

Evaluation of a Universal Interaction and Control Device for use within Multiple Heterogeneous Display Ubiquitous Environments

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Abstract

This paper provides an insight into the usability of our Universal Interaction Controller (UIC), a user interface device designed to support interactions in ubiquitous computing environments equipped with multiple heterogeneous displays. The results are presented of a user study we undertook to test the intuitiveness of Ukey, our UIC input device, comparing it to a wireless gyroscopic mouse, as benchmarked against a traditional mouse. We found that with no training, users were able to perform better with the UIC than with the gyroscopic mouse, but their performance with the traditional mouse exceeded both. With an hour of additional training, participant's performance with the UIC was better than their performance with a traditional mouse when interacting between display devices.

Keywords: Interaction model, ubiquitous computing, interaction device, multiple display environment

1 Introduction

Ubiquitous computing encompasses the concept of computing being woven into the environment of natural human interactions (Weiser 1991). One crucial stride in the move towards these computing environments is a shift from the use of conventional workstations as a principal computing interface, to environmental or workspace interfaces. In these environments the conventional input devices of mice and keyboards will be augmented with more human-centric approaches.

Reproduction for academic, not-for profit purposes permitted provided this text is included. A forte of ubiquitous workspaces is the diversity of display and interaction modalities that they support, which allows the user to select the best suited device for a particular class of application. The UIC project is investigating appropriate interaction devices to control and manipulate information across a large range of display devices, applications and tasks in the context of command and control centres (Slay and Thomas 2003). In particular, this project investigates the use of information visualisation in such environments (Slay, Thomas et al. 2001). The current user

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interface techniques that have been proposed concentrate more on control of the devices in the environment themselves rather than the data stored on them. Users are often forced to use traditional interaction techniques which are not suited for multiple display, collaborative environments.

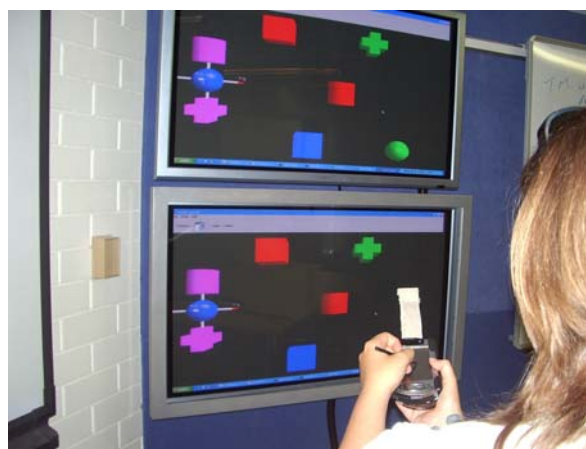


Figure 1 User interacting across displays with UIC

The UIC is our proposed solution, created in particular to support interaction in ubiquitous computing environments. The UIC is intended to allow more intuitive control of data across multiple displays, whilst still being accurate enough to be used on a single display. A significant attribute is that the device is designed to be mobile in the room, and not fixed to a table-top surface. The UIC is a physical device - *Ukey*, an interaction manager, and clipboard manager, which together provide seamless access and control of data across multiple displays. We envision the use of conventional keyboards and table-top mice for typical workstation activities such as word processing, and the UIC provides the user with the ability to manipulate data across multiple heterogeneous displays for activities such as select, copy, and paste. Figure 1 shows a user interacting with the UIC across multiple displays. Using the device, the user points at a display to select it, and then uses their stylus to perform fine grained interaction with the selected display.

This paper presents a user study to compare users' performance operating a wireless gyroscopic mouse, and the Ukey benchmarked against their performance with a traditional mouse. We chose the wireless gyroscopic mouse as it is one of the few commercially available mobile pointing devices. The aim of the study was to show that the combined features of the UIC are superior to the features provided by the wireless gyroscopic mouse when used with a continuous

desktop across multiple heterogeneous displays in a ubiquitous workspace.

2 Related Work

Like other researchers we are investigating interaction techniques and technologies to support ubiquitous computing environments. Project Oxygen at MIT has a focus on combining speech and vision to interact within intelligent spaces to such an extent that they boast of having no keyboards or mice in their environment (Brooks, Coen et al. 1997). Instead they rely on tracking the user's head, eyes and arms along with the capture of speech in the environments to permit users to interact intuitively with the room.

The Gaia project at the University of Illinois aims to create an operating system for physical spaces that are equipped with displays and devices (Román, Hess et al. 2002). To interact in these environments with heterogeneous devices, Gaia applications are required to provide interfaces that can be transformed to suit the requirements of PDAs, laptops and large screen displays.

