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HAND-MENU SYSTEM: A DEVICELESS VIRTUAL INPUT INTERFACE FOR WEARABLE COMPUTERS

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Abstract: *Although research on wearable computing is in fashion, few researches pay attentions on interface of wearable computers. This paper presents "Hand-Menu" System", an innovative input interface suitable for wearable computers, utilizing augmented realty techniques. Users can handle wearable computers by clicking a menu activated simply activated with exposed hand with another hand. As Hand-Menu is a "Deviceless" hand I/O interface, Hand-Menu is instant, place-independent and intuitive interface. Additionally, solidity on virtual menu given by tactile feedback from real finger used as a clicking target promotes users' reliability of Hand-Menu.*

Keywords: *Wearable Computer, Deviceless Interface, Augmented Reality, and Physical Sense*

1. INTRODUCTION

To own a computer-based partner supporting one's life at any moment of daily lives is a consistent desire of human beings since the birth of computers, although the first generation versions weren't transportable. Recent development of miniature-sized computer hardware and devices, such as wrist-watch-sized Linux PC [1], seems the grace for us.

Nowadays, many scientific reviews discuss wearable computing under various contexts; communication enhancer or substitution of the five (or six) senses, augmented memory woks as a gateway for cyber space, virtual secretary who suggests context-aware information and reminds his/her boss's behavior or surroundings in the past, etc. Thus, wearable computers have much potential to advance our way of life.

Much research has been done developing various wearable computer systems and applications. However, most important components of information systems, human interfaces, are still too immature and even uncultivated. As wearable computers, except for mere examples such as CyPhone [2] derived from mobile phone, originate from conventional desktop PCs, most of the foregoing wearable computers are equipped with miniature-sized conventional input devices such as mice and keyboards. However, such conventional input devices cannot maximize potentials of wearable computers as they are too optimized for desktop environments.

The greatest advantage of wearable computers lies in situation-independent-ness of its use and unconsciousness of its existence, that is, the wearable computers must be accessible under any conditions without great effort to use. Thus, the input interface for wearable computer needs to be instant, place-independent and intuitive.
This paper presents "Hand-Menu System", is an innovative input-interface suitable for wearable computers. Hand-Menu System is a "Deviceless" interface which lets users to input commands using their hands without holding any particular devices. The Hand-Menu System is kicked-up when a user is looking on his opened hand and accepts commands when a user clicks on a menu that is shown on the fingertips of the opened hand. Thus, the Hand-Menu System is instant and is as place-independent as it is deviceless, and intuitive. It lets users to manipulate commands by the most commonly used manipulators known human beings and in a manner that is often seen in our daily lives.

2. RELATED RESEARCH

2.1 Input-interfaces for Wearable Computers

As discussed in section 1, the greatest advantage of wearable computers lies in situation-independent-ness and the unconscious use of such devices. In order to be an instant information agent the wearable computer must be strongly bound up with the communication channels of human beings. Human beings obtain information mainly from visual and audio channel and transmit information mainly via audio channel. Thus, most of the information channels of human beings are concentrated around the face. Therefore, most of the foregoing wearable computers, such as Mobile Assistant (Xybernaut)[3], Wearable PC prototype (IBM)[4], Wearable Internet Appliance (Hitachi)[5], equip visual output interfaces, head mounted display (HMD), and audio output interfaces, headsets or earplugs. Several researchers developed wearable audio input interface based on voice recognition techniques [6][7]. However, voice recognition techniques cannot be used in noisy environments because the background noise overrides the input voice and they have limited use in quite places such as a public library because the lower tone of the voice will not activate the audio input interface. Moreover, audio channel is not suitable to transmit confidential information, such as a bank ID. On the other hand, human beings communicate with information "machines" using its main manipulators, that is, the hands. Therefore, most of the foregoing information systems are equipped with interfaces to be manipulated by the hands, such as keyboards and mice. As most of the foregoing wearable computers are derived from the conventional desktop PC, most of them use miniature-sized conventional input devices, such as keyboard [8], mouse and touch-pad [9], and several substitutional devices [10][11][12]. However, in order to be incongruous to wear, wearable computers should consist of a single component. As a wearable computer should concentrate around the face, where most of human communication channels are, such "Deviced" interfaces will be troublesome. Several researchers [13][14] utilize eye-tracking as a substitution of deviced interfaces, eye-tracking has the significant problem to be a substitution of mice, such as fatigues to gaze at a certain point and difficulties to distinguish conscious and unconscious eye movements. The most reliable approach to produce a "Deviceless" interface for manipulators of human beings in a single-united wearable computer is to develop an input interface based on image recognition techniques. Although, several researchers [15][16][17] developed image-based input interfaces for wearable computers, the foregoing interfaces regard human hands not as manipulators, but as posture generators: the interfaces require users to give a certain posture to input a certain command.

