Smart Wristband: Touch-and-Motion–Tracking Wearable 3D Input Device for Smart Glasses

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Abstract. The smart wristband is a novel type of wearable input device for smart glasses, and it can control multi-dimensional contents by using touch and motion. The smart wristband uses a touch-and-motion–tracking system with a touch screen panel (TSP) and inertial measurement unit (IMU) to help users control the smart glasses' interface accurately and quickly without environmental noise, distortion, and multi-leveled pattern recognition tasks.

This paper presents the availability and usability of the smart glasses; how exactly and quickly users can manipulate the smart glasses' multi-dimensional contents and augmented reality (AR) system by selecting, moving, and changing contents via touching and dragging a finger and rotating the wrist; the device's point-and-click capacity; and its navigation, program switchover, zoom in and out, undo and redo for interactions, and 3D virtual object manipulation aspects for application.

Keywords: Distributed, Ambient and pervasive interactions, Interactive matter and physical computing, Wearable computing, Input Device, Smart device, Smart glasses, Head-mounted display, touch-aware, motion-aware, multimodal/ multisensory interaction, Symmetric interaction in real and virtual worlds.

1 Introduction

The use of interactive 3D environments has increased the demand for ubiquitous technologies [1]. The continuous research on ubiquitous environments demands the development of wearable computers to control the system. Although various approaches were investigated to overcome the limitations of interaction between humans and wearable computers, products have had difficulty maintaining a foothold in the smart device market, and research has been limited due to the absence of a fast and accurately responsive system.

A see-through head-mounted display (HMD) can provide a transparent display area within a user's field of view, enabling a user to view both physical objects in the user's surroundings and visual elements on the display. In some situations, however, such as when the user is navigating a busy environment, displayed visual elements can be

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distracting and/or may impair the user from viewing physical objects in his or her surroundings [2]. Though a head-mounted display has a highly responsive output system, there is no stable input device that understands a user's command quickly and accurately without distraction or that enables multi-dimensional manipulation to interact with the 3D environment of the real world or virtual world.

The new input device in this project, a wristband-type motion-aware touch panel, is designed to resolve these problems, allowing for stability of input and a greater degree of freedom. In order to utilize a familiar input device, we chose a touch panel that has been popular since smartphones as a main input channel began to dominate the market for mobile devices. Obviously, using a touch panel for pointing is a more stable input method than using hand gestures or voice recognition because it is less influenced by the surrounding environment. Another problem of limited DOF can be mitigated by this device because it provides a higher degree of freedom by utilizing the rotation of users' wrists. The additional DOF can be efficiently used to deal with various GUIs available through the HMD.

The finger and wrist have an advantage as the position for the wearable device because these are the most familiar parts of body for manipulating devices, and they have the greatest range of space to control. A large portion of the population already uses their fingers and wrists to manipulate devices, manipulating devices that range from drills to computers. Since using the suggested motion-aware touch panel utilizes this familiar interaction, a motion sensor, and a touch pad with a cursor, users will not be confused and find the use of this device unappealing. Also, a wristband-type device is less likely to make people irritated, since the wearing sensation is similar to a watch, and they will find the device less likely to misplace compared to a wallet or a phone. The wrist is a very attractive body part for this device because it is connected to the finger, which is the most delicate part of the human body, and also to the shoulder and elbow, which have the largest range of motion among the body parts. The shoulder and elbow increase the wrist's position freely and widely. Although the wristband form factor requires a relatively small screen size, people can use the intuitive and delicate device without complicated procedures.

This paper presents a wristband-type 3D input system called *smart wristband*, which applies users' commands exactly by implementing the concepts above.

2 Prior Work

Smart devices have advanced rapidly. From the introduction of the first smart phone, "Simon," to the commercialization of the first wearable HMD took only twenty years. HMDs are simply reinvented wearable computing for a new era; many researchers are conducting research focused on HMD and related applications. HMD is a display device worn on the head or as part of a helmet. A typical HMD has either one or two small displays with lenses and semi-transparent mirrors embedded in a helmet, eye-glasses, or visor [3]. To widen the range of applications of HMD, including operation in cluttered environments and human-computer interaction on-the-move, a variety of input systems for HMD have been invented; however, due to limited input systems, these devices are not yet a perfect tool for human-computer interaction or wearable computing.