Stanford's Interactive Room Operating System (iROS) provides another operating system level approach to the design of ubiquitous computing infrastructure (Johanson and Fox 2003) (Johanson, Fox et al. 2002). The main communication mechanism in iROS is the event heap (a tuplespace), a mechanism by which multiple users, machines and applications can all simultaneously interact as consumers and generators of system events. Publishing and subscribing to the tuplespace is sufficient to participate in the room infrastructure while allowing components to remain very loosely coupled. The iROS data heap provides for more long termed storage of data. The data is keyed with an arbitrary number of attributes, and data is retrieved by a query specifying attributes that must be matched. By using attributes instead of locations, the data can be distributed over a number of physical devices.

A number of metaphors have been employed to describe clipboard behaviour for copying information in ubiquitous computing environments. These metaphors fall into one of three predominant categories of assigning information to: physical objects, the user, and walk-up displays. Assigning information to a physical object metaphor exploits user's intuitive understanding of moving physical objects from one physical location to another. The user can easily extend this concept to include moving the "attached" digital information along with the physical object. Rekimoto (Rekimoto 1997) proposes a device based clipboard called Pick-and-Drop that allows users to transfer information from one display device to another by "attaching" it to a pen with a unique pen ID.

Gustafsson suggests a user based clipboard (Gustafsson 1998) where each user is fitted with a smart badge. As well as being used for location awareness and verification of user identity, he proposes that the badges are used as personal clipboards to transfer data between computers. An example of walk-up infrastructure based clipboard is a Large Information Scale Appliance (LISA) (Russell and Sue 2002). Blueboard is a LISA that is an information kiosk with integrated personal identification that allows users to quickly and easily share information on a large screen walk up display. A user logs on to the system by swiping their RFID based smart card past a card reader attached to the bottom of the large screen display.

A personal icon or "p-con" is created for the user and stored in a panel on the right hand side of the screen, showing all users that are currently logged on to the display. Information can be copied from the currently selected user to another logged on user by dragging it onto their p-con. When the user logs off, the information is emailed to them (Russell, Trimble et al. 2002).

Numerous techniques have been proposed to support interaction across displays. A key field that provides similar techniques is augmented reality / virtual reality for selection of objects at a distance. Although similar, these techniques are not included in this discussion as they are more concerned with interaction with the remote object itself rather than controlling the input of a remote machine (Bowman and Hodges 1997). PebbleDraw is a drawing application from Carnegie Mellon (Myers, Stiel et al. 1998) that utilizes techniques for sharing a display between multiple participants. By connecting their PDAs to a shared display, users can either take turns controlling the one shared cursor, or have control of their own cursors. This investigation focused more on one display collaboration rather than controlling multiple displays. A related technique is Semantic Snarfing (Myers et al. 2001) that allows users to create a copy of a portion of a large display onto their PDA. This technique is named after the popular UNIX term *snarf* that describes the action of acquiring a file or set of data across a network. Semantic Snarfing can operate in three modes: screen capture, menu snarfing, and text snarfing.

The XWand (Wilson and Shafer 2003) is a 6DOF wireless pointing device; the novel application of this device is the selection gesture control of physical objects in a user's environment. For example by pointing at a lamp, users can either perform a gesture to turn it on or off, or press the button on the handle of the wand to toggle its state. To employ the XWand, a model of the environment must be created by pointing at each of the devices to be controlled and creating a Gaussian blob with mean and covariance values for each area of interest. As well as allowing users control of devices in their environment, the XWand provides a cursor control function that allows users to take control of the cursor of the display device they are pointing at. Because the XWand is an absolute 6DOF device, to perform fine grained manipulation of the cursor position, the user is forced to hold their arm relatively still for long periods of time, causing them discomfort and muscle fatigue. The XWand device is extended in the WorldCursor (Wilson, and Pham 2003) system that uses a laser spot instead of the geometric model previously used to determine object selection in an environment. This system supports interaction with multiple displays in an environment, but similarly to XWand suffers from arm fatigue, hand jitter and latency introduced by direction detection. The designers of WorldCursor found that a drawback of their system was that control of small displays from a distance was difficult because of the small "mousing surface".

