# 유비쿼터스 유저 인터페이스 (UUI) 환경에서 3D 물리 공간으로의 가상 아이콘 매핑 기법

# Mapping Virtual Icons to 3D Physical Space with Ubiquitous Space User Interface (UUI)

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## 요약

휴대용 장치는 폼팩터의 크기 때문에 일반적으로 작은 화면을 가진다. 따라서 휴대용 장치에서 작은 화면으로 GUI를 사용하기가 힘들다. 이 논문에서는 Ubiquitous Space User Interface (UUI)를 제안함으로써 공간 자원을 활용하여 사용자가 휴대용 장치를 효율적이고 쉽게 제어하고 사용할 수 있도록 한다. UUI 환경에서는 휴대용 장치의 작은 GUI 환경을 다양한 물체를 포함하는 3D 물리 공간으로 확장시킨다. 즉, 휴대용 장치의 가상 아이콘이 마치 데스크탑의 바로 가기 아이콘처럼 3D 물리 공간에 매핑이 되는 것이다. 이러한 공간 자원을 활용하기 위해 링 형태의 3D 포인팅 장치가 개발되었다. 따라서 사용자는 작은 화면의 작은 아이콘을 사용하는 대신에 3D 물리 공간의 가상 아이콘을 포인팅 장치를 이용하여 포인팅 함으로써 프로그램을 선택할 수 있게 된다. 또한 사용자는 이를 이용하여 프로그램을 실행 혹은 멈출 수 있게 된다. 우리는 중요한 시스템 파라미터를 추출하기 위하여 다수의 시뮬레이션을 거쳤으며 이를 실제 UUI 시스템에 적용하여 실제로 구현을 하였다.

## Abstract

A mobile device generally has a small display due to its compact form factor. It is definitely inconvenient to use the traditional Graphical User Interface (GUI) with a small display. In this paper, we propose the Ubiquitous Space User Interface (UUI) system which allows people to efficiently and easily control a mobile device using spatial resources. In UUI, the small GUI environment of a mobile device is expanded into the 3D physical space which includes various physical objects. The virtual icon of a program in a mobile device is mapped to 3D physical space as if making a shortcut icon in Desktop. A ring-type 3D pointing device has been developed to manipulate the spatial resources. A user can select a program by pointing to a virtual icon in the physical space with the pointing device instead of clicking a tiny icon on a small touch screen. A



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user can also execute or stop a program with it. We have conducted a sort of simulations in design step to extract important system parameters and used these results to implement the prototype of UUI system.

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Keyword: Ubiquitous interface, virtual icon, spatial resource, pointing device



## 1. Introduction

Recently, the utility of a mobile device is rapidly increased. The functionality of a mobile device also continues to grow so rapidly

that a mobile device can be actively utilized for various operations. Most mobile devices such as a mobile phone, PDA (Personal Digital Assistants), PMP (Portable Multimedia Player), and Ubiquitous Fashionable Computer (UFC) [1] have only a small-sized display and fiddly input devices like touch screens. However, the traditional Graphical User Interface (GUI), which is inefficient for a small display, is still used in mobile devices. Therefore, a new interface which is suitable for mobile computing environment is highly needed.

In order to solve these problems which are difficulties in controlling mobile devices [2], Ubiquitous Space User Interface (UUI) is proposed. Fig. 1 shows the concept of UUI. In UUI, the small GUI environment of a mobile device is expanded into the 3D physical space which includes various physical objects [3] and those abundant spatial resources are used to control a mobile device more easily. We have developed a new 3D pointing device [4] to manipulate the spatial resources. A user maps a shortcut icon of a program (e.g. e-mail client) to any object (e.g a post box to easily memorize where the icon is mapped to) in the physical space using a typical drag-and-drop manner with the 3D pointing device. And then, he can simply select the program by just pointing to the virtual shortcut rather than carefully clicking the tiny icon in the small GUI environment.

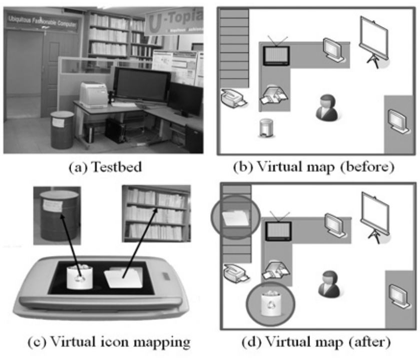



Fig.1. Concept diagram of virtual mapping

In UUI, accurate pointing is a critical operation because virtual icons are widely diffused in the physical space. In order to develop an accurate pointing device, we have conducted a sort of simulations and extracted important system parameters that affect the pointing accuracy. Using the simulation results, we have developed a wearable ring-type pointing device, called i-Throw.