2.2 Hand I/O under Virtual environment

Virtual Reality research has regarded human hands as manipulators from the beginning. The first commercial VR system RB2 (VPL research)[18] equipped a Dataglobe to let users handle virtual objects by hands and to give several commands by hand postures. Virtual environment [19] presents virtual input interfaces, such as a virtual keyboard, and virtual popup menu. Although a virtual popup menu producing possible commands make an input interface for virtual environment intuitive, the virtual menu cannot present any solidness to make user sure he/she clicked the menu. Several haptic display devices, such as CyberForce (Immersion)[20] or PinchGlove (FakeSpace)[21], may give the solidness for virtual input interface as Tulip Menu [22] indicates. However, theses approaches cannot produce a deviceless solution. Some research has been done on image-based hand I/O, such as a multiple camera input interface [23]. Other research [24] developed an image-based wearable hand I/O combined with Augmented Reality using see-through HMD (ST-HMD). However, most of the wearable hand I/O handles hands as pointer, not a manipulator. Moreover, the foregoing research produces no sense of solidness.

3. PROPOSED METHODS

3.1 System

As discussed in section 2, a wearable computer should produce a deviceless and menu-based hand I/O, as an instant, place-independent, and intuitive input interface. However, if the menu is always stuck within the users sight, it is too bothering. The input interface should be activated by intuitive actions to make the menu-based hand I/O intuitive and incongruous so as not to bother the users.

People from various cultures and various generations tap on their fingertips to count items as to remember things, be using the index finger to tap the opposite hand. Even different cultures cannot share gestures in many cases [25], the fact indicates that the shape of human hands holds a kind of "affordance" to remind us of "selections".

In this discussion the authors utilize the opened hand as the key to call up the menu interface to allow users to tap on their fingertips of an opened hand to select menu items. The authors believe this to be a reasonable approach. Additionally, by allowing users to tap on menu items, the interface can give sense of solidness on the interface. Therefore, the authors propose an innovative wearable input interface "Hand-Menu System" [26][27] as shown in Fig. 1. The Hand-Menu System is comprised of a Wearable Computer equipped with on ST-HMD and an image sensor. A user uses the Hand-Menu System up by opening his hand widely within his sight, and menu items are superimposed on each of the fingertips of the opened hand ("menu-hand"). Consequently, the user can select one of the menu items by touching it with the index finger of the opposite hand ("selection-hand").

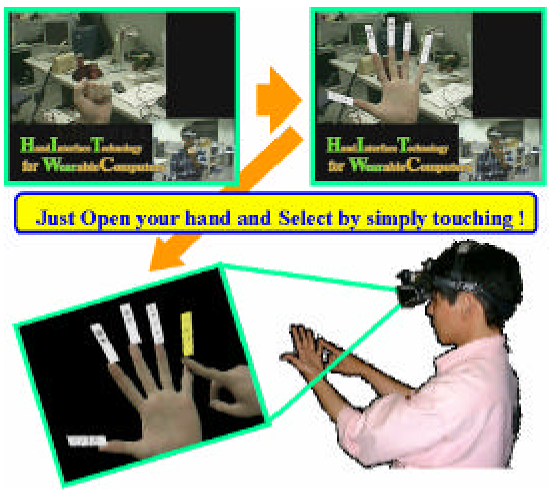

Fig. 1. Concept of 'Hand-Menu System'

By utilizing affordance of the human hand, a Hand-Menu System will let users to operate the wearable computer intuitively by simply touching menu items given on the fingertips. As our Hand-menu system is deviceless and available on one-unit, an eyeglasses-type wearable computer unified with ST-HMD and a miniature-sized imaging device by future improvement of compact hardware, users can have a wearable computer on just like eyeglasses which can operate hand free. Additionally, as the Hand-Menu System utilizes Augmented Reality to present menu items, the Hand-Menu System is a secure interface to input secret information by hiding information on which the user looks and operates.