Pointer redirection techniques map discrete displays into a continuous display; a logical mapping between displays describes how screens are connected together. Once the screen topology has been created, the user may move their cursor to the edge of one display, and the cursor and mouse movements are automatically forwarded onto the next logical display. Gaia supports a pointer redirection system called Clicky (Andrews, Sampemane et al. 2004), and iROS uses an application called

PointRight (Johanson, Hutchins et al. 2000). Both Clicky and PointRight provide the similar functionality for their respective environments. However, Clicky and PointRight only provide an intuitive solution for a linear arrangement of displays, where connections between displays may only be specified between edges of physical display devices. Also, a reasonable supposition is for ubiquitous workspaces to be equipped with mobile devices such as laptops that may be moved around the environment, rendering the logical mapping illogical.

3 Universal Interaction Controller

Our ubiquitous workspace is constructed from the LiveSpaces infrastructure, an overarching project that is addressing how physical spaces such as meeting rooms can be augmented with a range of display technologies, personal information appliances, speech and natural language interfaces, interaction devices and contextual sensors to provide for future interactive/intelligent workspaces (Bright 2004). The LiveSpaces software infrastructure has been created to form the basis for integrating, controlling and coordinating activities and technologies within these future workspace environments. The environment is equipped with 6DOF tracking facilities to determine the position and orientation of marked objects in the environment (Slay, Vernik et al. 2003). The LiveSpaces project builds on iROS as one of its primary communication mechanism between distributed components.

The UIC consists of three major components that work together to provide the seamless access and control of data across multiple displays: Interaction Manager, Clipboard Manager and physical UIC device. Each of these components will be discussed further. Figure 2 depicts the UIC architecture in terms of the major software components and how an application is connected to the UIC. The architecture is split into computing device specific components and ubiquitous services for the workspace. Each computing device is able to communicate to the *Event Heap* and *Data Heap* and has a set of applications. The UIC supports the following two major functions for an application: replacing the cursor control with a portable device for multiple heterogeneous displays and clipboards suitable for ubiquitous workspaces.

The following ubiquitous workspace services for cursor control are depicted in Figure 2: Interaction Manager, Ve-World, PDA client, and Track Devices. The *Interaction Manager* has two operations, selecting the display for cursor control and redirecting cursor control. The *Interaction Manager* listens for cursor control commands from the *PDA Client*, along with the selected display from *Ve-World* and posts interactions task to the *Interaction Client* for appropriate computing device. The *PDA client* monitors pen cursor events from the physical PDA that forms the basis of the UIC handheld device and posts these events onto the event heap. *Ve-World* subscribes to pose data of the UIC handheld device from *Track Devices* service. From this pose information, *Ve-World* posts which display the UIC handheld device is pointing at onto the event heap. The *Track Devices* service provides a tracker abstraction for the 6DOF tracking infrastructure of the LiveSpace.

Ve-World is a Java3D based application that is used to both view a dynamically updated representation of a work environment and to monitor for screen selection events. It

receives pose data from the Tracking Device service. When a collision occurs between a virtual ray that extends from the top of the Ukey in the direction that it is pointing and a display, an event is posted on the event heap that records the IP address of the currently selected display device.

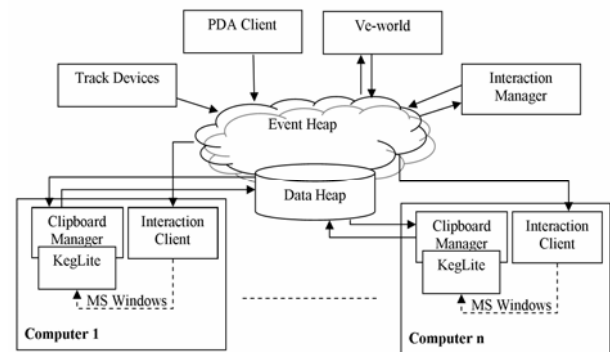


Figure 2. UIC Architecture

4 Ukey – An UIC Handheld Device

The Ukey, Clicky, and PointRight all share the aim of creating a continuous mapping between discrete displays in an environment. Clicky and PointRight create a logical mapping between screen positions and connections between displays, whereas the UIC relies on a physical mapping between the screens. The UIC approach creates an added requirement of a tracked environment, but it is considered a tolerable trade-off for intuitive control of multiple heterogeneous displays.

The XWand takes an approach that can be seen to be a combination of the Clicky / PointRight approach and the UIC approach. Like the UIC, the XWand allows users to select a display by pointing at it. As with Clicky / PointRight, the XWand works on a lower level than the Ukey, being concerned primarily with wand (mouse) movements and button presses instead of the interaction task that is being performed. Also, the XWand is the only device supported by its architecture. The architecture that supports the UIC has been designed to be generic enough to support interaction and control within the environment from a number of different devices, and the UIC handheld device is just one instantiation.

