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Master's Thesis
Academic Year 2019

Watch Spaces : A Spatial User Interface for Smart Watch

Keio University
Graduate School of Media Design

Keitaro Tsuchiya

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Keitaro Tsuchiya

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Abstract of Master's Thesis of Academic Year 2019

Watch Spaces : A Spatial User Interface for Smart Watch

Category: Science / Engineering

Summary

Alan C. Kay presented the possibility of human thinking with devices and GUI due to the development of information technology. However, what is revealed is not only the GUI but also the social environment design based on the combination of somatic sensation, human cognitive ability, and information technology. Based on this philosophy, we developed and evaluated devices and systems considering how UI / UX can be updated from the perspective of spatial recognition ability.

The contributions of this thesis are as follows:
(1) We introduced the concept of "Watch Spaces" that can provide more valuable UX to smart watch users.
(2) Presentation of a platform to prototype spatial user interfaces for smartwatches and the initial implementation,
(3) Assessment of two fully functional, proof-of-concept applications: A Spatial-Pin for watch applications and a digital magnification glass.
(4)Demonstrated the feasibility and effectiveness of this approach. In experiment, our Watch Spaces was shown to be easier and faster.

Keywords:

Wearable Device, Spatial Design, Human-Computer Interaction, Human-centerd Computing

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Chapter 1

Introduction

Alan C. Kay [1] proposed the concept that computer devices would evolve faithfully into the personal computer. However, when he introduced this concept, only professional engineers could handle computers. Still, in his paper, he presented a diagram of the idea that children would use computers as like toys.

Today we live in a society in which anyone can access the Internet using a computer such as a smartphone and interact with digital content ubiquitously. Which means, Alan C. Kay predicted the future society's methods of designing interactive personal computer devices and graphical user interfaces (GUI).

However, at present, the processing speed of computers, the speed of evolution of computer specifications, and miniaturization have peaked. The progress of miniaturization of devices in particular lead to the concept of wearable devices. This concept was further assisted by the development of devices that were close to the user's body.

A smart watch is a device that can connect to smartphones and the Internet and access ubiquitous digital content. In addition to smartphones, smart watches have become digital devices that have blended into our lives. Wearable devices, together with the Internet, have enabled us to access any type of information anywhere. Even though early wearable computing work presented a lot of other paradigms [2]. We often still use the two-dimensional window metaphor for information interfaces. In current consumer product smartwatches, interfaces with multi-touch, voice, and a crown dial are used. Yet, mainly people use the touch screen and touch interaction.

However, the reliability of touch interaction has two significant problems.
First, the information in the position where the finger is placed is naturally hidden. Second, the range of information input is basically limited to the size of the display.

Therefore, it is very difficult to use a small screen-sized device closely attached to the body.

In the Human-Computer Interaction field, there are research efforts to extend the interaction area from just the watch area to the arm or even to the space above of the watch [3–5].

On the other hand, along with the evolution of VR/AR, technology such as object tracking and gesture recognition based on physical position and body posture have been greatly developed and are being introduced into consumer products. In addition, research related to these technologies in the academic field has become active, and the importance of spatial user experience has become clear.

Wearable devices have particularly high compatibility with such technologies, and thus the further fusion of wearable devices and spatial interaction technologies is expected. In the near future, interactions and devices that take in to account the human's spatial ability will increase in implementation. Resulting in an updated society that has greater fusion with its environment and information. We expect that new values will be developed that will allow for future devices and designs to be more aligned with our human perception. Thus, it is necessary to redesign the user experience based on a new concepts rather than current interactions. Hence, purpose of this research is updating the user experience of the smartwatches to give users a more valuable experience.

We propose a slightly different approach, using the physical space relative to the user's body as a "Work Space" with the watch. The watch acts as a window into the virtual work space. The work space location and orientation is relative to the user's body, following early work on wearable spatial user interfaces [6]. Every time the user moves his/her hand to the same location relative to their body, they will see the same information screen, or the same application will open. In addition to the work space metaphor, we also explore a "Digital Magnification Glass" concept. This concept proposes using the smartwatch as a digital lens that can show more information about a visualization, map, or other physical objects.

The contributions of this paper are as follows:

1. We present a concept of "Watch Spaces".
2. Presentation of a platform to prototype spatial user interfaces for smart watches and the initial implementation.

3. We provide two fully functional,proof-of-concept applications: A Spatial-Pin for watch applications and a digital magnification glass.
4. Demonstrated the feasibility and effectiveness of this approach. In experiment, Our Watch Spaces was shown to be easier and faster interface.

1.1. Thesis Structure

This thesis is divided into 6 chapters. This chapter is an introduction to this project. Chapter 2 discusses related works, chapter 3 describes in depth about the design of Watch Spaces, chapter 4 explains the implementation of concept of the design, chapter 5 explains about experiment and its result, and chapter 6 concludes with the findings, limitation and future work.

Chapter 2

Related Works

2.1. Wearable Devices and Smart Watch

In recent years, there are many wearable devices on the market that collect bio signals to provide applications for coaching and visualization. One such example is the Fitbit AltaHR(Fig.2.1). This device is equipped with a heart rate sensor, acceleration / angular velocity sensor, and proximity light sensor. These sensors are used to track the user's movement, meals, sleep, and more. Through icons, the clock functions, the person's status, and count information is presented on a small organic light-emitting diode (OLED). Basic interactions are buttons and touch interactions. While all detailed settings and data information must be accessed through Bluetooth on an application on one's smartphone.

