Using Handheld Devices for Mobile Interaction with Displays in Home Environments

Andreas Lorenz[1], Clara Fernandez De Castro[1], Enrico Rukzio[2]
[1] Fraunhofer Institute for Applied Information Technology, St. Augustin, Germany,
Andreas.Lorenz@fit.fraunhofer.de ; cfdzcastro@gmail.com
[2] Computing Department, Lancaster University, UK, rukzio@comp.lancs.ac.uk

ABSTRACT
An increasing number of households are equipped with a large number of TV sets and more and more of them are large high-resolution displays. Furthermore, we see the integration of web browsing and email functionalities in these devices, which are then often controlled via a wireless mouse and keyboard. The latter were rather designed for the usage on a desk, rather then by a person sitting on their sofa in a living room. Therefore, this paper investigates the usage of a PDA, as a replacement which can be used for controlling a remote cursor and for text input. The results of the experimental comparison of these input devices show, as expected, the superiority of mouse and keyboard (as the study participants were very experienced with them). Surprising results were the task completion time and usability satisfaction when using the mobile device. These results show the applicability of using a mobile device for controlling an application on a remote screen. Using a mobile device provides the advantages that every person can e.g. use their own mobile phone or that these devices can be used in multi-user scenarios.

Categories and Subject Descriptors
H H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Input devices and strategies; Prototyping.* H.1.2 [**Models and Principles**]: User/Machine Systems – *Human Factors.*

General Terms
Human Factors, Performance, Design, Experimentation.

Keywords
Interaction with handheld devices, mobile interaction with displays, remote interaction in home environments.

1. INTRODUCTION
We currently see the emergence of more and more displays and wireless Internet connections in normal households that enable family members to access the Internet at anytime and at low costs. So far, this has predominately involved the usage of a fixed desktop PC which is increasingly becoming replaced with portable laptops. A disadvantage of the latter is that they are still very technical devices which are not really suitable for a living room or kitchen. Furthermore, laptop displays are often optimized for low power consumption, and consequently, their brightness and the angle of view is limited.

MobileHCI'09, September 15 - 18, 2009, Bonn, Germany.
ACM 978-1-60558-281-8.

Moreover, we see the trend that the number of displays or TV sets per household is increasing and sales of more large high-resolution displays have significantly increased. Furthermore, some already provide functionalities for accessing the Internet and it is predicted that these additional functionalities will become more popular in the future. One drawback is that these devices provide usually only a remote control which is not designed for controlling a remote cursor or for typing in text. This is needed when considering tasks like web browsing, chatting or writing emails. When thinking about home multimedia and Internet systems, they often provide a mouse and a keyboard, which were rather designed for the usage on a desk as opposed to users sitting on their sofa in a living room.

Especially in home environments is the usability of the interaction between users and computer systems of crucial importance. In this particular setting, designers of computer systems must ensure usability of user interfaces, take care of comfort of the user, and enable ad-hoc data transmission between remote devices and home services. The remote interaction device therefore needs to have some specific attributes:

- The device is not associated with a fixed location.
- The device is equipped with communication capabilities for local-area networking (Bluetooth, infrared, or wireless network).
- The device offers powerful components available for user-device interaction.
- The device is popular to customers and its operating is quite common to a large community.

This paper investigates whether a mobile device, such as a mobile phone or PDA, could be used instead of a mouse and keyboard. The advantages of these devices are that most users are familiar with them and that they provide means for text input and controlling a cursor. The application has been specially designed for home environments, where we have envisioned users to perform multimedia tasks without being restricted by their location.

For our work, we selected a commercial variant of a handheld device with touch-sensitive display. We developed a local user interface in Java ME which receives mouse and keyboard data from the user. The data is transmitted to the home-PC that is connected with a large high-resolution display. While the user is sitting on the couch interacting with internet and multi-media services, we compared the use of two different interaction styles employing the handheld device with the use of wireless mouse and keyboard in the traditional way.

The presented research focuses on two different scenarios: web browsing and writing an email using a remote display. Through this it was analyzed how effective a mobile device is when controlling a remote cursor and when using it for text input when compared with a conventional keyboard and mouse setting. Two different input modes using the mobile device were analyzed: a combination of virtual keyboard and stylus, and the usage of the built-in joystick and the keypad. Performance was measured in terms of user acceptance, task completion time, error rate and usability satisfaction.