The UIC handheld device is a tracked object that allows users to interact with displays by pointing at them. By 6DOF tracking of the displays, a dynamically updated model can be created, showing the position of displays in the environment (laptops and wall displays) and the Ukey using the Passive Detection Framework (PDF) (Slay, Vernik et al. 2003). Because of current accuracy limitations, this is not a feasible solution. Instead, the Ukey is tracked with a Polhemus tracker which provides far more accurate tracking results over small distances, and the other displays are placed in known locations. The hardware and software aspects of the Ukey will now be discussed separately

4.1 Hardware

The Ukey employs an IPAQ 5450 with a Polhemus sensor mounted on a pointer, 20 cm from the top of the device. The sensor was mounted this distance from the PDA for two main reasons: visual cues to the user of pointing direction and

magnetic interference reduction. The PDA is composed of ferrous components, and it creates magnetic interference to the tracker’s sensor. After brief experimentation, it was found that the sensor was required to be mounted at least 10cm from the PDA to obtain accurate position and orientation data.

4.2 Software

The GUI for the Ukey was implemented in Java for the Crème JVM for Windows Mobile 2003. As shown in Figure 3, the user interface of the UIC consists of two primary containers: the modify container (left image) and the paste container (right image). Both containers are controlled with three buttons and one label that are clearly visible on the interface: *Modify* button, *Paste* button, *Exit* button and the selected display field.

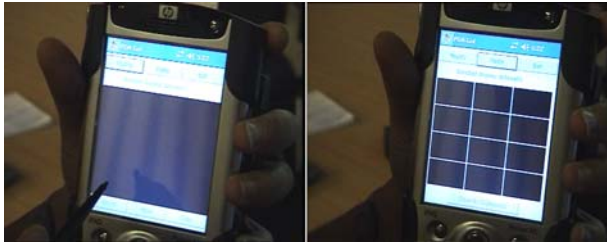


Figure 3: Modify and paste containers of Ukey

The *Modify* button activates the modify container, and the *Paste* button activates the paste container as shown. The *Exit* button closes the application. The selected display field indicates the name of the currently selected display. This information is updated by subscribing to the event heap for all events showing the currently selected display. All pen movements or button presses are automatically sent via the Interaction Manager to the computing device associated with the currently selected display.

The modify container consists of four widgets: pen control area, *Select* button, *Move* button, and *Copy* button. In the pen control area, stylus movements on this area are translated into cursor movement messages being sent to the Interaction Manager. The Interaction Manager then forwards these messages on to the appropriate display, in the form of a path interaction task detailing the relative movements of the stylus over time. When the *Select* button is pressed, a select task message is sent to the Interaction Manager, who then forwards a message to the appropriate Interaction Client telling it to perform the selection task. The *Move* button is a modal button that when pressed once, maps all movements of the users stylus on the pen control area to a movement of the currently selected object on the currently selected display. When pressed a second time, the mode is switched to stop move and all further stylus movements on the pen control area are mapped to movements of the selected display’s cursor. If an object is currently selected, the Interaction Manager sends a path request specifying the new position for the currently selected object. Otherwise the path request refers to the position of the cursor. When the *Copy* button is pressed, the currently selected object on the currently selected display is sent to the clipboard manager and assigned to the Ukey’s clipboard. Finally, a visual representation of the object is added to the paste container.

The paste container consists of 12 clipboard containers and one *Clear all Clipboards* button. The Ukey can be set to use a

device based or a session based clipboard. With the session based clipboard type, any information copied within the workspace can be viewed and pasted using the Ukey. The current implementation of the device only provides 12 clipboard containers. This is not a limit on the total number of objects that can be copied, but the number that can be displayed at one time and is due to the small screen size of the Ukey. When objects are copied, they are consigned to the next empty clipboard container. If all containers are full, the object is placed in the container with the oldest timestamp. To paste an object displayed in a copy container, the user selects a destination display device with an up and down pointing gesture. Once the display is selected, the user taps on the copy container that contains the information to be pasted. Finally, the *Clear all Clipboards* button sets the contents of each of the clipboard containers to be empty, and sets the next available container to the first container.