Figure 2.1 Fitbit AltaHR

The AppleWatch(Fig.2.2) is another example of a popular commercial wearable device. It has a 368 x 448 touch display, microphone, and digital crown. This device incorporates touch input, physical buttons and a digital crown input, and voice input interactions. However, because the screen is not narrow, it stylistically prevents user's from gaining the maximum benefits of these inputs.

Figure 2.2 AppleWatch

2.2. Spatial Information Displays

Our work is inspired by early mobile and wearable computing research, which evaluates how to manage and display information in mobile scenarios with limited screen estate [2]. For this research, we suggest providing a spatial virtual display space relative to the user's body so that the user can explore this space with their smartwatch. Billinghurst et al. showed that "Body-stabilized Information Space" concept, that provide benefits over head centered displays. They are easier to use and more intuitive as well as faster on search tasks [6]. Grubert et al. showed a similar approach, yet focus on interactions on multiple devices devising methods to combine a head-mounted display with the smartwatch interfaces [7]. There are also a couple of other works that focus on extending/augmenting the smartwatch display [8,9]. Another large group of researchers focuses on smartwatch interaction techniques to overcome the limited input space. Most of them implement novel wrist-worn sensors/devices [10] [11]. Kening et al. developed a smartwatch that extended to five displays [12]. While this work is closely related to our own, we see our work as complementary. We hope to provide a platform for prototyping these types of interactions. Also, for the implementation of our concept, we focus on a single device (smartwatch) and exploring the relative physical space around the user.

2.3. User Interaction

Gesture input is one of the most socially acceptable methods [13]. Jun Gong et al. suggested interactions related to arm movements (mostly involving the elbow joint) [14]. They also evaluated hands-free interactions on the smartwatch space [15]. This research supports our work as these types of interactions could also be used to interact with the Watch Spaces concept we introduce in this thesis. Alex Olwal showed a new interaction on a smartwatch with Clock hands [16]. This is not directly related to our proposal, but shows an interaction approach that replaces the existing touch-button voice input, with the focus on clock hands in smartwatch interactions. In addition, Alex Olwal [17] has made it possible to identify what the hand wearing the smartwatch is holding, using an application of sensor feature built-in the smartwatch.

2.4. Human's Spatial Ability

Pedro Lopes et al. show an interaction design method that focuses on somatosensory, especially proprioception, without relying on vision or existing interactions [18]. Regarding spatial memory, Ken Igarashi et al. presented a novel approach to augment human memory based on spatial and graphic information mediated by an electronic device [19]. Wilson et al. explored human's spatial ability in VR space [20].

We use spatial perception in everyday tasks such as picking things that are in front of you. We can pick your mug and drink without paying much attention to it (such as still focusing on the Laptop). Because we recognize the relative position of your body and objects. According to recent discovery in neuroscience, our physical body and immediate surroundings are processed by the same neural structures.

Chapter 3

Watch Spaces

In the following, we will present the general concept of "Watch Spaces," as well as the underlying design ideas.

First, the current smartwatch interaction is shown in the table3.1 below.

Touch	Obviously, the current wearable devices such as smart watches use interaction by touch display most.
Optional Button	Digital crown and buttons.
Mic	For voice assist agents and voice input.

Table 3.1 Current Smartwatch Interactions

Smart watch interactions were designed based on hand held mobile devices so the standard interactions are touch, buttons, and voice input. These designs do not take full advantage of the user ' s spatial environment and thus limit the device ' s ability to augment the user ' s reality and be non-intrusive.

0n the other hand, there are three goals to be achieved by the Wearable device shown by Billinghurst et al [2].

1. Must be mobile: By its definition, a wearable must go where its wearer goes.
2. Augment user ' s reality: Unlike virtual reality, augmented reality seeks to enhance the real environment, not replace it.
3. Provide context sensitivity: When a wearable device is worn it can be made aware of the user ' s surroundings and state. And wearable device and their interaction should be non-intrusive.

Current smart watch interactions do not meet Billinghurst et al.'s No.3 goal of three goals because they require two arms (the arm that wears the smartwatch and the arm that taps). Also, the condition of No.2 is not satisfied.

While other researchers have explored spatial usage with wearable computing devices. They are not always practical and do not explore to a great extent the relative physical space around the user as a means of interaction. Based on the concept of the "Body-stabilizing information space" [2], we reconsidered the goals that wearable devices should aim.

From these backgrounds and related studies, it is hypothesized that smartwatch interaction with physical body movements will provide smarter operation and more intuitive and efficient operation.

We developed a concept of system that realize non-intrusive interaction and environmental enhancement by using somatic sensation and spatial cognition, and we named the concept “ Watch Spaces ” .

The next section explains the details of the concept.

3.1. Concept

To answer the hypothesis, we designed the concept and identified the elements needed for a new interaction.

Watch Spaces is a concept aimed at updating the concept of a smart watch by combining the concept of a user's body stabilization information space with the space recognition ability and wearable device. The Watch Spaces design is based on three key points we think are important for smartwatch operations.

1. One-hand only input: It should not be necessary to use two hands.
2. Utilizing 3D physical space: we do not want to rely on finger movements for major interactions and want to use the whole 3D physical space.
3. Virtual Extended Workspace & Anchor: The user should be able to access a large number of applications or tasks.