After setting the background and describing the implementation phase, we will show the results of a study evaluating the use of handheld devices to overcome the problem of carrying (wireless) mouse and keyboard when interacting with remote services in home environments

2. RELATED WORK

In home environments, the selection of items can be sufficient if the state of the device is just alternated, for example to switch a device on or off; for non-binary states it is not sufficient. The zoo of remote controls indicates high relevance of remotely expressing specific input to environmental devices. Excluding mouse and keyboard input of a PC, the type of remote input can be categorized with rapidly decreasing percentage of use:

1. Action events like On/Off, Up/Down, Play/Stop. Such control commands are present at almost all remote controls.
2. Numbers and short texts, for example to operate the phone, switch TV channels, name movie recordings on a DVD Recorder, or short message service.
3. Almost no usage of longer text and pointer controls.

In our work we will analyze if smarter devices are usable to perform smarter tasks in home environments. Because of the usual distance to the object, the application of wired mouse and keyboard in home environments is not possible. As an expected outcome of our work, we will show that carrying a wireless mouse and keyboard is not a desirable option either.

Many studies in smart home environments have proved that users can easily interact with their context using handheld devices. Nichols [14] presented positive results after performing an exhaustive study of the efficiency of users using handheld devices to remotely control a stereo and a telephone/digital answering machine. Some authors introduce the mobile phone as the user's favorite device for remote controlling [13]. Others have already presented software solutions for PDAs that simulate a remote control, certifying that from the user's point of view the handheld interfaces are easier and clearer to use than remote controls or complex buttons panels [18]. A survey of different interaction techniques that use mobile phones as input devices to ubiquitous computing environments is available in [4].

Already in 1999 Eustice et al. detailed the requirements that a wearable device must meet in order to become a portal into the user context such as input and output mechanisms, local data storage and network communication [6]. As a conclusion, any wearable device with the minimum functionality could act as remote control for all appliances. They already envisioned that users should have the freedom to select from a wide range of devices depending on the situation or preference.

Sweep [5] lets users move a camera-phone along the desired direction of the cursor motion. By comparing consecutive frames of the camera, it offers indirect control of the cursor position. Direct Pointer [8] allows direct manipulation of the cursor with continuous visual feedback, closely resembling the laser pointer. It enables to use cameras equipped on handheld devices, such as mobile phones and Personal Digital Assistant (PDA). It captures a view of the screen with the handheld camera. If the cursor is identified at a different location in the frame, its position should be updated so that it will move back to the center of the camera frame. The primary advantage of this technique is that it only requires equipment that is readily available: an electronic display, a handheld digital camera, and a connection between the two. Comparable systems use a pre-calibrated, fixed camera to visually track the bright dot on the display [15][17]. Head-tracker solutions like [10] are designed to work with gestures for replacing traditional pointing devices. Using a webcam, it allows users to point and click by simply aiming their face.

All these systems have the advantages of natural interaction and immediate feedback. Depending on the depth of objects in the camera images, short-distance motions may generate different distances for the cursor to move, making control difficult. Additional effort is required for the implementation of key strokes and text input. A combination of pointer position and keystroke input device is described in [2], using miniature video cameras that track finger position where the user can type or point in the air.

Iftode et al. [7] identified the need for a simple, universal solution to control different applications in the environment of the user, which end-users are likely to accept easily. The remote device should be programmable and support dynamic software extension for interaction with additional embedded services.

For controlling the service, many approaches allow users to design their own remote control by creating new graphical interfaces that are downloaded to the remote device after compilation. Beside these haptic input capabilities, it is also possible to use speech recorded by a mobile device to control a remote system. Using e.g. the Personal Universal Controller (PUC) as described in [13], users are able to select from different interaction styles and devices, such as GUI on a handheld device, and interactive Braille or headset that supports speech recognition. The PUC communicates with the appliance to be controlled, downloads a specification of its functions, and generates a remote-control interface. The focus here is on automatic creation of the user interface from a service description language.

The research in projects like IBM's "Universal Information Appliance" (UIA, [6]) or XWeb [16] results in the definition of a set of incompatible description languages like MoDAL (an XML-based language used by UIA) and UIML [1]. These were frequently referred to as "model-based", where the programmer provides a specification (model) of the application, the display, and the user.

The iStuff Mobile architecture [2] is a platform combining (physical) sensor enhanced mobile phones and interactive spaces. The platform uses an Event-Heap [9] for distributing iStuff-Events of a specific type with specific fields. The mobile phone is then capable of sensing (local) user activity (e.g. key pressed) that is posted as events on the heap.

3. IMPLEMENTATION OF THE PROTOTYPE

This section describes the implementation of a web service based approach for integrating the mouse and keyboard events from any mobile device into the local system queue on the service host. During the implementation phase of the prototype, we defined the challenges to be achieved, which are mainly in three areas:

Adaptable and portable client user interface: Clients can have variations in display and support different interface paradigms, such as touch, pen, or keypad.

Communication middleware: A client-server model that must provide fast communication and efficient synchronization between the handheld and the remote device.