5 Experiment Design

The goal of our user study is to determine the intuitiveness of a Ukey to support interaction and control of data displayed on heterogeneous devices simultaneously in a multi display environment. In particular we are interested in understanding the effects on the time taken to accomplish the task, the accuracy to which it is completed and the subjective ease of use derived by using this tool. PointRight was used to enable the traditional mouse and the wireless gyroscopic mouse to control devices other than the one that they were physically connected to. The user study sessions were performed at the e-World Laboratory at the University of South Australia. Three front-projected large screen displays and two laptops were used for all tasks within the user study. A diagram showing the top down view of the configuration of the e-world lab is included in Figure 4. The red X in the diagram shows the position users were required to stand in while using the wireless gyroscopic mouse and the Ukey. The red dash shows the position where users were required to sit while using the traditional mouse.

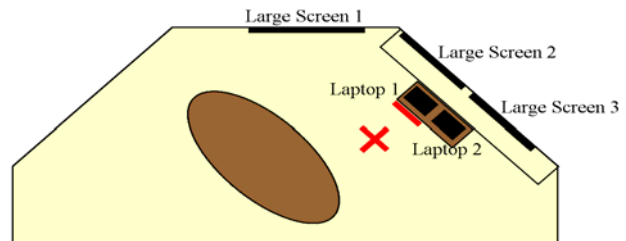


Figure 4: Workspace configuration for user study

KegLite, a minimal version of KegMaster (Slay, Thomas et al. 2003), was the application used in this study, and as such restricted the user’s possible actions that they could perform accidentally. KegLite allows users to move, copy, paste, delete and connect shapes from its workspaces. KegLite was operating on each of the five displays: three wall displays and two laptop displays. Each instance of KegLite shows a standard toolbar with buttons to copy, paste, connect and delete selected nodes. When the study was being run, an additional toolbar was displayed on the left-most display with two additional buttons: start timer and stop timer. These buttons were used so the participant could explicitly specify the beginning and end of each task.

The user study has two phases. The first phase compares users' performance across three devices: traditional mouse, a wireless gyroscopic mouse and the Ukey. A wireless gyroscopic mouse was chosen as we believe this device coupled with cursor redirection (PointRight) comes closest to a commercially available ubiquitous workspace cursor manipulation device. The second phase compares users' performance with traditional mouse and Ukey after receiving additional training on the Ukey.

5.1 Phase One

In phase one, the participants were asked to complete the following four tasks on the three devices: **Task 1.1** *Copy objects by colour*. Move all objects of a particular colour from all displays to the display specified by the observer, with an optimum number of button presses of 32. **Task 1.2** *Copy objects by shape*. Move all objects of a particular shape from all displays to the display specified by the observer, with an optimum number of button presses of 32. **Task 1.3** *Link objects across displays*. Create a link between each object of a particular shape, with an optimum number of button presses of 10. **Task 1.4** *Fine grained manipulation*. Line all objects up in 4x2 rectangle on one display, an optimum number of button presses of 16.

Phase one of the experiment used a 1x2 experiment and was based on a two-group, post-test only, relative comparison, randomized experiment design. Participants were randomly assigned to one of two treatment groups. For each treatment, participants performed each task with the traditional mouse first. This was designed to allow users to learn the task with a device they were familiar with, in order that their subsequent performance with the wireless gyroscopic mouse and the Ukey would not exhibit errors to do with learning the task, but rather with difficulties with the devices themselves. The order in which the remaining devices were presented to the participants was switched between treatment groups in order to show that any improvements in user performance were related to the intuitiveness of the device as opposed to the amount of experience with each device for each task. Because of the strong learning curve involved with using new devices, participants were asked to complete the user study twice within two weeks.

The independent variable in this phase was the order in which devices were presented to the participant. Dependent variables were time taken to complete each task, number of errors produced while completing each task, and participant satisfaction as recorded in a questionnaire.

The hypothesis for phase one is that the UIC would outperform the wireless gyroscopic mouse when interacting in a multiple display environment. The null hypothesis therefore was that users' performance with the UIC would equal their performance with the wireless gyroscopic mouse. This can be expressed as:

H0: Performance with UIC = Performance with wireless gyroscopic mouse

H1: Performance with UIC > Performance with wireless gyroscopic mouse

5.2 Phase Two

Participants in phase two performed two tasks with the traditional mouse and the Ukey. **Task 2.1** was same as from phase one, and **Task 2.2** was a select by number task. Nine objects across five displays had a number attached to them, and the participants selected the objects in ascending order of numbers. The optimum number of button presses to complete this task is 9.

It was expected that with the additional training that is provided in phase two, participants increased familiarity with the Ukey would improve their performance with the device to equal or better their performance with the traditional mouse. Phase two of the experiment follows the two-group post test-only, randomized experiment design. Participants were randomly assigned to one of two treatment groups. In treatment group one, users were required to attend four 15 minute training sessions, and one twenty minute user study in one week. Participants from the second treatment group were only required to attend the twenty minute user study.