3.1.1 One-hand Input

Currently, smartwatches often apply touch input as the standard operation method. Such input operation means that the users need both hands to operate the device. The requirement of two hands is very limiting, especially if the user is on the go

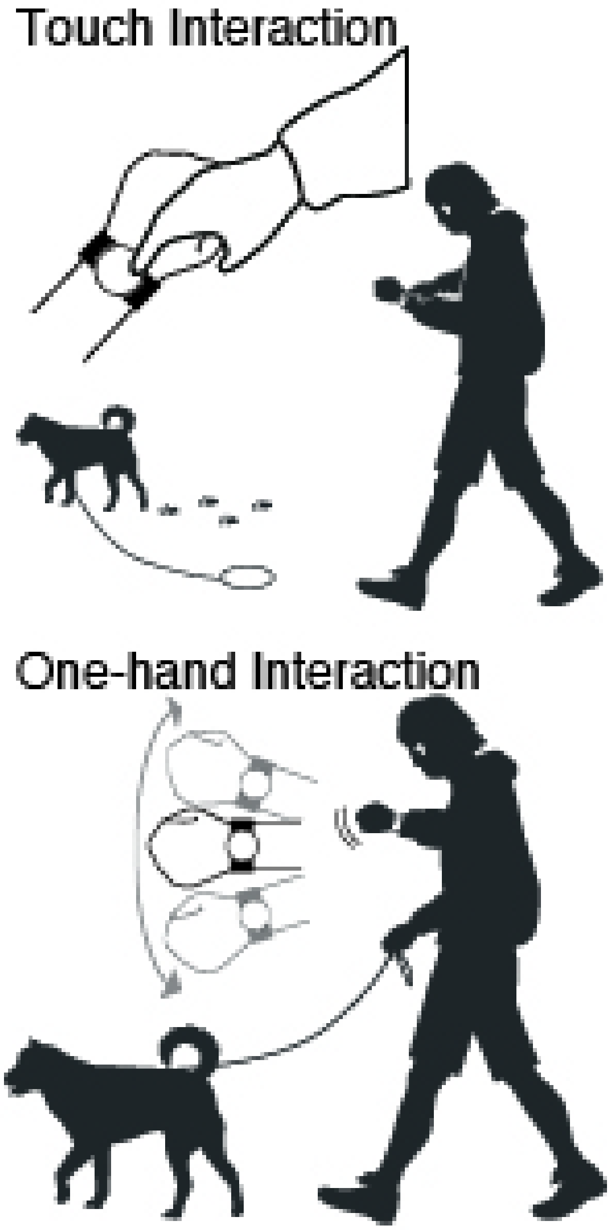

Figure 3.1 Touch interaction and one-hand interaction

and carrying bags etc. It can be particularly challenging to operate a smartwatch in the case of holding something with the other hand (see Fig.3.1). Even if a user reluctantly touches the smartwatch, since the interface is small, this can cause many cases of miss-touch.

3.1.2 Utilizing 3D physical space

Since the current design of smartwatches limits usage to one hand, we wanted to make the input space more expressive. Therefore, we designed interactions that make use of all 3 Dimensions (3D) of the user's physical space (see Fig.3.2). The user can move the smartwatch closer to and away from their face. The user can also move their wrist and the arm horizontally as well as up and down. This type of 3D movement can represent the switching, zooming, and even more specific functions of an application.

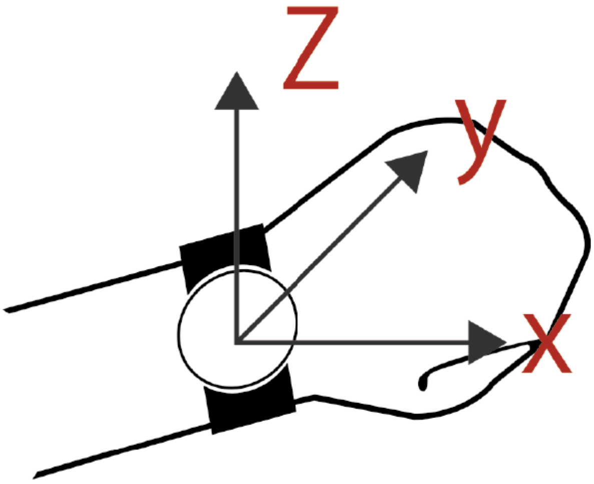

Figure 3.2 XYZ axis on the smartwatch

3.1.3 Virtual Extended Workspace & Anchor

As the display space of the watch is limited, we present the concept of an extended virtual 3D desktop for interaction around the user's body. The application "App-Pin" described later uses a curved space around the user versus the "MapLense," which uses the flat 2D space in front of the user (see Fig. 3.3). By using our concept, the extended workspace can be defined by the application programmer.