Input-event driver: Design and implement a driver that handles the user input addressed to windows-based applications.

3.1 Device Requirements

The prototype consists of distributed components. The components must meet three essential requirements: (1) maximal portability, (2) wireless communication, and (3) fast network communication.

From a hardware perspective, the prototype is distributed into two devices: a handheld device (client) and a remote device embedded in the environment (application host). The minimum required functions for a handheld device to work with the prototype are:

1. A mechanism to receive input from the user, such as a touch screen, buttons, or a keypad
2. A mechanism to render output to the user, such as a display
3. Wireless support of network communication for data exchange.

The requirements (2) and (3) do also concern the remote application host.

3.2 System Architecture

The prototype serves as a user's portal into the windows-based application domain. It has been built in a client/server framework and is component-based.

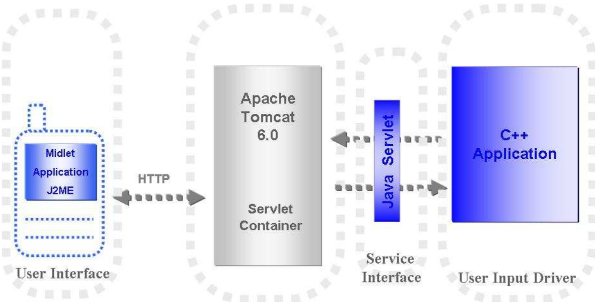

Figure 1. System architecture.

Figure 1 illustrates the system architecture. Addressing the requirements previously stated and from a software perspective, the prototype requires four major components.

A handheld application that builds the client user interface, collects the input events, and communicates with the service interface. This application consists of a Java program for mobile devices, suitable for the Java ME platform for small, resource-limited, wireless-connected mobile information devices (MIDlet) and a Java module that manages a communication across HyperText Transfer Protocol (HTTP) with the remote device.

A **service interface application,** which acts as a middleware communicator between the handheld application and the user input driver. Basically, the application receives a request from the client, forwards the request to the user input driver, monitors the driver for any meaningful events, and generates a response for the client. To implement this module we have developed a Java servlet.

A **servlet container**, currently available at the time of the implementation, is responsible of the communication between the handheld application and the service interface.

A **user input driver**, a C++ application that sends the input event to the windows-application on the PC and waits for any change in the state of the system.

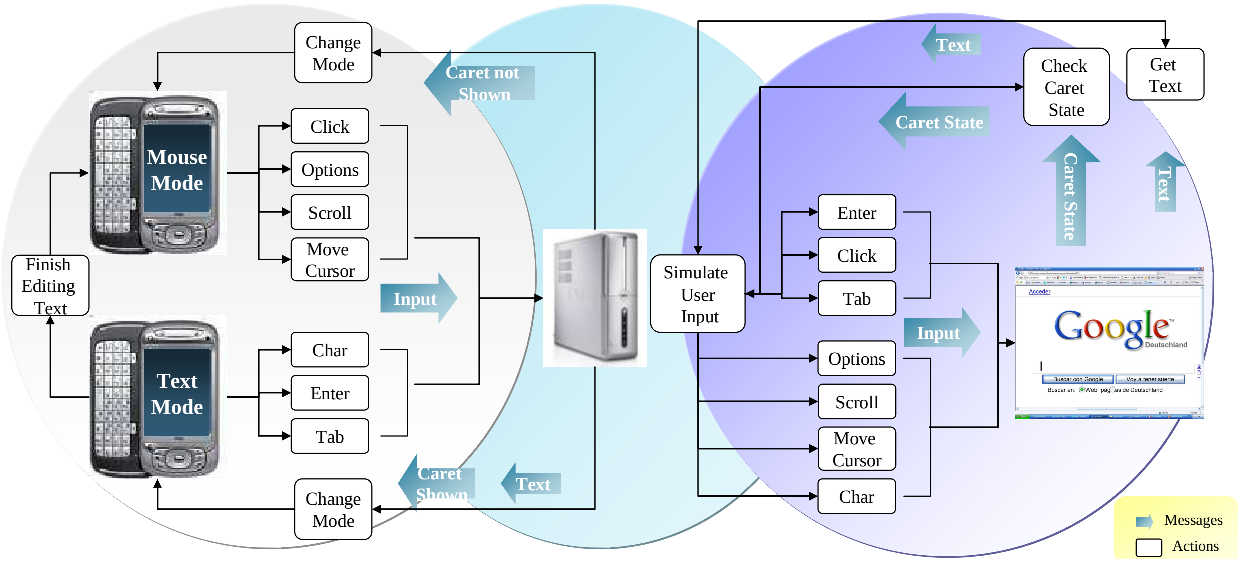

Figure 2. Event flow in the system

3.3 Event Flow / Behavior of the System

The basic flow of events starts with the *user interface* collecting user input events from the handheld device. Input events are sent to the *service interface*, which has two main functions: command the *user input driver* to simulate the input events, and send feedback on the windows-based application to the handheld device. The overall information flow in the system is illustrated in Figure 2.