The independent variable in phase two is whether the participant was provided with training. As with phase one, the dependent variables were time taken to complete each task, number of errors produced while completing each task and participant satisfaction as recorded in a questionnaire.

The hypothesis for phase two is that with additional experience, the UIC will outperform the traditional mouse when interacting in a multiple display environment. The null hypothesis therefore was that users' performance with UIC would equal their performance with the traditional mouse. This can be expressed as:

H0: Performance with UIC = Performance with traditional mouse

H1: Performance with UIC > Performance with traditional mouse

6 PARTICIPANTS

Ten female and fourteen male participants participated in phase one of the user study. They were randomly assigned to one of the two treatment groups. All participants were computer literate and had at least five years experience using traditional input devices. None of the participants had any previous experience with interaction in ubiquitous computing environments. Four female and six male participants who completed phase one participated in phase two of the user study.

7 PROCEDURE

7.1 Phase One

In the first session, participants were shown an eight minute introductory video demonstrating the use of Ukey, a wireless gyroscopic mouse, and a traditional mouse in a multi display environment. The video demonstrated the basic interactions supported by the devices, and showed a user undertaking all of the four tasks that they were going to be asked to perform. The video ensured participants received equal training for each device. The participants were then given four minutes of free-play to familiarize themselves with the three devices and the four tasks they would be required to perform in the study. At

this point, participants were informed that the study was about to begin and that all of their button presses were going to be logged. After the participant had finished each of the four tasks they were presented with a brief questionnaire to complete. After completing the user study, the participants were given a final questionnaire to complete prior to leaving the room.

In the second session, the participants did not watch the introductory video or have any time to re-familiarize themselves with the three devices, but instead were asked to start the user study straight away. The participants completed the same procedure as the first session from this point onwards.

7.2 Phase Two

Participants from the first treatment group were required to attend the four training sessions. In each of the training sessions, participants were asked to perform the two tasks at least once each with the traditional mouse, and as many times as time permitted with the Ukey. During the training sessions, the observers were instructed not to answer any questions related to the use of either device, but to allow participants to figure out their problems for themselves. After each training session, participants were given a questionnaire for each of the two tasks to complete.

Both treatment groups were required to perform the same tasks in the user study. When they entered the room, the two tasks they would be asked to perform with the traditional mouse and the Ukey were described. Participants were then given four minutes to re-familiarize themselves with the devices. Again, observers were instructed not to answer any question related to the use of either device during the user study. During the study itself, after completing each task, participants were given a questionnaire to complete. At the end of the user study, participants were given a final questionnaire to complete prior to leaving the room.

8 RESULTS

This section reports on the results for phase one and phase two of the user study. To counter the effects of participant's previous experience with traditional input devices, this study does not use time in its raw form. Instead, for each task their performance with the traditional mouse was used as a benchmark for their performance for that particular task. Comparisons were made between the ratio of their performance with the wireless gyroscopic mouse to their performance with the traditional mouse (referred to as gyroscopic mouse ratio), the ratio of their performance with the Ukey to their performance with the traditional mouse (referred to as Ukey ratio), and the ratio of their performance with the traditional mouse to their performance with the traditional mouse (referred to as traditional mouse ratio). This will always equal one but is used as a benchmark for comparison between devices). In mathematical notation, these three ratios can be expressed in the following equations:

$$GyroRate = \frac{GyroTime}{MouseTime} \quad UICRatio = \frac{UICTime}{MouseTime} \quad MouseRatio = \frac{MouseTime}{MouseTime}$$

8.1 Phase One

Results are presented in this section for the three factors of interest: time taken, errors produced and participant

satisfaction. For time taken and errors produced, a one-way ANOVA was performed between treatment groups one and two to determine if the user study design had an effect on user's performance. For both factors of interest, the p-values were far above the significance level of $p < 0.05$. This shows that there was no statistically significant difference between the two groups.

8.1.1 Time taken

Paired t-tests with assumed equal variance were performed to determine if there was a statistically significant difference between the time taken to perform each task with the wireless gyroscopic mouse and the Ukey for each of the treatment groups. The results of these tests found that for all tasks except for fine grained manipulation, there was a statistically significant difference ($p < 0.001$) between the user's performances, with user's performing tasks faster with the UIC than the wireless gyroscopic mouse. For the fine grained manipulation task, the results showed no statistically significant difference.