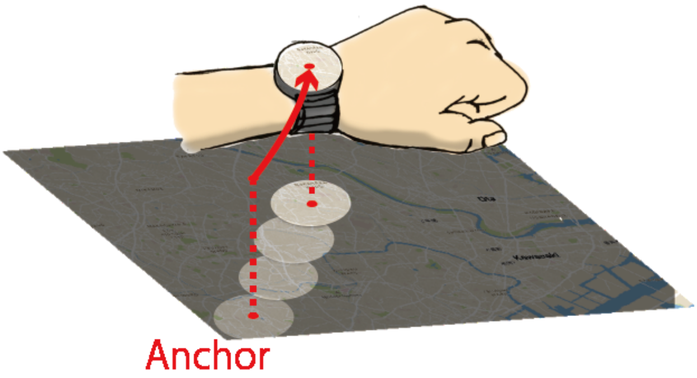

Figure 3.3 Extended Display & Anchor

3.2. Approach

From the concept, an approach was devised to achieve this concept. We believe that the workspace extension should be spatially based relative to the user. For example, when accessing a large virtual workspace, the user defines an initial anchor (the starting point of their exploration) and due to proprioception, this makes it easy for the user to find their way back to their starting point.

Position tracking needs to be used to implement key elements for anchor points and spatial interactions. Realize concepts such as anchor points with technology that can accurately track the position of the device. In addition, making a prototype as a modification of an existing wearable device or smart device, and the expanded Workspace is displayed on the device display. We applied this approach to my concept.

3.3. Application Scenario

3.3.1 AppPin

With this concept, a user can "pin" applications based on the relative position of the smartwatch to their chest. The user can then switch back and forth between applications just by moving his arm again to the same position. In our proposed interaction, an anchor point is always located in front of the user's chest. This point is established when the application is started.

This interaction can be used to check multiple pieces of information, such as when you cannot open your smartphone during an office or meeting.

With this interaction, it is possible to switch between displayed information and applications intuitively. For example, if the user places the anchor point as the clock application, then they move the hand to the left side. The calendar application will display on the left of the clock. Then if the user moves their hand to the right side, the weather forecast can be presented to the right of the clock. Another scenario is that of the user using their arm as a scroll interaction to access scrolling text. This interaction allows for hands-free access to information in some situations, such as holding luggage by both hands. The user can move their arm up and down from the anchor point, making it possible to check a large amount of text. Moreover, the amount of information accessed per the user's swing-motion range can be pre-designed by the user. Establishing such parameters based on movement allows the swing movement to work in much the same way as current scrolling functions.

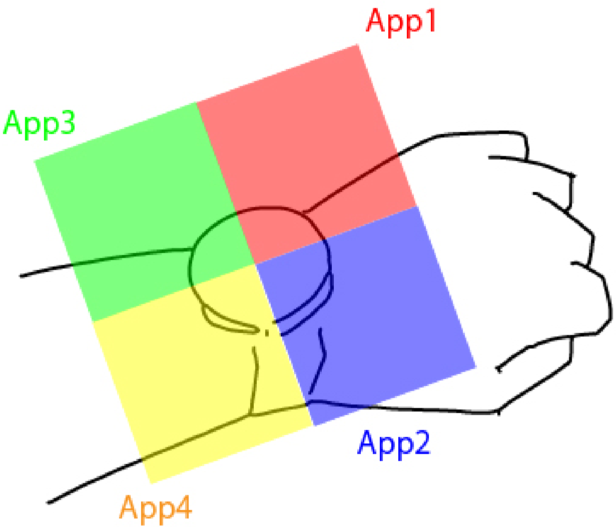

Figure 3.4 Concept of AppPin

Figure 3.5 Concept of MapLense

3.3.2 MapLense

Navigating and reading a map is often an important use case. In this application case, the user can utilize the watch as a kind of lens or digital magnification glass. This magnification function allows the smartwatch to show more detailed information about a place, either giving the user the option to zoom in and out or get a different information overlay (maybe a population heat map or other types of data). This interaction has the advantage that the user can search the map and grasp user's own position when going out, carrying luggage, or in a situation where the smartphone cannot be taken out.

Chapter 4

Implementation

4.1. Pilot Study

As a way to realize the concept and the approach, we devised an interaction method that linearly reflects the physical movement of the smartwatch. Among these methods, we investigated using technology that can track the position of the device, especially the relative position to the user's body. The table below outlines our findings.

IMU	Although possible in principle, there is a problem in terms of tracking accuracy due to the large effects of accumulated errors and drifting.
Motion Tracking	Motion tracking such as OptiTrack [21] can perform tracking with high accuracy, but requires a base station and external equipment.
AR Tracking Feature	Apple's ARKit [22] SDK provides an AR function for smartphones, and also has a function to track the position of the device. However, the area that can be tracked is the relative position from the start of the application.

Table 4.1 Tracking Method

As a result of our survey, there is no dedicated method for tracking the device's relative position from the body, but we decided to try testing with an application using ARKit.

We created a test prototype application(Fig.4.1) using tracking with the Apple ARKit feature and Unity platform. Additionally, we made a case(Fig.4.2) with a wristband to make it possible to attach the iPhone to the wrist.

This prototype was created to verify the position tracking application designed using the ARKit camera and IMU could be used as a wearable device function. Although the function of tracking the position of absolute coordinates in the real world was achieved, the function of tracking the relative position around the user's body could not be achieved.

Figure 4.1 Test Prototype

4.2. Prototype

After testing the tracking and interaction around the body with our Test Prototype, we designed another prototype with a tracking camera on the body and a tracking marker on an actual smartwatch.

In the above-mentioned selection on the tracking method, the size of the equipment was a problem for the motion tracking. However, our solution to this problem was to use an infrared camera (Leap Motion Controller) that can be attached to the body and a small reflective blob attached to the watch that reflects infrared light in the incident direction.