Finally, we have implemented the prototype of UUI system which includes UFC as a mobile device, i-Throw as 3D pointing device, and testbed. Ultra Wide Band (UWB) technology is adopted to track the location of users [9]. Our Virtual Map Manager (VMM) manages virtual icons and the mapping information of the physical space.

The outline of this paper is listed as follows: Section 2 introduces an application scenario of UUI and its components. The design flow of pointing device, i-Throw, is described in section 3. In section 4, we describe our testbed. In section 5, the related works are introduced and the conclusion is given in section 6.

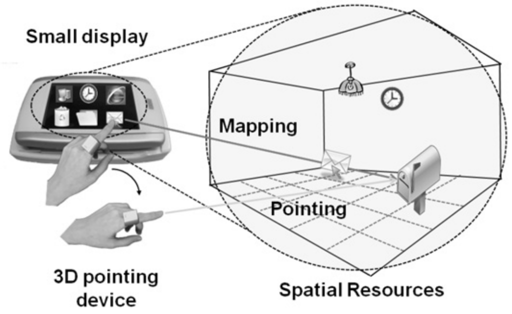



Fig. 2. Concept diagram of Ubiquitous Space User Interface

## 2. Ubiquitous Space User Interface System

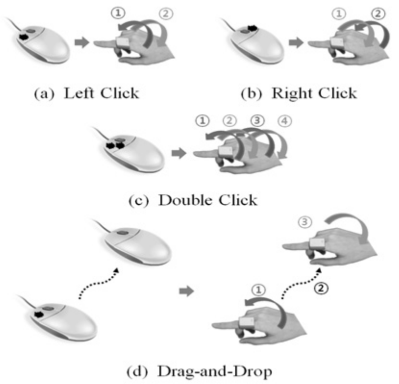
In this section, we provide an application scenario of UUI and explain four components that compose UUI system.

### 2.1 Application Scenario

Fig.2 represents the concept of virtual mapping in UUI. Fig.2(a) shows our testbed which includes several physical objects such as a bookshelf, wastebasket, TV, printer, and so on. The location information of these objects are managed by the Virtual Map Manager (VMM) which has the virtual map of the testbed as shown in Fig.2(b). As described in the previous section, a user can create virtual icons using the 3D pointing device. Fig.2(c) represents one possible mapping of virtual icons to physical objects: ‘Delete’ operation is mapped to the wastebasket and a ‘folder shortcut’ to the bookshelfFig. . Mapping mouse operations to hand gestures with 3D poining device in our testbed. Then the virtual map is updated as shown in Fig.2(d).

After that, we can easily select the folder in our mobile device by pointing to the bookshelf with the 3D pointing device instead of clicking the tiny folder icon on the small touch screen. Like opening the folder by double-clicking the icon in Desktop, we can open the folder by double-clicking the virtual icon with the pointing device. For this purpose, we have mapped various mouse operations such as left/right click, double click and drag-and-drop to hand gestures with the pointing device as shown in Fig.3.

In UUI, virtual icon creation is done by a typical drag-and-drop manner. In order to create a new virtual icon of a program in a mobile device, a user first selects the program by clicking its icon. After that, he takes the drag gesture and point to a physical object which he wants to map to with 3D pointing device. To easily memorize where the virtual icon is mapped to, he usually chooses a physical object that is related to an icon of a program. For example, an e-mail program is




| Mouse Operations | Mapped Gesture |
|---|---|
| (a) Left Click | Tilt hand to right-side and return |
| (b) Right Click | Tilt hand to left-side and return |
| (c) Double Click | Repeat twice of Left Click |
| (d) Drag-and-Drop | Tilt hand to right-side, moving and return |

Fig.3. Mapping mouse operations to hand gestures with 3D poining device

mapped to a post box. After mapping a virtual icon of a program, he doesn't need to click the tiny icon in the small GUI environment any more. He just points to a virtual icon and double click with 3D pointing device in UUI environment.

He can also change the location of a virtual icon to another physical object and delete a virtual icon if he doesn't want to use it any more. Overwriting is also permitted. He can use almost all of operations of GUI in UUI. In UUI, it is more conveniently and easily control a mobile device than that in GUI.