8.1.2 Errors produced

Paired t-tests with assumed equal variance were performed to determine if there was a statistically significant difference between the number of errors made with the UIC and the wireless gyroscopic mouse. The results of these tests showed that for all tasks, there was a statistically significant difference ($p < 0.001$) between the number of errors made with the wireless gyroscopic mouse and the Ukey. Regardless of whether interacting in a single display or a multi display environment, users performed with more errors with the wireless gyroscopic mouse than with the Ukey.

8.1.3 Participant satisfaction

A one-way ANOVA was performed between treatment groups for each of the questions asked across all of the questionnaires. The results showed that for each question, there was no statistically significant differences between the responses provided by participants across the two treatment groups. All data to be presented when discussing this factor is therefore presented across both treatment groups one and two.

In the questionnaires that participants were asked to complete, each of the four tasks were separated into sub-tasks, each of which they were asked to rank on a scale of 1 (hard) to 7 (easy). Paired t-tests with assumed equal variance were performed on the rankings for each of the sub-tasks for the wireless gyroscopic mouse and the Ukey respectively. For both of the copying tasks, there is a statistically significant difference between participants rankings with a preference towards using the Ukey to the wireless gyroscopic mouse for all of the sub tasks except for deleting objects in Task 2: Copy by shape, with $p < 0.001$ for the former group and $p < 0.05$ for the latter task. For the paste from clipboard sub-task in both Task 1 and Task 2, there is a statistically significant preference for the UIC. In the first three tasks, users ranked selecting objects with a Ukey quite highly on their scales. For fine grained manipulation, there was no statistically significant difference between the UIC and the wireless gyroscopic mouse.

8.2 Phase Two

Results are presented for three factors of interest: time taken, errors produced and participant satisfaction.

8.2.1 Time Taken

Figure 5 shows the mean Ukey ratio for each of the tasks over each session (T1 – Treatment group one and T2 – Treatment group two). The red line shows the traditional mouse ratio. If the bars are below the red line, this indicates faster performance with the Ukey than with the traditional mouse and vice versa.

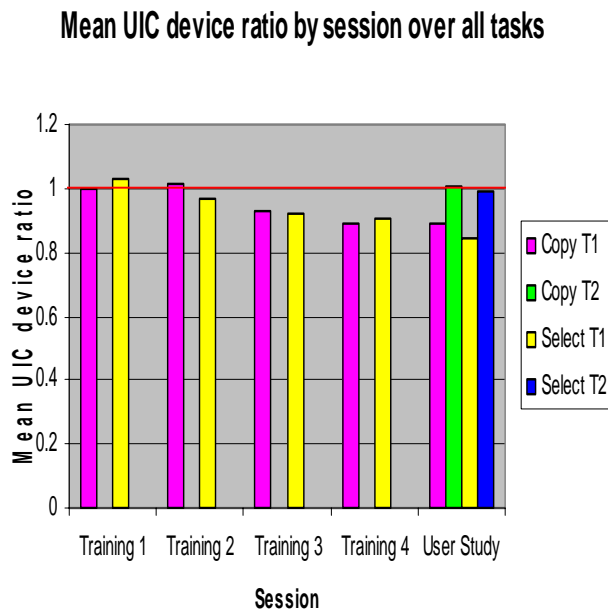


Figure 5: Mean Ukey ratio for phase two

Paired t-tests with assumed equal variance were performed over the following groups: between treatment groups and over treatment group one. A t-test was not performed over treatment group two because of the small sample size. The t-test between treatment groups shows that there is a statistically significant difference ($p < 0.001$) between user's performance for both tasks when one group had undergone training and one group had not. The t-test results over treatment group one shows that after one hour of experience with the Ukey, there is statistically significant difference ($p < 0.001$) of a user performing both tasks as good or better with the Ukey than with the traditional mouse.

8.2.2 Errors produced

In phase two of the user study, users performed accurately across both devices and both tasks. Under all conditions in treatment group two, the mean errors as compared to the optimal number of button presses for each task was under 1%. In treatment group one, all but one participant performed as accurately as this over all conditions, with the outlier performing at 4% accuracy with the traditional mouse.

Paired t-tests with assumed equal variance were performed over the same groups as with the analysis for time taken. The between group results show a statistically significant difference ($p < 0.002$ for copy, $p < 0.001$ for select) between the number of errors made with the Ukey to the number made with the traditional mouse, with the user performing more

accurately with the Ukey. Also, the treatment group one comparison showed that there was a statistically significant difference ($p < 0.001$) between user's performance with Ukey and traditional mouse after users had one hour of training with the devices, with users creating fewer errors with the Ukey.

