected gestures effectively. In the meanwhile, there are trade-offs between the trigger mechanism and natural operations, we should have more discussions in future.

2.3. Multiple Uses with a Single Interface. Ubi-Finger realizes the operation techniques for multiple devices in real world with a single interface. Although users can control multiple devices with learnable remote controls, there are significant problems that the correspondence between functions and buttons becomes more complicated as the number of target devices increase. Thus, user's loads on learning gets increased severely in such existing systems.

Using Ubi-Finger, users can control various devices in real world simply and sensuously. The brief steps of controls are as follows.

1. Select a target device with pointing. A user can select a target device by pointing it with her/his index finger, and send the ID via infrared.

2. Control the device with gestures of fingers. A user can control the target device with gestures of fingers like "push a switch", "turn a volume knob", and so on. Since she/he has selected the target device previously, the control methods don't become complicated regardless of increase of target devices.

3. Development.

3.1. Device Architecture. In this section, we describe the device architecture of Ubi-Finger. Ubi-Finger consists of three sensors (a bending sensor, an acceleration sensor, and a touch sensor) to detect gestures of fingers, an infrared transmitter to select a target device in real world and a microcomputer to control these sensors and communicate with a host computer. Each sensor detects motions of fingers and hands such as (1) a bending degree of an index finger, (2) tilt angles of a wrist, and (3) operations of touch sensors by a thumb. We use (1) and (2) for recognition of gestures, and use (3) for the trigger mechanism to start and stop gesture recognition.

3.2. System Architecture. We describe the system architecture to control real-world devices with Ubi-Finger. As shown in Figure 2, the system consists of four main factors: Ubi-Finger device, Ubi-Appliance (an information appliance with an infrared receiver, LEDs, and a network connection), Ubi-Host (a host computer of Ubi-Finger device), and Ubi-Server (a server to control Ubi-Appliance).

We explain the system flow briefly. First, a user points at an information appliance (Ubi-Appliance) with Ubi-Finger, and transmits her/his unique ID via infrared signal.

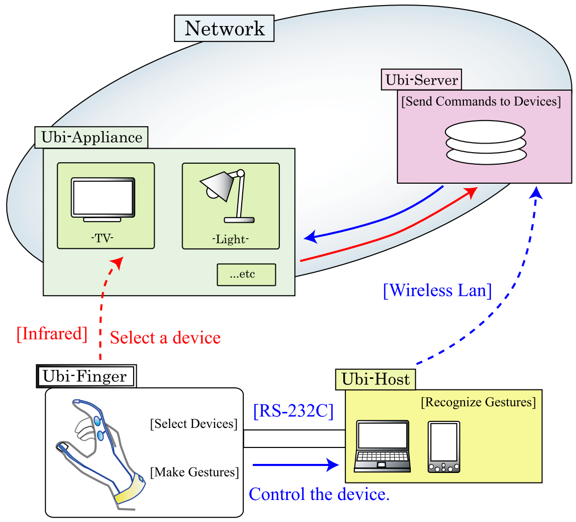

FIG. 2. *System architecture of Ubi-Finger.*

When the Ubi-Appliance receives the signal, it transmits both its own ID and the user's ID to a server (Ubi-Server), and the Ubi-Server associates these IDs together to get the correspondence of the user and the Ubi-Appliance. Then, the Ubi-Server transmits a feedback signal to the Ubi-Appliance, and the Ubi-Appliance shows its state of selection with LEDs.

After the user confirms the state of the target Ubi-Appliance, she/he performs a gesture with Ubi-Finger. A host computer (Ubi-Host) recognizes the gesture, converts it to a specific ID, and transmits it to the Ubi-Server with the user's ID. The Ubi-Server identifies the target Ubi-Appliance with the user's ID, converts the gesture ID to an appropriate command for the Ubi-Appliance, and controls it via network.

3.3. Prototypes. We have developed prototype systems of Ubi-Finger based on the above concepts. We describe the architectures, technologies, and properties of the prototype systems.