One of the input systems for HMD, speech recognition that enables human interaction with computers through a voice/speech platform in order to initiate an embedded service or process has been advanced. Apple's Siri and Google's Voice Search can find directions and set important reminders. Moreover, research on gesture recognition, which recognizes and identifies sign language by using cameras and computer-vision algorithms, allowing humans to communicate with a computer by hand-tracking and hand-posture recognition [4], has been conducted at research fields through computer vision and image processing. Speech- and gesture-activated control offer limited accuracy that varies from user to user and depends on ambient noise levels. Speech and image input also raise user-privacy concerns when used in public spaces and speed concerns for multi-processing tasks [5]. Even though hand-held point-and-click controllers or one-handed keyboards like the Twiddler [6] are a more stable input method, their degree of freedom is limited because of physical constraints.

Recently, as interest in wearable computers has increased, the method to utilize a wearable input device in the mobile environment has also investigated. Thomas et al. endeavored to discover what part of the body is the most appropriate position if a TSP can be attached to the body [7]. In this study, they showed that the thigh is the position where a TSP made the best performance among the body parts. However, a thigh is hard to utilize in the mobile environment because it is not easy to be reached by the hands. The wrist, by contrast, is reached easily by the hand even while a user is running. Moreover, using a TSP attached to the wrist showed similar performance to that of a thigh. Therefore, we could conclude that the wrist is a proper position for a wearable TSP. The wrist is a very attractive body-part that is connected to the finger, which is the most delicate part on the human body. The degree of freedom of the wrist is six, which means users can manipulate six directions intuitively, and this range of motion is the highest among the body parts. When the anatomical position is considered as 0°, around our wrist there are two major exceptions: (1) shoulder rotation—arm abducted to 90°, elbow flexed to 90°, with the position of the forearm reflecting the midpoint 0° between internal and external rotation of the shoulder; and (2) supination and pronation—the arm next to the body, elbow flexed to 90°, and the forearm in mid-position 0° between supination and pronation [8]. The shoulder and elbow increase the range of the wrist's motion, which indicates that a wrist has a wide range of input variables such as position, speed, and acceleration, even while the user is on the move.

3 Implementation

3.1 User Interface

The user interface is composed of the 3D HMD and the smart wristband, and the smart wristband consists of three inputs and one output: TSP, IMU, HMD camera, and HMD projector. In the wearing HMD environment, a user controls implanted modes (applications), augmented information, and augmented objects with a smart wristband. First, augmented computing information is projected on the glasses. Second, as the user moves his or her head, a camera takes information from an object. Third, the TSP assists as a touch sensor for drawing an image or moving a cursor to select an object of the screen projected on the glasses to search for information on the object. Fourth, an IMU functions as a motion sensor to control the selected object to switch program mode or to scroll the projected screen. Finally, the input information transfers to a computer, and the processed information is displayed on the glasses.

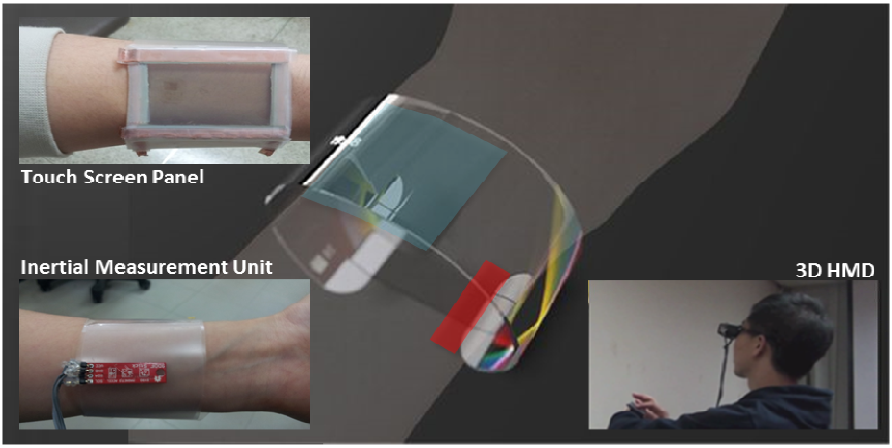

Fig. 1. Concept sketch (Back) and actual implementation (Front) of the smart wristband

Touch Screen Panel. The touch screen panel (TSP) is fabricated by nano-device processing. The indium tin oxide (ITO) on a flexible substrate and a multi-layer composite of silver nanowires and carbon nanotubes on a glass substrate are used as upper and lower electrodes, respectively [9]. The resistances of four sides on electrodes are translated by the "eGalaxTouch" program to apply finger-touch on the TSP to move the cursor, write text, or draw shapes on the projected display.