8.2.3 Participant satisfaction

A one-way ANOVA was performed between treatment groups for each question asked across all questionnaires. The results showed that for each question, there were no statistically significant differences between the responses provided by participants across the two treatment groups. All data is therefore presented across both treatment groups one and two. In the questionnaires participants were asked to complete, each task was divided into sub-tasks and they were asked to rank their difficulty on a scale of 1 (hard) to 7 (easy). Paired t-tests with assumed equal variance were performed on the rankings for each of the sub-tasks for the traditional mouse and the Ukey respectively.

We found it statistically significant ($p < 0.001$) difference between user's ranking of copying and pasting with the UIC and traditional mouse showing a preference for the UIC. All but one of the other subtasks becomes statistically significant when p is relaxed and increased to $p < 0.05$. With this value, deleting object and navigating from one display to another become statistically significant, depicting a higher ranking for the Ukey than for the traditional mouse.

9 Analysis and Discussion

In phase one of the study, it was expected that the Ukey would outperform (in speed and accuracy) the wireless gyroscopic mouse in all but one task, Task 1.4: Fine grained manipulation. Task 1.4 was included in the user study to determine the limitations of the Ukey. This was because the Ukey was designed primarily for interaction across multiple displays, and we theorised the indirect nature of the cursor manipulation would be difficult for users. It was also expected that users' performance with the traditional mouse would surpass their performance with the other two devices in phase one because of their previous experience with the device.

The results of the study were as expected, with users performing faster, more accurately and with more satisfaction with the Ukey than with the wireless gyroscopic mouse when undertaking coarse grained manipulation across multiple displays (Tasks 1.1 – 1.3). For the fine grained manipulation task (Task 1.4), users performed slower, but surprisingly more accurately with the Ukey than with the wireless gyroscopic mouse. In a previous study by MacKenzie and Jusoh, they showed that users were 40% slower and made 12.5% more errors with a wired gyroscopic mouse than with a traditional mouse for fine grained selection of objects on one display (MacKenzie and Jusoh 2001). This supports our findings that user's performed better with a traditional mouse than a wireless gyroscopic mouse.

In the second phase, the two tasks participants were asked to perform can both be classified as coarse grained tasks with components of fine grained manipulation involved in them. Both tasks involved users navigating to a screen in a multi display environment, but when there they were required to select particular objects on the display. After selecting the

objects they were required to perform various operations on the objects, and then navigate to a new screen. This is the type of task that it is envisioned the Ukey being used for in multi display environments: a mixture of fine and coarse grained interactions. After undergoing one hour of training, there was a positive effect on users' performance with the Ukey. Over all tasks, the amount of time users took to complete the tasks with the Ukey was less than that taken with the traditional mouse. Participants were able to complete the tasks more accurately with the Ukey than with the traditional mouse, and also ranked it higher across all tasks than the traditional mouse. As the graph in Figure 5 shows, the UIC ratio does not reach a particular value and flatten out for each task, we predict user performance improve over what we have measured.

In general, the participants were quick to understand how to use the Ukey within the ubiquitous computing environment. Several stated that it took two or three minutes to adjust their mental model of interaction from that with a single computer to an environment with multiple computers, but when they had, they said they had a sense of satisfaction and power to be able to both (a) select the display that they wished to interact with by pointing at it, and (b) have different clipboards attached to different devices and applications in one environment. They reported that the Ukey made interaction with ubiquitous computing environments seem effortless, especially in comparison to the traditional mouse. In particular they stated that they enjoyed the fact that when using the Ukey, they did not need to traverse through a specific path to navigate between displays as is required with the traditional mouse and the wireless gyroscopic mouse. They went further to say that they felt the Ukey allowed them to interact naturally, without the restrictions of movement they felt with the traditional mouse and the wireless gyroscopic mouse. Another point made by participants was that they liked that the Ukey was not a dedicated piece of hardware, but a PDA with a slightly large case. They commented on the fact that people could use their PDA as usual, and when they wanted to interact with multiple displays, slot it into the special Ukey case.

10 Conclusion

The Ukey was designed to allow for intuitive gross movements in a multi display environment. For tasks such as navigating between displays, the Ukey allows users to point at the device they wish to control instead of having to navigate through a specified path to get to it. More fine grained interaction tasks like movement of objects within one display device are possible with the Ukey, but the performance benefits are diminished as compared with its use across multiple displays. With a little training, users can perform better with the Ukey than with the traditional mouse.

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12 References

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