### 2.2 System Components

The overall system of UUI is composed of four components: Mobile Device, 3D Pointing Device, Location Tracking System, and Virtual Map Manager.

• **Mobile Device:** The first component of UUI system is a mobile device such as a mobile phone, PDA, PMP, Ubiquitous Fashionable Computer (UFC), and so on.

• **3D Pointing Device:** It is used to exploit spatial resources. A user can point to any location in the physical space and input simple commands like left/right clickFig. . Ray–based minimum angle selection of the mouse device in GUI. We have developed a ring–type device, called i–Throw. We explain it more detail in following section.

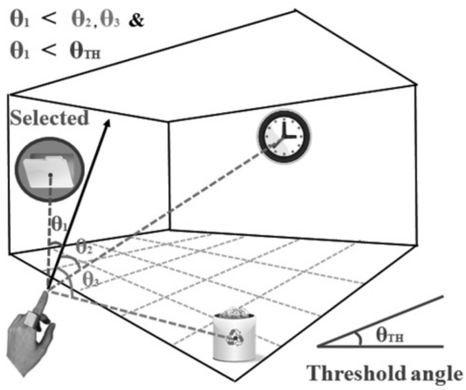



Fig.4. Ray–based minimum angle selection

• **Location Tracking System:** It keeps track of the location of users and physical objects in 3D physical space. This system is essential because the absolute location information of users and physical objects are critical to find the target object that users point to with 3D pointing device. We have utilized a Ultra–Wideband (UWB)–based location tracking system whose typical accuracy is 6 inches (15cm).

• **Virtual Map Manager (VMM):** The role of a VMM is to manage virtual icons and the mapping information of the physical space. It has a virtual map like Fig.2 for this purpose. When a user points to certain location, the VMM automatically finds which virtual icon is mapped to that location.

## 3. Design of 3D Pointing Device

3D pointing device is the main component of UUI system. In this section, we explain the design flow of 3D pointing device.

### 3.1 Selection Technique

In order to design a pointing device, we first have to choose a proper selection technique. We have considered three tasks of selection which are feedback, indication of object, and indication to select. First, we have chosen a graphical feedback because most mobile devices have a screen and it is the most exact and intuitive way. Second, we have chosen a 3D hand

pointing method to indicate target objects. It is the easiest and most intuitive method to use spatial resources and indicate objects. A user points to an object andFig. . Pointing accuracy with a standard deviation ($\sigma$) of a sensor and a location error (loc_err)

object and can verify what he selects with a screen (graphical feedback). After that, a user takes any gestures like Fig.3. Therefore, the method of indication to select is not needed separately. Pointing is both indication of object and indication to select.

We have taken a ray-based minimum angle selection as a naive approach which is described in Fig.4. When a user points to a physical object with 3D pointing device, a ray from a user toward a pointing direction in a virtual map is casted. Then a physical object which is the closest to a ray is

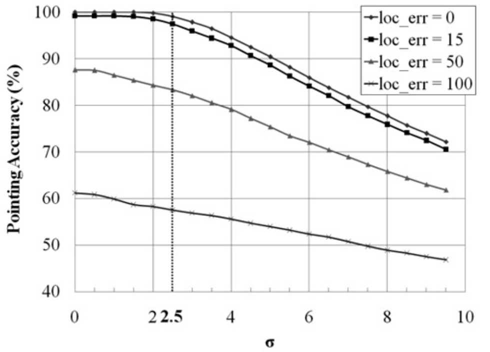



Fig.5. Pointing accuracy with a standard deviation (σ) of a sensor and a location error (loc_err)

selected if an angle between a ray and a selected icon is smaller than $\theta_{TH}$. If a minimum angle is larger than $\theta_{TH}$, no physical object is selected. The reason why $\theta_{TH}$ is needed is that we have to find an empty space or an empty physical object which is not mapped a virtual icon. If not, we can't find an empty space when one virtual icon is mapped in a room.

### 3.2 Requirements

We have to consider the pointing accuracy when developing 3D pointing device. In UUI, it is important to exactly point to physical objects. The pointing accuracy is influenced by the human factors and the device factors. The human factors are the hand trembling and miss alignment but they are not crucial components to change the pointing direction. The device factors are the variation of a value from a sensor and the error of a location tracking system. They are the critical factors to design a pointing device. Therefore, we ignore the hand factors and focus on the device factors when designing a pointing device.