Figure 4.2 Backside of Test Prototype

4.2.1 Hardware

Fig.4.3 and Fig.4.4 show the hardware implementation. And In this system, an Android smartwatch with one infrared tracking blob attached is tracked by Leapmotion device attached to the user's neck. The purpose of this smartwatch is to prepare for development by using AndroidOS driven by a smartphone instead of google's smartwatch OS wearOS. Table4.2 is specification of the smart watch we used.

The reason why Leap Motion is installed at the neck is that at least about 30 x 30 x 30 [cm] of the space in front of the chest is set as an operation area and tracking is possible.

4.2.2 Software

Fig.4.5 shows the system configuration.

In this system, an Android smartwatch with one infrared tracking blob attached is tracked by Leapmotion device attached to the user's neck. We used Leapmo-

Figure 4.3 Smart watch prototype equipped with IR Marker

Figure 4.4 Tracking camera attached to the neck

Name	Kospet Hope
OS	Android 7.1.1
CPU	MTK6739 QuadCore 1.25[GHz]
Display	AMOLED 1.39 [inch] 400 x 400 [px]
RAM	3[GB]
ROM	32[GB]

Table 4.2 Specification of Smart Watch

tion to track the bright pixels from the image obtained from the internal image application programming interface (API) instead of the existing hand tracking function in the watch. The difference from the position of Blob obtained from the image of Leapmotion on Host PC and the position of the Anchor point was calculated. Tracking information can be monitored by using Unity System as middle ware. Fig.4.6 shows a screenshot of the tracked marker blob and infrared camera image. The position of Anchor can be set arbitrarily. And the calculated location information was sent to the smartwatch via user datagram protocol (UDP). The smartwatch then displayed the position and magnification of the Extended Workspace corresponding to the received tracking position information.

Currently, we still need a Leapmotion device on the body for tracking. In future, we believe it will be possible to remove this requirement by implementing inertial motion tracking with a body model and a nine-axis inertial motion sensor. Yet, this is considered part of our future work. For now, we wanted to present an easy to use, and easy to setup platform for prototyping spatial smartwatch interactions as we not interested in product design.

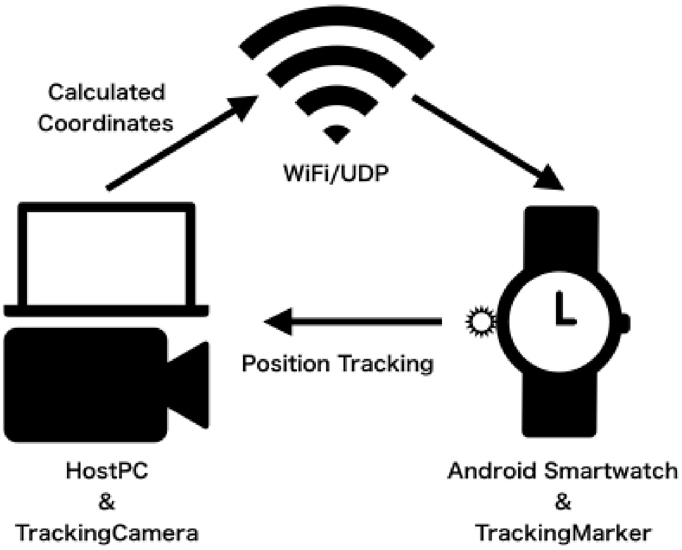

Figure 4.5 Configuration of system

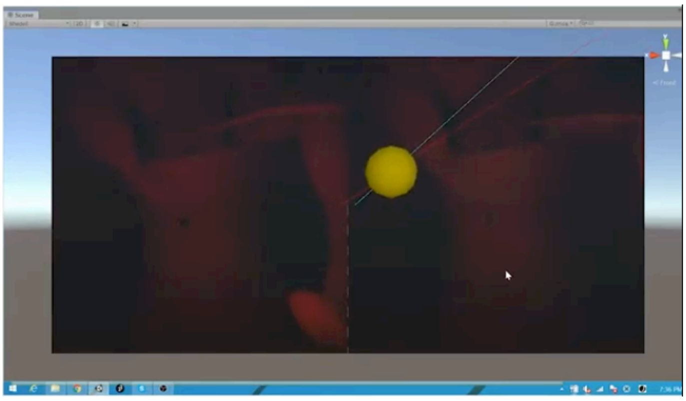

Figure 4.6 Tracking Monitoring in Unity Application

Chapter 5

Evaluation

In this chapter we describe about the experiment we conducted and demonstration at conference.

We demonstrate our prototype and applications(we described at Chapter3) at MobileHCI'2019 conference and KMD Forum. During MobileHCI we had about 50 visitors at our booth, and during kmd forum this system was tried by about 20 people.

Through experiment we investigated how our proposing method is how fast and how intuitive compare to existing wearable device interaction.

From the gathered feedback, positive opinions were obtained from the experiences. On the other hand, there was an opinion that physical demand for the arm was large in long time usage.

Some suggestions included implementing a more continuous UI screen design and creating specific applications with detailed scene settings, such as when riding a bicycle.

Figure 5.1 Demo Booth at MobileHCI'19 Conference

5.1. Feedback from Demonstration

The following summary is feedback from our demonstration.