Ubi-Finger Hardware. We explain the prototype of Ubi-Finger hardware (Figure 3). The size of the prototype device is as compact as a fingertip. The device architectures of the prototype are as follows. We attached a bending sensor (BendMini by Infusion Systems[1]) on an index finger and two compact switches on the side of an index finger. In addition, we have set a 2-axis acceleration sensor (ADXL202E by Analog Devices), an infrared transmitter, and two LEDs on the portion of an index finger. We used a microcomputer (Tiny-H8 by Akizuki Denshi Tsusho[2]) to convert the information generated by the sensors to numerical values, and transmit them to a laptop computer (OS: Windows 2000 Professional). Then, the Ubi-Host software on the laptop computer recognizes gestures by analyzing the input value in real time, and communicates with Ubi-Server via wireless network.

Ubi-Appliance and Attachable Controller. While the necessary factors of Ubi-Appliance such as an infrared receiver, LEDs, and a network connection will

[1]http://www.infusionsystems.com/
[2]http://www.akizuki.ne.jp/ (in Japanese)

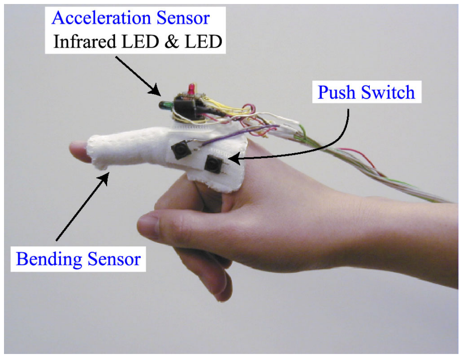

FIG. 3. *Prototype of Ubi-Finger hardware.*

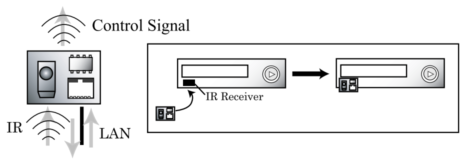

FIG. 4. *Basic concept of Attachable Controller.*

be satisfied by many information appliances in near future, it will take some time that these information appliances become popular. Therefore, as shown in Figure 4, we have developed "Attachable Controller" that can add the necessary factors of Ubi-Appliance to existing home electronics by only attaching it to them. As shown in Figure 5, Attachable Controller consists of three subsystems: "Infrared receiver system", "Network connection system", and "Device control system". We describe here each subsystem briefly.

1. Infrared receiver system. The function of this subsystem is to receive infrared signals from Ubi-Finger and show the selection state of Ubi-Appliance. This system consists of an infrared receiver, two LEDs, a microcomputer (PIC16F84A by Microchip Technology[3]), and other surrounding circuits.

2. Network connection system. The function of this subsystem is to communicate with Ubi-Server via network. This system is mainly based on a product called "PICNIC" released by Tristate[4]. PICNIC is a microcomputer which has a LAN interface and functions just like a web server.

3. Device control system. The function of this subsystem is to control electronic appliances via infrared or other ways. This system consists of infrared transmitter, a convertible EEPROM[5], a micro computer (PIC16F84A), and other surrounding circuits.

4. Applications. In this section, we describe three applications of Ubi-Finger.

4.1. Control of Home Appliances. We have developed an application to control home appliances with Ubi-Finger. When users control electronic appliances in real world with existing remote controls, they must use multiple remote controls as

[3]http://www.microchip.com/
[4]http://www.tristate.ne.jp/ (in Japanese)
[5]Electronically Erasable and Programmable Read Only Memory