When developing a pointing device, we also have to consider the pointing speed. If we want to increase pointing accuracy, we have to add some devices such as low-pass filters for reducing the

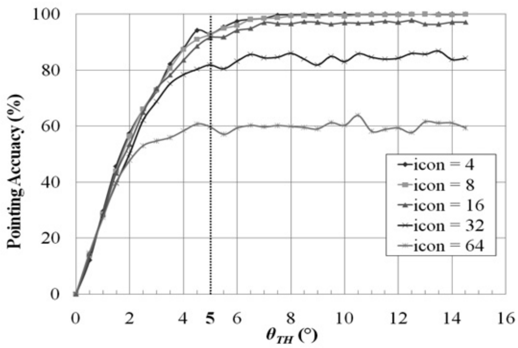



Fig.6. Pointing accuracy with the number of virtual icons and $\theta_{TH}$

error of a value. Because of additional devices, pointing speed decreases. Therefore, it is important to choose appropriate values of various factors for pointing accuracy and pointing speed.

### 3.3 Simulation of Pointing Accuracy

We have conducted a sort of simulations to show a variation of pointing accuracy under various factors which are the standard deviation of a sensor, location error, $\theta_{TH}$, and the number of icons.

First, we have conducted a simulation under a location error as the standard deviation of a sensor rises from 0 to 9.5. Fig.5 shows the pointing accuracy with a location error and a standard deviation. As increasing the standard deviation and the location error, pointing accuracy decreases. Therefore, we have to reduce the standard deviation and the location error. The UWB-based tracking system which we have used has 6 inches (15cm) accuracy. As shown in Fig.5, pointing accuracy is hardly affected by the location error that is 6 inches (15cm). If we only use a Zigbee-based tracking system that has 100cm location error, pointing accuracy will be very low. The standard deviation of a sensor is also a critical factor for pointing accuracy. It is impossible to reduce a standard deviation of a sensor until zero. Therefore, we have to reduce it until an appropriate value. We believe that 2.5 is an appropriate value for a pointing accuracy because it start to decrease at 2.5 when a location error is 6 inches (15cm).

Second, we have also conducted a simulation under the number of virtual icons as $\theta_{TH}$ rises from 0 to 14.5. When conducting this simulation, we have set that the standard deviation is 2.5, the location error is 6 inches (15cm), and the size of a room is 10*10㎡. Fig.6 shows pointing accuracy with the number of icons and $\theta_{TH}$. As increasing the number of icons, pointing accuracy is decreasing because of

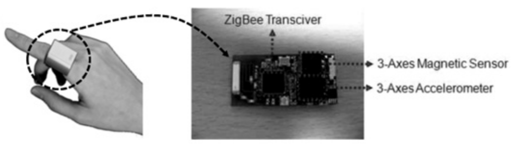



Fig.7. i-Throw Design and Implementation

a short distance between virtual icons. $\theta_{TH}$ also affects pointing accuracy. $\theta_{TH}$ is a selection range of a virtual icon. If it increases, it is easy to point to a target icon because a selection range is increasing. However, if $\theta_{TH}$ is too large, it is hard to find an empty space or an empty physical object which will be mapped a virtual icon. Therefore, it is also important to select an appropriate value of $\theta_{TH}$.

From the simulation, we have shown a variation of pointing accuracy with various factors which are the standard deviation of a sensor, $\theta_{TH}$, location error, and the number of icons. Finally, we have chosen an appropriate value of these parameters. The standard deviation of a sensor is 2.5 and a location error is 6 inches (15cm) which a UWB-based tracking system has. An appropriate value of $\theta_{TH}$ is 5 and less than 20 icons in 10*10㎡ room is an appropriate number. If applying these values of parameters to real system, we will obtain over 90% pointing accuracy.

### 3.4 i-Throw

Using results of simulations, we have developed 3D pointing device, called i-Throw. As shown in Fig.7, i-Throw is a ring-type device for reducing an error of miss alignment. And we have selected a magnetic sensor for determining the direction which we point to because it is less influenced by obstacles and the variation of a sensor value is small compared to Radio Frequency and Infra Red. In order to execute various programs, we have developed i-Throw as a gesture-based system. A gesture-based system is more intuitive and higher usability than other systems such as voice commanding and button-based system.

i-Throw has three-axes accelerometer [10] and a three-axes magneto-resistive sensor [11]. Using them, we can get the direction that we point to. And we have mapped mouse operations such as right click, left click, and drag-and-drop to i-Throw in order to conveniently use UUI like GUI.