Positive Feedback

- Easy to Use and get used to.
- Appreciated single hand usage.
- Received the best demo award at MobileHCI'2019.

Negative Feedback

- Physically demanding.
- ”Is detailed operation possible?”

Suggestions

- Continuous UI
- Application for input

5.2. Experiment Setup

In evaluating the interaction with this prototype, we compared it with traditional touch input. In addition, we designed the experiment based on the operation using the tap and tap movement (Swipe), which is estimated to be the most frequently used in smart watch interaction.

Therefore, we implemented the same search task application, performed those tasks with both touch interaction and our proposed method, and compared the completion time and the load due to interaction.

The same task was performed by the two types of interaction methods, and as a result, the time was measured four times each, and the average time was calculated. After the task, A question about load by NASA-TLX [23] was also obtained from participants for each interaction.

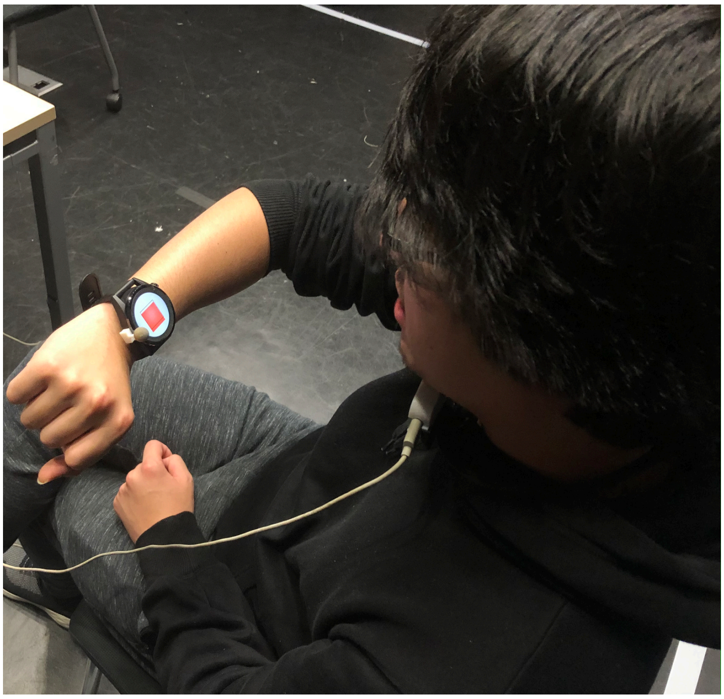

Figure 5.2 Overview of Search Task

5.3. Experiment Procedure

First, the subjects received an explanation of the experiment as an introduction session and spent 5-10 minutes to get used to the interaction. After that, the subject performs a task to match the square frame drawn with the black line on the smart watch with the red square displayed in the position and size of the fixed pattern on the extended workspace.(see Fig.5.4 and Fig.5.3)

One task is to search for red boxes that appear randomly in eight directions from the initial position and match black squares 16 times. This was performed four times for one interaction, and a total of eight completion times were measured.

In the Watch Spaces Prototype task part, participants could adjusted the Anchor Point each time the task started.

The task completion time was compared between the operation method using the relative position with the body by the proposed method and the method of operating the touch display with a finger.

Furthermore, after tasks in each method, subjects were asked to answer NASA-

TLX, and based on answers, the mental and physical demands were compared. NASA-TLX is the most commonly used mental workload evaluation method in UI/UX and task evaluation.

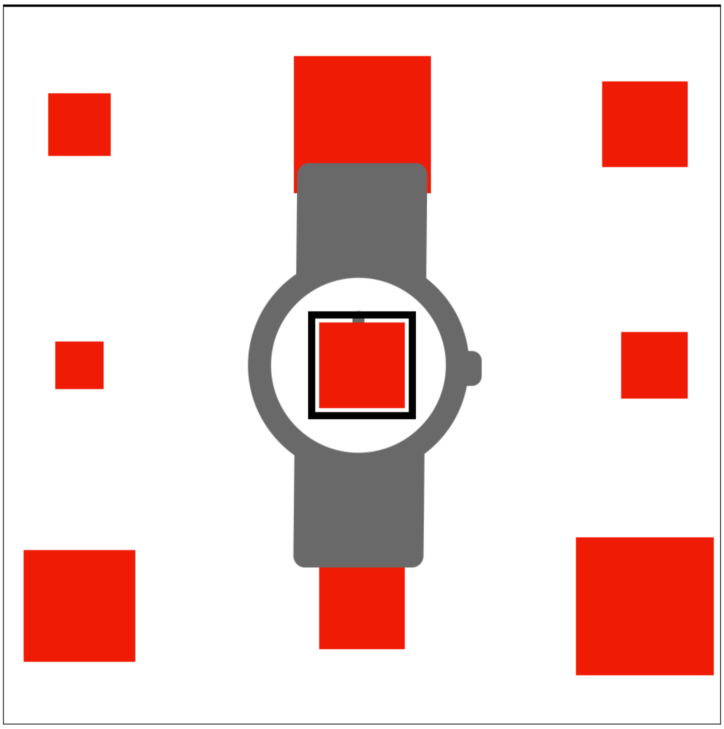

Figure 5.3 Overview of Search Task

5.4. Result and Discussion

In this section, we describe the result of evaluation.