3.2 Algorithm

Hand-Menu System recognizes user's action by the following six steps.

1. Hand-Area detection
2. Fingertips detection
3. Distinguishing the menu-hand and selection-hand
4. Distinguishing between the palm and back of the hand
5. Displaying menu-item
6. Detection of menu-selection action

The following sections describe details of the each process.

- *Hand-Area detection*
  This paper utilizes an area detection method based on hand color information to pick up the region of the hand [28][29].
  The system filters hand-colored pixels from obtained image using the H and S values of the HSV color space. V value is ignored in order to restrain the variations of lighting conditions. Consequently, the system scales the filtered image down to one sixteenth of the original image in order to speed up following processes and to reduce noise. The biggest connected region and the second biggest connected region are selected as candidates from the hands. Fig. 2 shows the detection procedure.
  In order to simplify and speed up these processes, a look-up table is developed in advance from several images taken under the same environment used in the following experiment.

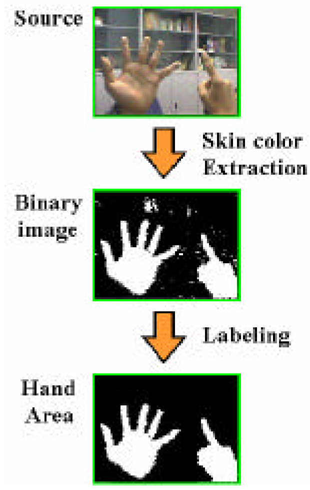

Fig. 2. Hand-Area detection

- *Fingertips detection*
  The system detects fingertips using a curvature of an outline of the hand using the outline tracking algorithm is shown in Fig. 3.

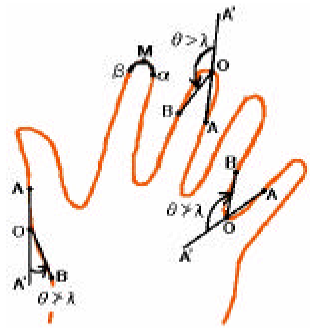

Fig. 3. Fingertips detection

When a searching point ***O*** is given on an outline, ***A*** and ***B*** are points, which are on the outline at a certain distance from ***O***. The triangle ***AOB*** constitutes the fingertip detector. When the exterior angle ***?*** of the angle ***AOB*** becomes bigger than a certain threshold ***?***, the point ***O*** is marked as a candidate point of a fingertip. Through this process, the candidate section ***a-ß*** is extracted.
In order to avoid selecting the bottom of a ravine as a fingertip, direction of the angle ***?*** is decided in an anti-clockwise direction. As the angle ***?*** becomes negative, the ravine cannot be a candidate.

Finally, the system regards the middle point ***M*** of the candidate section ***a-ß*** as a fingertip.

- *Distinguishing the menu-hand and the selection-hand*
  The method to distinguish the menu-hand and selection-hand is quite simple. The system recognizes the region with five fingertips as the menu-hand and the region with one fingertips as the selection-hand.
- *Distinguishing the palm and the back*
  The system distinguishes orientation of the menu-hand, that is, whether the palm faces to the user's eye or not, by examining the relation among the index, thumb and pinkie. The points M_1 to M_5 in Fig. 4 are detected fingertips. The distances between neighboring fingertips gives the index, thumb and pinkie, because the longest line segment is the thumb-pinkie ($\boldsymbol{M_1}$-$\boldsymbol{M_5}$) line and the second longest line segment is the thumb-index ($\boldsymbol{M_1}$-$\boldsymbol{M_2}$) line. When the angle ***?***, the rotation from $\boldsymbol{M_1}$-$\boldsymbol{M_5}$ to $\boldsymbol{M_1}$-$\boldsymbol{M_2}$, is anti-clockwise direction, the palm of the left hand (or the back of the right hand) is exposed, and vice visa.