Inertial Measurement Unit. The inertial measurement unit (IMU) is the Sparkfun 9DOF Sensor Stick [10]. The values from the accelerometer, magnetometer, and gyroscope sensors are fused by the razor-9dof-ahrs method [11]. The dimension of the IMU is 34.8 mm * 10.7 mm * 2.4 mm.

Fig. 2. Implementation of TSP (Left) and IMU (Right)

3.2 Tools and Commands

All of the interactions of the smart wristband are composed of two basic interactions: between the HMD and finger touch and between the HMD and wrist rotation.

The function of TSP is similar to a touch pad on a laptop. While users see a display from the HMD, they can move a pointer to a certain location on the screen and then tap, with a short touch, on the TSP, which is recognized as a click-of-a-mouse input.

IMU is used to detect the motion of the wrist. Users can manipulate the wearable computer system through a quick or slow rotation of the wrist. The position, velocity, and acceleration of the motion of the wrist are measured and reproduced on the projected screen, as is the motion of the wrist.

The following interactions are combined for different applications of 1-dimensional, 2-dimensional, and 3-demensional interactions in various ways.

Finger Touch – Point and Click. The first application is a 1 and 2-dimensional interaction; users point and click the GUI interface on the screen through finger-touch interaction with the TSP. The TSP is a specialized surface that can translate the motion and position of a user's fingers to a relative position on the operating system that is outputted to the projected screen [12]. The TSP has features in common with the touch pad of a laptop, a substitute for a mouse where desk space is scarce. “Point” is the way that users move a pointer, and “click” is the way that they select or enter the target.

Wrist Rotate – navigation. The second application is a 2-dimensional interaction; people can scroll the screen. When users want to see the other side of the screen displayed on the HMD, they scroll augmented information by rotating the wrist. As the size of a head-mounted display is small, the contents shown to a user at once are limited. Therefore, it is probable that users will have to scroll the contents. Here, scrolling through the TSP would trigger fatigue because it would require repetitive clutching. In contrast, scrolling with wrist rotation allows users to control the augmented information easily and intuitively. This interaction can expand the range of contents and application of HMD by extending the screen that users can see and control.

Fig. 3. Navigate screen by using wrist rotation

Quick Wrist Rotate – Program switchover. The third application is a 1-dimensional interaction; users can switch contents with the device. When a user needs to switch the display to show different contents, this can be done by rotating the wrist quickly. The different speed of rotation can be used to trigger the change of contents on the display. Contents implemented in this project are search screen, wallpapers, schedule, and email. In addition, HMD users feel embarrassed when they must speak or gesture in public to change contents. To rectify this, the smart wristband provides private and natural interaction.