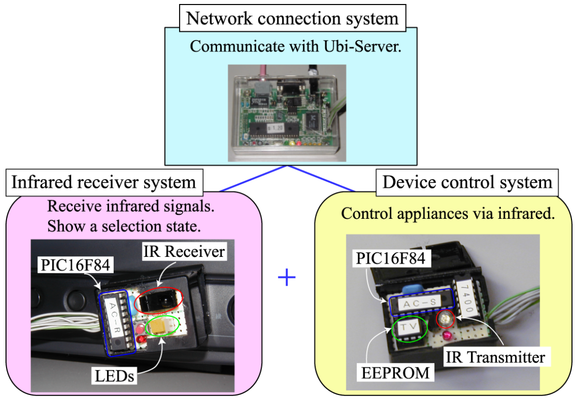

FIG. 5. *System architecture of Attachable Controller.*

many as target devices and learn different control methods with each device. Although users can control multiple devices with learnable remote controls, the correspondence between functions and buttons becomes more complicated in those approaches, and user's loads on learning increase more severely. In contrast, users don't meet such problems using Ubi-Finger since they can simply select target appliances with "pointing", and control them naturally with gestures of fingers.

We have developed some examples to control electronic appliances such as lights, TVs, component stereos, and video recorders with Ubi-Finger and Attachable Controller. We concerned here with the example to control a TV.

We have provided six functions to control a TV, that is, "Turn on/off a TV", "Turn up the volume", "Turn down the volume", "Change to next channel", "Change to previous channel", "Mute the volume". We have proposed easy-to-understand correspondence between these functions and gestures using existing metaphors. For example, since the "turn the volume up" function makes users think of a motion to "turn a volume knob right", we have allocated that function to a gesture to "turn a wrist right". We show the examples of correspondence between functions and gestures in Figure 6.

4.2. Assistant Input Methods for Computers. We have developed an application to scroll a window efficiently with Ubi-Finger during inputting texts. When users input texts or code programs with a text editor, it's a popular situation to scroll the window in order to refer other parts of the texts. There have been some existing methods to achieve the task such as mouse wheels or touch-pads, however, those approaches are not so efficient since users must leave their fingers from keyboards. Using Ubi-Finger, users can efficiently achieve the task by only moving their index fingers slightly, without leaving their fingers from keyboards (Figure 7).

4.3. Give Presentations more smoothly. We have developed an application to give presentations with gestures. When users give presentations with conventional ways, they had to control presentation software in front of laptop computers. But such control methods are sometimes bothering, especially when users give presentations in front of a large number of people. Using Ubi-Finger, users hardly need to mind controlling computers, and give presentations more smoothly.

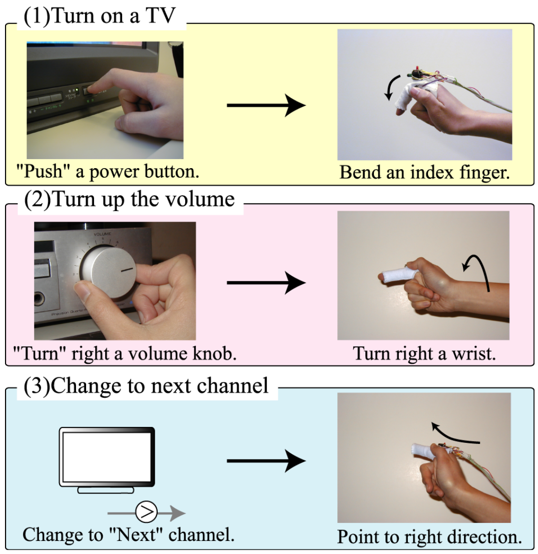

FIG. 6. *Examples of operations using Ubi-Finger.*

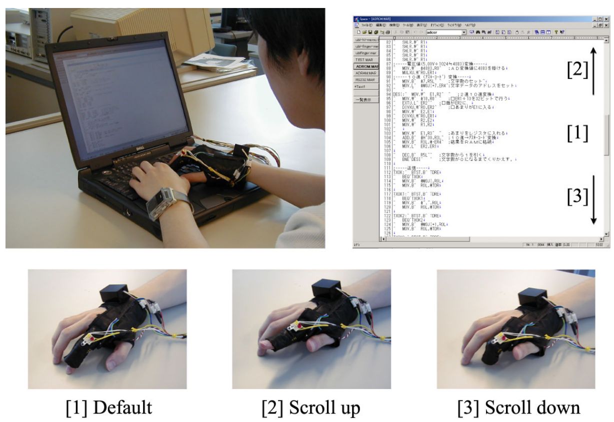

FIG. 7. *Help efficient window scrolling of computers.*

5. Evaluation. We have evaluated the effectiveness of Ubi-Finger features such as the selection method of target devices with pointing and the control method of the devices with gestures. We have performed experiments that users control multiple appliances with the prototype of Ubi-Finger. We have selected 10 test subjects who had never used Ubi-Finger before. Their ages are between 23 and 47.