There were 9 participants (Male:5 Female:4 Age:23-32) in this experiment, and we received a total of 72 measurements and 18 answers for questions about task load.

5.4.1 Result

A comparison of the results of task completion time (Fig.5.5) shows that our proposed method can complete the task approximately 12 [sec] earlier. This chart

Figure 5.4 Display while Experiment

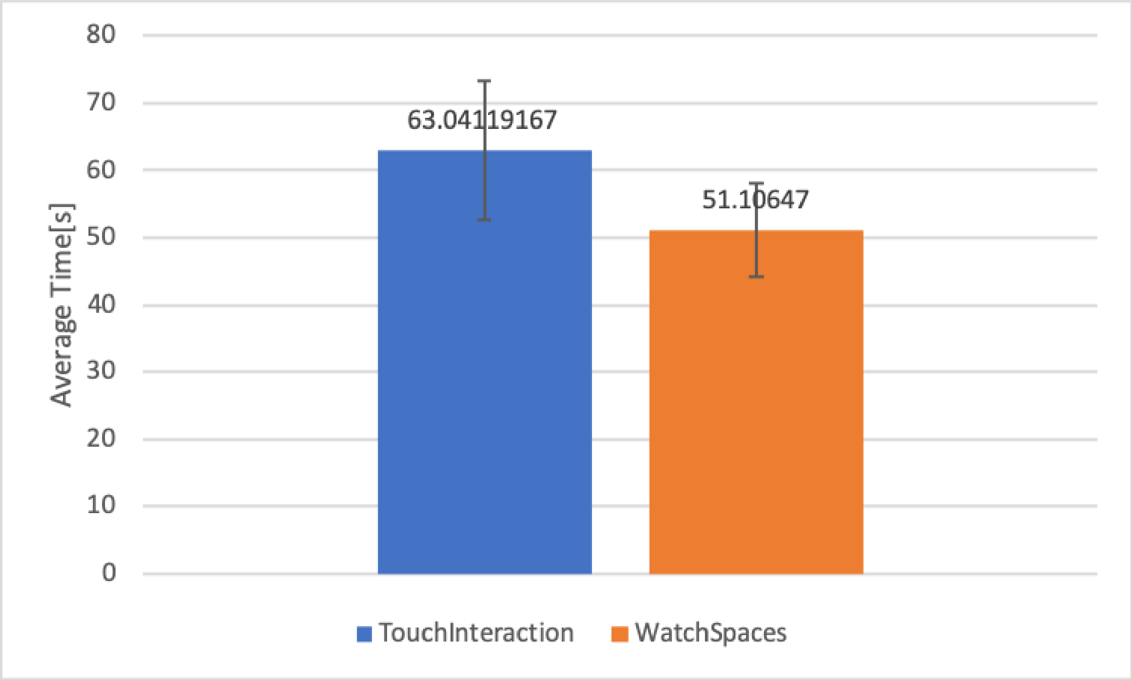

Figure 5.5 Result

shows that my system is much faster even though participants had only 5min of practice. The difference in time for my system and touch interface is statistically significant ($p = 0.0341 < 0.05$). Which is interesting considering that everyone uses touch screen interface everyday, but our approach is new to all users.

Fig.5.6 shows the results of answers to NASA-TLX questions from the participants. As we can see from the graph, our method has about half mental demands and frustration. of traditional touch operation.(Mental Demands:p=0.047619<0.05 Frustration:p=0.000807<0.05). According to the NASA-TLX questionnaires , our Watch Spaces requires significantly less mental demand, effort and is less frustrating. Although the perceived performance differences are not statistically significant , difference is quite large. Also perceived temporal demand was slightly lower for my system.but not low enough to be statically significant.

In addition, the feedback from the demonstration suggested that the system may be more physically demanding, according to this experiment it requires the same physical effort as traditional touch interface. Also perceived temporal demand was slightly lower for my system.but not low enough to be statically significant.