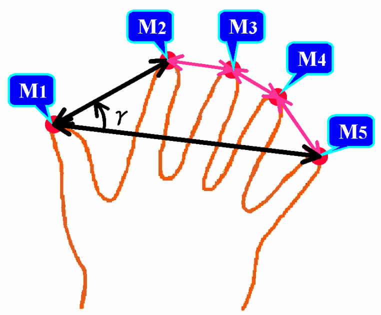

Fig. 4. Distinguishing the palm and the back

- *Displaying the menu-items*
  The menu-items are displayed into rectangle boxes as shown in Fig. 5, which are parallel to radial lines with vectors from point ***S***, the middle of the palm out to each fingertip. Here the point ***S*** is on the perpendicular line of the line ***TP***, and ***TP*=2*SN***, where the point ***N*** is in the middle of the fingertip point ***T*** of the thumb and the fingertip point ***P*** of the pinkie.

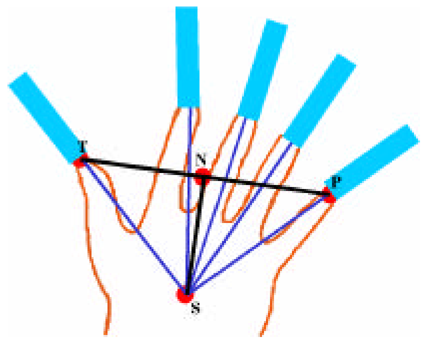

Fig. 5. Displaying the menu

- *Detection of the menu-selecting action*
  The system detects menu-selecting action using distance between the fingertip of the index finger of the selection-hand and each of the fingertips of the menu-hand. When the distance between the fingertip of the index finger of the selection-hand and a certain fingertip of the menu-hand is within a threshold in 3 continuous frames, the system regards a menu is selected.

4. EXPERIMENT

4.1 Prototyping

The authors developed a prototype wearable computer that consists of HMD, 1/3 inches CCD camera and hand-made PC/AT compatible small-computer (11.9x16.8x5.7) mm. Fig. 6 shows the overview of the prototype and Tab. 1 shows the specifications.

Table 1. Specification

Core unit	CPU :Intel Mobile PentiumIII 500MHz Video:CT69990 RAM:128MB HDD:20GB LAN:Wireless11Mbps (PCMCIA)
Display	Sony PC-Glasstron PLM-S700 (resolution 800x600Pixels)
Camera	Watec WAT-230

The Hand-Menu is implemented is Linux on the prototype using the GNU-C compiler and OpenGL Graphics Library.

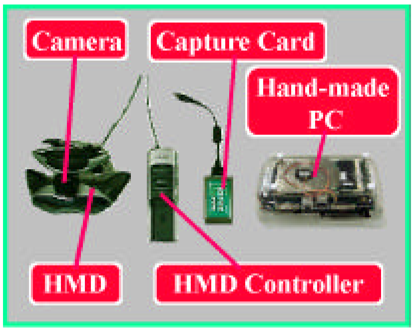

Fig. 6. Prototype wearable computer

4.2 Evaluations

The performance and the usability of the prototype were evaluated through three criteria, start up the menu by opening hand, menu selection by index finger and using the drawing tool, as discussed in 4.2.1 and 4.2.2 below. All experiments were performed in the same room under a fixed lighting condition. Subjects were 10 master course students of the Graduate School of Information Science, Nara Institute of Science and Technology.

4.2.1 Performance of the prototype

The frame rate of the prototype was 4.73 Hz. As the most time consuming process was video capturing, improvements of the algorithm cannot help improving performance of the prototype even if the frame rate is not sufficient. In order to evaluate the recognition rate of the menu-hand, subjects tried to kick up the Hand-Menu by exposing a wide-opened hand in his/her view. Each subject performed 10 tests. Table 2 shows the result. The result shows that the recognition rate of the proposed algorithm was more than 90% and that the prototype is robust enough under fixed lighting conditions.
In order to evaluate the recognition rate of the Hand-Menu, subjects tried to select a certain menu, which he/she was asked to select. All requests where given by voice in a random order, and each of the subjects performed 30 tests.