5.1. Evaluation Methods. We have prepared a component stereo and a table light, and gave test subjects the task to control both devices continuously. We set the distance between target devices and test subjects by two meters, and set the distance between each device by one meter. We focused on commonly used functions of these appliances as shown in Table 1. Then, we have made questionnaire survey to get their subjective feedbacks, and asked them oral questions about problems of the prototypes and so on.

TABLE 1
Correspondences between functions and gestures in the experiment.

Gestures	Table Light	Component Stereo
Bending an index finger	Turn on/off the light	Play/stop music
Turn a wrist right	Brighten the light	Turn the volume up
Turn a wrist left	Dim the light	Turn the volume down

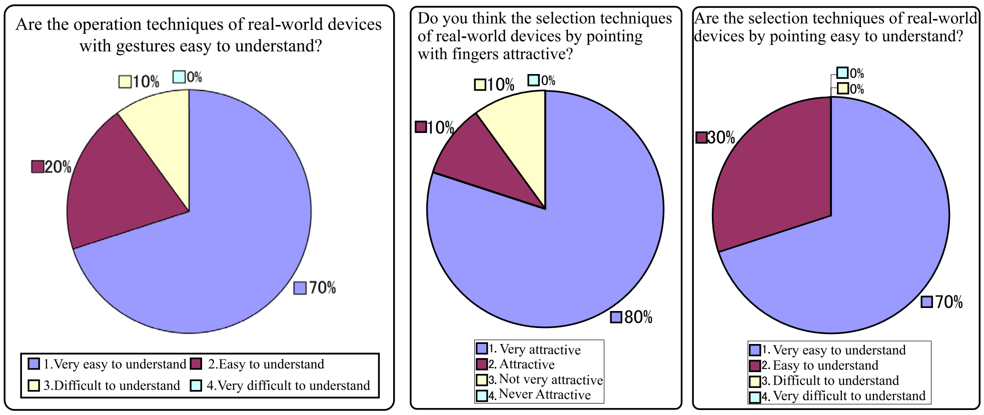

FIG. 8. *Left: Evaluation of operations with gestures. Center & Right: Evaluation of operations with pointing.*

5.2. Evaluation Results. First, we round up the typical result of the questionnaire survey. We asked the test subjects "Are the operation techniques of real-world devices with gestures easy to understand?", and got answers with four options as follows: "Very easy to understand", "Easy to understand", "Difficult to understand", and "Very difficult to understand". In result, 70% of the test subjects chose the option of "Very easy to understand". Along with the users who chose the option of "Easy to understand", 90% of them affirmed our control techniques of real-world devices with gestures (Figure 8).

Moreover, we asked the test subjects "Do you think the selection techniques of real-world devices by pointing with fingers attractive?", and got answers with four options as follows: "Very attractive", "Attractive", "Not very attractive", and "Never Attractive". In result, 80% of the test subjects chose the option of "Very attractive". Furthermore, we asked them "Are the selection techniques of real-world devices by pointing easy to understand?", and got answers with four options. In result, that all of them chose the options of "Very easy to understand" or "Easy to understand", and affirmed our selection techniques of real-world devices with pointing (Figure 8).