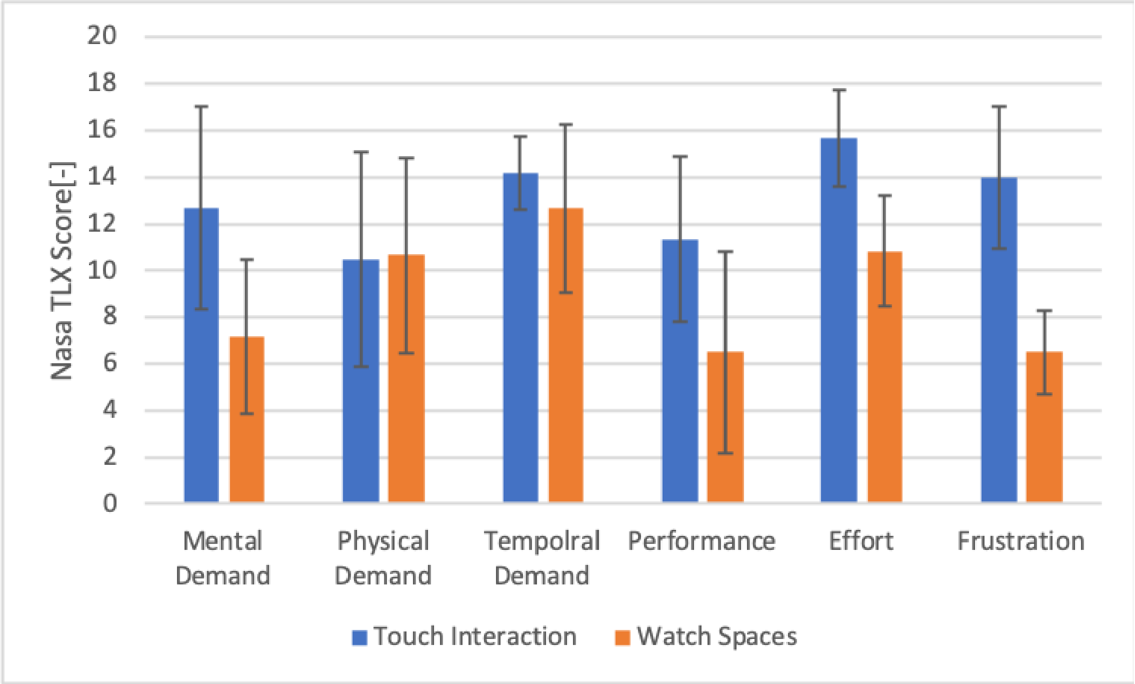

Figure 5.6 Display while Experiment

The results show that daily search tasks with smart watch such as those performed in experiments (for example, applications that search for a destination on a map or require more than one swipe operation) can be executed faster. Furthermore, it was found that the physical load was low, the frustration was low, and high performance could be exhibited.

5.4.2 Discussion

The following is a summary of comments from participants of this experiment.

- ”I felt that the task was a bit difficult.”
- ”Wouldn’t it be faster and easier to combine touch and Watch Spaces interactions?”
- ”Touch interaction can be fine-grained, but is difficult to use for a wide range / a large amount of information such as search tasks. Conversely, I felt that the Watch Spaces interaction was difficult to do small things.”

- ”By moving back to Anchor Point, I can operate without losing my position in the information space.”

During the experiment with touch interaction and during the introduction time, the participants lost their own position in workspace when searching the area and could not perform tasks. However, in experiments with the Watch Spaces prototype, participants could naturally return their arms to Anchor Point and continue their search. Feedback also showed a good response to the operation corresponding to the body and the relative position of the self-position in the virtual extended workspace.

As a result of the observation, during the task with the watch spaces prototype, the operation until the target finding was quick, but thereafter, the operation of adjusting the target to a predetermined position took long time. Furthermore, it is considered that the reason why participants felt that the task was difficult was due to the setting of a threshold (error distance from the target) of the task completion in addition to the difficulty of the detailed operation.

What is more interesting is that the feedback in the demonstration was a concern for the physical load, but as a result, the physical load was the same level compared to the touch interaction that the subject could do daily with a smartphone and the first experience of the Watch Spaces Prototype operation. These results suggest that performance and other physical/mental load changes may occur as the level of proficiency in our method increases.

Chapter 6

Conclusion

In this paper, we described a new method of spatial user interface for smart watches and presented a platform that implemented two prototype applications related to the concept. And we demonstrated the feasibility and effectiveness of this approach.

In chapter 1, we explained the features of smart watches from the evolution of wearable computers.We also discussed the current state of smart watch interaction and explained the structure of thesis.

In chapter 2, we discussed the previous works that we rely on, recent developments of wearable/spatial interaction and human spatial ability.

In chapter 3, we mainly described about the main concept of this research, the process leading up to the development of my first prototypes, the principles and direction of the whole project. Problems with existing smartwatch interactions were identified from the perspective of the goal of wearable devices, and a concept incorporating the Body-stabilized information space concept was presented.In addition, we also provide two proof-of-concept implementations.

In chapter 4, We describe the development of the prototypes. The major contribution is not so much the novelty of the concept, but the prototyping platform that lets developers and researchers explore interactions based on Watch Spaces. Watch Spaces Prototype is a smarter, simpler device that enables spatial interaction with One-hand and a Virtual Extended Display.

In chapter 5, we conducted experiment to evaluate our prototype. We compared touch interaction and Watch Spaces Prototype with search task completion time and NASA-TLX load on users. The result of the experiment showed that completion time of our prototype is much faster than traditional touch based interaction. The difference in completion time for our prototype and touch interface is statistically significant. In addition, our ptototype requires significantly less mental demand, effort and is less frustrating.

6.1. Limitation and Findings

The results of the user studies also showed that our prototype has limitation.

This prototype requires free space to operate in front of the chest. Requires free space meaning it may be hard to use on a crowded train, for example.

It also requires physical movement, which may be a problem for people with physical disabilities.

It is also interesting that the subjects at the time of the experiment were able to use the new interaction fairly quickly. In addition, the task completion time was faster for the first-time interaction than for the touch interaction with which participants are familiar. This shows that the interaction design was quite easy to introduce to users.

6.2. Future Work

The next step is to update the system. Currently, it requires a tracking camera and a separate PC to process that information, and is not yet a practical prototype. Using limited tracking with forward kinematics using multiple IMUs, we believe that the same functionality and interaction can be achieved with a smartwatch device stand-alone.

Development of new applications is also ongoing. We are considering using it in limited scenes and implementing a continuous UI based on feedback.

In addition, this concept focuses on the relative position around the body, but we also want to apply it to interactions that combine with the real world environment, such as AR, and the use of Watch Spaces for communication between wearers.

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