Table 2. The result of the practicability of fingertips detection

	Success	Failure
Examinee 1	10	0
Examinee 2	10	0
Examinee 3	9	1
Examinee 4	10	0
Examinee 5	10	0
Examinee 6	10	0
Examinee 7	10	0
Examinee 8	10	0
Examinee 9	9	1
Examinee10	10	0

Fig. 7 shows the result of the tests.

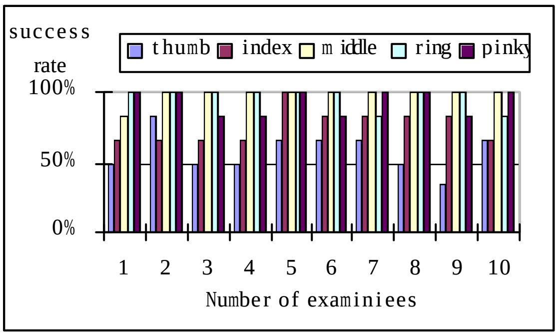

Fig. 7. Recognition rate of menu-selecting action

The result shows that to select a menu item related with thumb and index is rather difficult. It is because the developed algorithm cannot distinguish between the menu-hand and selection-hand when they are overlapped as shown in Fig. 8.

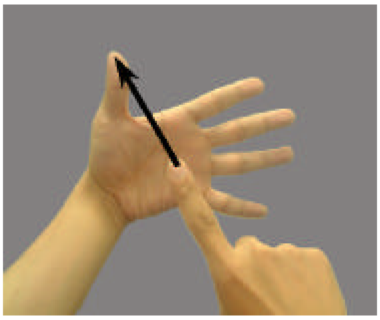

Fig. 8. Menu-selection (Failure)

Therefore, the algorithm forces users to select the thumb as shown in Fig. 9.

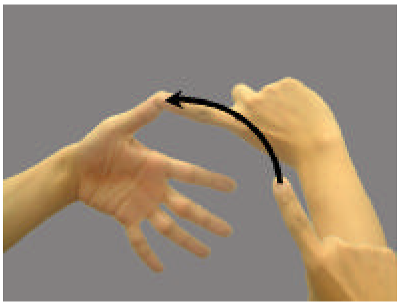

Fig. 9. Menu-selection (success)

Another reason of failure is poor throughput of the prototype. As the prototype can handle only 4.73 frames per second, the system cannot such catch fast motion. In fact, as examinee 3 tends to operate quite fast, the authors asked him to operate it slowly. After the request, the prototype could catch his action precisely.

4.2.2 Usability of the Hand-Menu System

The subjects playing with a drawing tool using on the Hand-Menu and evaluated its usability. The subjects wrote their impressions on the questionnaire sheet which asked the advantages and disadvantages of the Hand-Menu in free format.

Given this, the following results were obtained:

- Advantages
  - To start up and close the menu is quite easy, as I just need to open or close my hand to perform.
  - To move the menu is quite simple and comfortable, as I can move it by simply moving my menu-hand.
  - The tactile feedback given by fingertips seems to ensure I selected the menu. So the feedback gave me reliability on using the menu system and allowed me to operate without stress
- Disadvantages
  - To visualize the depth of the hands was quite difficult.
  - It was difficult to select the menu from time to time.

The comments about the advantages of the Hand-Menu System proves that the proposed approach produces an instant and intuitive interface and that the solidity given by contact with real fingertips make users feel confident in their input action as the authors anticipated. Thus, the results show the effectiveness of a Hand-Menu System as an input interface for wearable computers. However, some subjects said that they failed to select menu from time to time because they cannot visualize the depth of their hands. In fact, those subjects' hands sometimes miss each other by misinterpreting the differences in depth as shown in Fig. 10. However, after the subjects used the "Hand-Menu System" for a while and were acclimatized to it, they could select a menu without any problems.