In this way, almost all users valued the basic concepts of Ubi-Finger such as selection techniques with pointing and control techniques with gestures. These results clearly show the effectiveness of our approach. In the meanwhile, some problems of the prototype systems became clear by the oral questions, such as "Cables are troublesome", "Size of the Ubi-Finger device should be adjustable", "Users should be able to add or modify gestures", "Control of trigger mechanism is a little difficult". In addition, our experience shows another problem of "Difficulty in selection of close-in multiple devices". We will make efforts to solve these problems.

6. Related Works. First, we discuss here researches and products of gesture input systems. We divide them into two approaches: the first one uses sensors, and the second one uses image analysis.

5DT DataGlove [1] and CyberGlove [2] are typical gesture input systems using sensors. Those systems detect bending of fingers with five or more bending sensors, and detect three dimensional position in a specific environment with polhemus sensor. There also some researches that uses many acceleration sensors to detect gestures of fingers [6, 13].

Since those existing researches focused on multipurpose uses such as Virtual Reality, sign languages, and so on, they applied the approach to attach sensors to all fingers. In the meanwhile, we focused on simple gesture input method that excels in portability, and applied the approach to concentrate all sensors around an index finger. Our approach is more suited for daily use in a mobile environment, such as control of mobile computers and home electronics.

Wearable ASL(American Sign Language) and Gesture Pendant are typical gesture input systems using image analysis. Wearable ASL [17] is a wearable gesture input system that recognizes ASL with a camera attached on a baseball cap. Gesture Pendant [16] is a pendant-type wearable device that consists of infrared LEDs and a camera. Gesture Pendant realizes operations for home electronics by recognizing gestures with the camera. Our approach is different at recognizing gestures with wearable sensors. Advantages of the method using wearable sensors are that users can perform gestures without caring about views of cameras and external noise. In addition, in the application to control home appliances, our approach is unique at smoothly selecting and controlling target appliances with pointing and gestures.

There are some researches on controlling information appliances with particular remote controls such as FieldMouse and Air-Real. FieldMouse [11] consists of a barcode reader to select a target device and motion-sensing devices such as a mouse or an acceleration sensor. FieldMouse realizes controls of target appliances by some motions such as tilting. Our approach can realize more sensuous controls of appliances by providing easy-to-understand correspondence between functions of appliances and gestures using existing metaphors. Air-Real [7] consists of remote controls with laser-pointers, a camera to track motions of the laser-pointers, and a projector to show user interfaces near target appliances. Air-Real realizes controls of target devices by pointing with the laser-pointer. While Air-Real needs very large-scale systems, our approach only needs compact systems. We can apply Ubi-Finger to various appliances only by attaching Attachable Controller on existing appliances.

UbiButton [4] is a bracelet-type wearable interface that realizes a 1-bit command input method like Morse code using an acceleration sensor attached to a user's wrist. In the meanwhile, our approach realizes a simple gesture input system using minimum sensors attached around an index finger.

Attachable Computer [8] proposed a concept to add existing appliances new functions of showing additional information by attaching microcomputers and sensors to the appliances. While Attachable Computer focuses on adding appliances output functions, our Attachable Controller mainly focuses on adding appliances input and control functions.

Gesture Wrist [15] proposed a simple gesture input technique, using an acceleration sensor and sensor electrodes on a wrist. Gesture Wrist can recognize several variations of gestures only by wearing a compact device on a wrist. However, since Gesture Wrist doesn't provide the function of clear trigger mechanism to start and stop gesture recognition, it had still some problems on unexpected recognitions.

7. Conclusion. We have proposed a wearable interface in mobile environment called "Ubi-Finger" that realizes sensuous controls of mobile computers and information appliances with gestures of fingers. We have also developed prototype systems, and evaluated the effectiveness of our approach.

Using Ubi-Finger, users can select target appliances with "pointing", and control them with gestures of fingers. Our approach enables users to control multiple appliances without bothering about complicate control methods, and realizes sensuous operations using existing metaphors and corporeality. Almost all users valued our approach in the evaluation, and we have confirmed the effectiveness of it.

When we solve several existing problems of current prototype systems, we believe that Ubi-Finger will change the interaction between users and various appliances in Ubiquitous Computing more naturally.

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