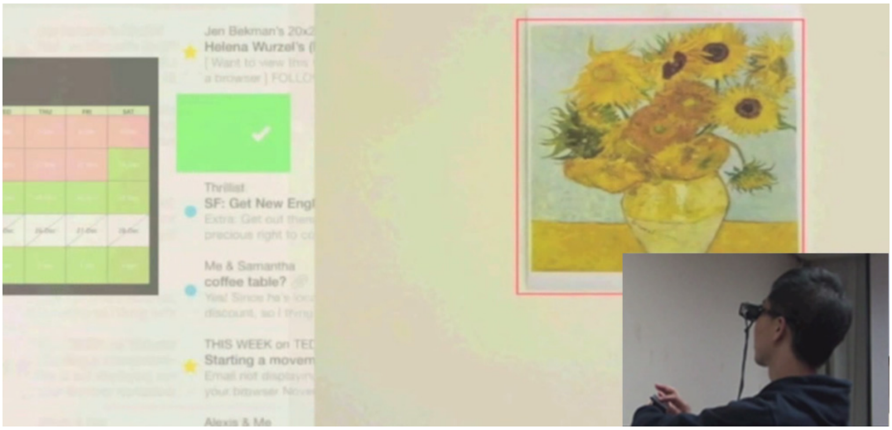

Fig. 4. Switch program by using quick wrist rotate

Wrist Rotate with Finger Touch – Zoom in and out. The combination of wrist-rotate and finger-touch tasks results in a zoom-in or zoom-out function. When a user rotates the wrist clockwise and touches the finger on the TSP at the same time, the user will gain a close-up view of contents on the HMD to see the enlarged page at a reduced size. Contrary to this, a counterclockwise rotation with finger touch results in zooming out quickly. To adjust the percentage of zoom setting, a user controls the degree of rotation of the wrist.

Quick Wrist Rotate with Finger Touch – Undo and Redo. When a quick wrist rotation and finger touch occur at once, undo and redo tasks are performed. While touching the finger on the TSP, a quick rotation of the wrist counterclockwise undoes the last action or actions that the user made. In addition, when a user quickly rotates his or her wrist clockwise with a finger touch on the TSP, the system redoes the last action or actions that the user made. To undo/redo several actions at the same time, the user would repeat the quick rotation several times.

4 Results

To emphasize the usability of the interface and interaction, we developed an application—3D virtual object manipulation. A 3D-augmented reality (AR) environment was constructed by Qualcomm Vuforia SDK [13]. For selection, a user can click on the 3D object and then use drag-and-drop for translation of the object by using the TSP. When the user wants to rotate the 3D virtual object, he or she can rotate the wrist, making the 3D object rotate according to the wrist rotation. As a test, we created a target picture paper augmented on a table, and then had a user attempt to fit the target with randomly distributed 3D virtual objects. As the demo shows, the user seemed confident in using the device and correctly matched the objects to the pictures. This application suggests that the smart wristband is a 3D input device that can control a 3D virtual environment. Moreover, by combination of TSP and IMU, people can control the devices in more than three dimensions; for example, by moving the wrist and touching on the screen at once, people can control other functions at once, such as depth, time, and so on. This multi-dimensional control presents development possibilities as a 3D-drawing tool.

To confirm usability, we conducted several experiments to analyze how fast and accurately users can react with this input device. We hired three subjects from our university (two males and one female, with an average age of 27). The goal of this experiment was to estimate the precision and task-completion time of using the wristband-type TSP, depending on the degree of freedom given to be controlled by wrist rotation. The task was for the subjects to rotate their wrists to the given angles of yaw, pitch, and roll; to help the participants understand the target position and actual position of their wrists, a physical target and a physical object rotated by the given yaw, pitch, and roll angles were displayed. When participants believed their wrist positions corresponded to the given angles, they were required to click the screen by tapping the TSP on their wrists. Through the experiment, we were able analyze the behavior of users with regard to how fast and accurately users can utilize our device. We estimated the time and error to complete each trial. The result shows that task completion time increases as the number of DOF increases, as shown in Figure 3d.

We additionally analyzed the task completion time within the same numbers of DOF, as shown in Figures 3a, 3b, and 3c. We also estimated errors of angles, the difference between the target angles and the angles at the moment when the user finishes a trial. The result shows that 1 DOF produces significantly fewer errors than 2 or 3 DOF cases. However, 2 DOF produced more errors than 3 DOF. According to these results, although higher DOF provide more variables to control, the experimental results illustrate that it is not more effective than a lower DOF in speed and accuracy. Therefore, the interaction should not have the highest DOF, but rather has to have the minimum DOF following the number of variables of each different control. As a result, the 1D, 2D, and 3D interactions use 2, 2, and 3 DOF of control, respectively [14].