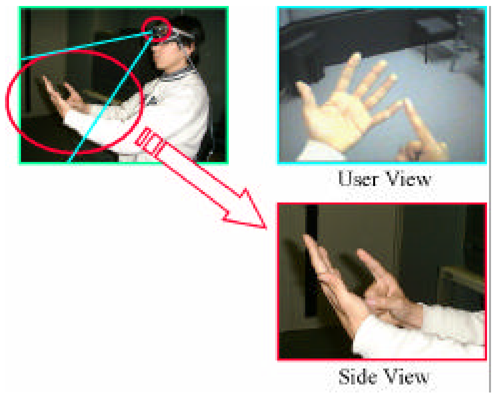

Fig. 10. Problem of the depth in selecting action

5. DISCUSSION

The experimental results clearly demonstrates that the proposed algorithm has enough performance for the Hand-Menu use under a fixed lighting environment, even though the performance of the prototype is not sufficient. Additionally, the results proved that the proposed Hand-Menu is an instant and intuitive deviceless input interface for wearable computers and that the Hand-Menu promotes reliability on the wearable computer by giving a sense of solidness. As the Hand-Menu can be activated by intuitive action, it should not be a nuisance during wearable computer operation when any input interface is required. Thus, the experimental results prove that the Hand-Menu System can be an ideal input interface for wearable computers.

However, the experimental results also exposed several problems of the proposed approach, although the improvements of computer hardware and devices may dissolve the problems, such as failing to recognize quick actions, caused by the poor performance of the prototype hardware.

- *Inconsistency of sense of depth*

  The given comment of users and the phenomena shown in Fig. 10 clears the mismatches between the sense of depth given by visual feedback from the prototype and the one given by physical feedback.

  As the prototype is equipped with just a single camera and video-based ST-HMD because of the hardware limitations, only a monocular video image is available for users. Therefore, most of the visual keys to obtain depth of objects, such as parallax, depth of focus, scale, etc., were lost on the given view, although the authors tuned a scale of image and the depth of focus carefully in advance. Optical ST-HMD may overcome the problem of inconsistency of sense of depth. However, in order to utilize optical ST-HMD, the system needs to obtain the depth of the menu-hand to give a precise parallax in visualizing the menu to reduce the visual mismatch between the real and virtual image. Moreover, to improve system performance is indispensable to put virtual menu items always on the fingertips.

- *Limitations of menu-selecting action.*

  The proposed algorithm doesn't allow the selection-hand to cross the menu hand as shown in Fig. 8, which recognizes the skin-colored region as a region of hands, cannot distinguish between the selection hand overlapped over the menu hand.

  Although conventional image processing techniques, such as edge detection, may distinguish the selection hand from a connected skin-colored region, the conventional techniques may not give a clear answer on the fundamental question, whether the fingertip of the selection hand is actually touching on a certain fingertip of the menu hand. A certain active or passive stereo-measurement technique may give a clear answer for this question. However, to secure enough base-line length for stereo measurement on the small wearable computer seems to be a very difficult problem. Additional development of the imaging sensor technology is required.

- *Adaptation for various lighting and background conditions*

  The current algorithm, which filters the skin-colored region under the HSV color space, has certain difficulties to extract the skin-colored region under unstable lighting conditions. Moreover, the algorithm is almost impossible to extract from the hand in a pitch-dark place or from a skin-colored background.

  An imaging sensor available for near infrared combined with a near infrared lighting source [30] may be a good solution for this problem, even though sizes of the devices are too large to be placed on wearable computers.

6. CONCLUSION

This paper presented a Hand-Menu System, an input interface which is most suitable for wearable computers.

As the Hand-Menu System utilizes affordance of human hands, users may handle wearable computers via the Hand-Menu System with intuitive actions; users can activate the Hand-Menu by exposing the opened hand under their sight and transmit a command by clicking on a menu on their menu hand by the fingertip of another hand.

Evaluation of performance and usability of the Hand-Menu is performed on a developed prototype and the results show the effectiveness of the proposed approach, even though

additional developments are required.
The wearable computer is a tool to augment the users ability to work under various contexts. As a deviceless interface such as the Hand-Menu is available in one-unit, eyeglasses-type wearable computer unified with ST-HMD and a miniature-sized imaging device by future improvement of compact hardware, users can have a wearable computer on just like eyeglasses and can operate it with their main manipulator, hands. Thus, this deviceless interface may be a powerful tool to make the wearable computer available under various conditions including daily lives. Additionally, as an Augmented Reality based interface the Hand-Menu System hides information, which users are looking at and manipulating. Thus, the Hand-Menu System produces a secure input environment.

The authors believe that a deviceless virtual interface such as the Hand-Menu System accelerates the development of wearable computing for practical use.

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