## 4. Testbed

We have constructed a testbed to realize the UUI system. Three important components of the testbed are a communication infrastructure, a location-tracking infrastructure, and middleware.

- **Communication infrastructure :** Communication infrastructure lays the groundwork for ubiquitous computing. Two well-known standards are used to support anytime and anywhere wireless communication services; IEEE 802.11 (WLAN) [12] and IEEE 802.15.4 (ZigBee) [13]. We have installed an enough number of ZigBee sensor nodes and WLAN access points in a wide mesh manner. In this environment, communication could be done via multi-hop sensor nodes for low speed data transmission and WLAN for high speed data transmission.

- **Location-tracking infrastructure:** It is necessary for location-based services. The ZigBee sensor nodes are used for location tracking but we have found that the resolution of location sensing using this mechanism was not sufficient for our target application. Thus, we have also utilized a UWB-based location tracking device whose typical accuracy is 6 inches(15cm).

- **Middleware:** We have developed middleware, called μ-ware [5], in order to keep up with highly dynamic environment. μ-ware is composed of light-weight service discovery protocol, distributed information sharing, context manager, instance service loader, and VMM, all of which are useful to manage dynamic data such as mapping information and to develop a new application that utilizes various resources such as spatial resources. This framework, μ -ware, supplies a private computing environment to users as well as enables users to interact with user-centric services from various infrastructure service areas.

## 5. Related Works

To achieve high usability of a mobile device, many research efforts have been performed. Rukzio et al. [6] proposed a framework for the development of systems which takes physical mobile interactions into account. They mean any communication between the entities user, mobile device, and physical objects in the physical world whereby every entity can exist one or more times with it. They have used typical technologies supporting these interactions that

are Radio Frequency Identification (RFID), visual marker recognition, Near Field Communication (NFC), or Bluetooth. They have made mobile interactions with various services, which were inadequate and inflexible in a mobile device for small screens, fiddly keys and joysticks as well as narrow and glutted menus, easier and more convenient. Valkkynen et al. [7] presented a user interaction paradigm for physical browsing and universal remote control. The paradigm is based on three simple actions for selecting objects: pointing, scanning, and touching for choosing tags with readers. Therefore, these paradigms should be supported for any tagging technology. They have provided an optimal support for natural interaction with physical objects. And they can control augmented physical objects with tags and get information from them. All of these previous work, however, used augmented physical objects with tags. Therefore, they can only interact with specified objects that has augmented tags. Compared to the previous work, we can use more abundant spatial resource because physical objects in our work don't need augmented tags for the interaction.

Ailisto et al. [8] analyzed the physical selection which offers a promising method for using mobile device, such as smart phones and digital assistants, as tools for communication between a human and the digitally objects and services in the environment. They have focused on different technologies, which may be used to implement the physical selection paradigm: visual patterns, electromagnetic methods or Infra Red. Visual patterns have very short latency, no power consumption, and no interference hazard, but unidirectional data transfer type and need a camera. Infra Red has bidirectional data transfer type and medium power consumption, but is interfered by obstacles. Electromagnetic (RFID) has unidirectional data transfer type and short latency. In comparison with them, a magnetic sensor has bidirectional data transfer type and a little variation of sensor values, is not interfered by any obstacle, and uses all of physical objects which don't have tags or receivers. Therefore, we have selected a magnetic sensor for pointing to physical objects.

### 6. Conclusion

This paper presents Ubiquitous Space User Interface (UUI) system that allows people to efficiently and easily control a mobile device having a small display and fiddly keys. We have proposed and developed two things to achieve UUI system: Ubiquitous Space User Interface (UUI) and 3D pointing device, called {\em i-Throw}. The concept of UUI is expanding the small GUI environment of a mobile device into 3D physical space which includes various physical objects. Those abundant spatial resources are used to control a mobile device more easily. 3D pointing device in UUI acts as a mouse in Graphical User Interface (GUI). Therefore, it is important for 3D pointing device to exactly point to a virtual icon. In order to develop 3D pointing device with an high pointing accuracy, we have conducted a simulation and extracted important parameters which affect the pointing accuracy. Finally, we have implemented the prototype of UUI system which includes UFC as a mobile device, i-Throw as 3D pointing device, and testbed.

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