Fig. 5. Applications for the 3D input device: 3D virtual object manipulation

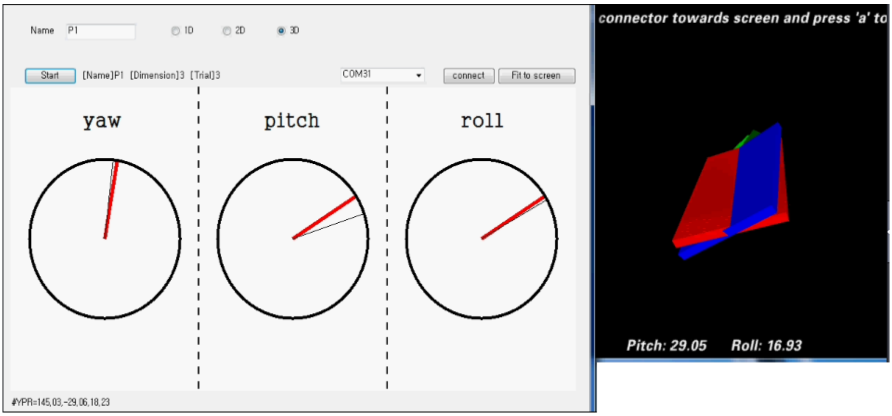

Fig. 6. Survey task: participants rotated wrist to the given angles of yaw, pitch, and roll, and then to click on the screen with the TSP on the wrist

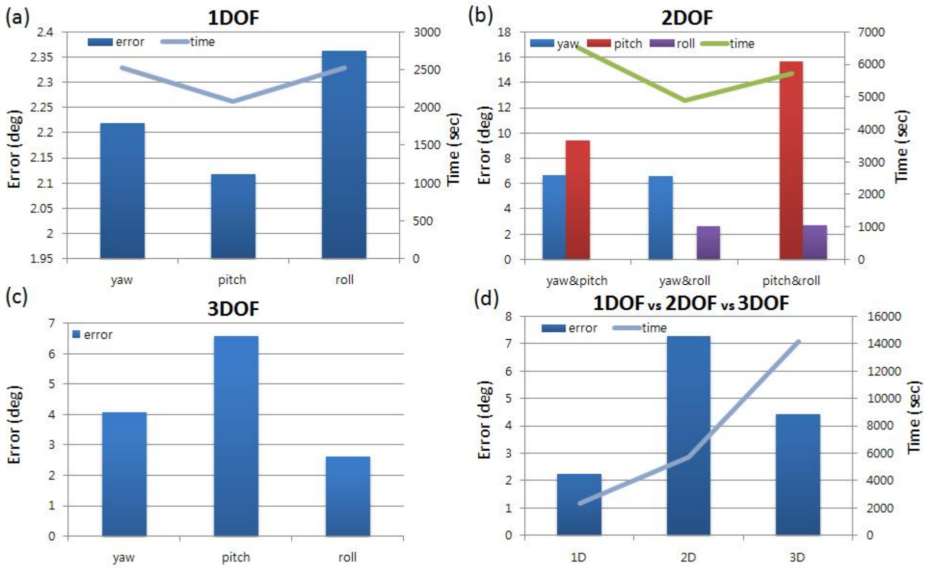

Fig. 7. Precision and task completion time in each dimension of (a) 1 DOF, (b) 2 DOF, and (c) 3 DOF, as well as (d) overall task completion time and error for each DOF

5 Conclusion

In this research, to improve the low degree of freedom and the instability of wearable input devices, we presented a new input device with the ability to select and command correctly, directly, and easily through the use of tactile and wrist motion: a wristband-type motion-aware touch panel. It was demonstrated that users were able to effectively use the wearable 3D input device for HMD-display object selection and control it by using tactile input via a finger to select the correct object and by using gestures and wrist rotation to control the screen or point at objects. In addition, five kinds of interactions—tools and commands—have been implemented, and one application—results—has been realized; these were point and click, navigation, program switch-over, zoom in and out, undo and redo for the interactions and 3D virtual-object manipulation for the application.

We humans have a lifetime of experience in perceiving our environments and interacting with physical objects with our fingers and wrists. As a higher level of technologies has been continuously developed, our human requirements have grown exceedingly challenging and include high spatial accuracy and resolution, low latency, and high update rates. Therefore, this 3D-input device would satisfy our desires for an intuitive and simple but delicate interaction by using cursor movement (TSP) and a hand-gesture awareness system (IMU).

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