The basic functionality needed to control windows-based applications is grouped into two categories: mouse events (clicking, scrolling, and moving the cursor) and keyboard events (entering text and pressing enter or tab).

Accordingly, our handheld application implements two different modes to enable the two categories of input events: the mouse mode for handling mouse events, and the text mode for handling text events. Transitions between modes depend on the event triggered and the feedback sent back to the handheld application.

There are three input events that can potentially change the mode of the handheld application: click, enter, and tab. After the corresponding input event messages have been sent to the windows-based application, the user input driver verifies the state of the system caret. The user input driver will first search for the caret on the active windows-application running on the foreground. If the caret is active, the handheld application will switch to text mode enabling text input and editing. If the active text box already contains text, the state of the caret will be sent to the handheld application along with the text appearing inside the text box so that the user can edit it. From the text mode, the application can be directly switched to mouse mode at any time.

3.4 Web-Service Implementation: The Service Interface

3.4.1 *The Servlet*

The service interface is actually a servlet application that handles requests from the client (the handheld application) sent across HTTP and forms the corresponding responses. We chose Java servlets technology over the Common Gateway Interface (CGI) programming because servlets are more efficient (there is only one copy of the servlet loaded into memory and a new thread is created for every new request), easier to use, more powerful (they can communicate directly with the Web server), and more portable (as they are written in Java).

The handheld application initiates an HTTP client request containing predefined parameters that describe the input event. Those parameters are represented by a value indicating the type of event, the character inserted, and the x-y movement of the cursor. The servlet reads the parameters from the HTTP request and calls the user input driver, responsible of inserting input events into the system input streams. Because small response time and minimum transit delay are crucial requirements, the servlet waits for the driver's feedback on the state of the caret only when the input events simulated in the system could provoke a change in the handheld application mode. The servlet's response to the client is a simple string that indicates the state of the caret, or text if the simulated event was a click-action inside a text area that contained text already.

3.4.2 *The User Input Driver*

We have developed a C++ application that uses the Microsoft Windows XP Software Development Kit (SDK) to insert events serially into the keyboard or mouse input stream, withdraw the system's caret state, and if necessary, copy text from the windows-based application.

3.5 The User Interface

For the handheld device, we have developed a MIDlet application that implements the user interface for the mouse and the text mode, as Figure 3 shows.

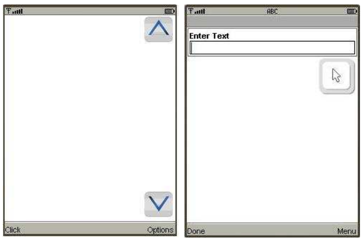

Figure 3. Mouse mode (left) and text mode (right) screens

The interface enables interaction through touching contact or button navigation depending on the device's profile. For example, it is possible to move the cursor dragging the stylus pen over a touch sensitive surface or using the navigation button. Similarly, click events can be initiated using "tap and click" on the screen or just pressing the corresponding button.

For our prototype we developed three different setups for interacting with a remote display:

- Wireless mouse and keyboard (Figure 4, left)
- PDA, stylus pen, and virtual keyboard (Figure 4, right)
- PDA, joystick, and real keypad (Figure 4, center).

Figure 4. The three interaction styles

Every setup supported the same functionality, but differed in execution. Table 1 shows the three actions that were performed differently depending on the modality of the experiment.

Action	Wireless Mouse and Keyboard	PDA, Stylus Pen, Virtual Keyboard	PDA, Joystick, Keypad
Move pointer	Wireless Mouse	Stylus pen	Joystick button
Input text	Wireless Keyboard	Virtual keyboard	Physical keypad
Click	Mouse-Button	"tap and click" Fire button Select button	Fire button Select button

Table 1. Input mappings

4. EVALUATION

In order to measure the user acceptance of the application, we ran a controlled experiment over 11 participants, where we used an adapted IBM Post-Study questionnaire to collect their scores for three different interaction conditions.

The study was conducted in the library of our institute in order to simulate a living room, with a big screen projected on one of the walls. During the experiment, participants tested the three modalities to interact with the projected screen**.**

4.1 Hypotheses

For the proposed scenario, we predict that the features of handheld devices are more suitable than those from the wireless mouse and keyboard. Theses devices are not wearable and need a supportive surface to ease their interaction. Handheld devices, besides being wearable, can be hand held. We expected users to feel more comfortable using handheld devices in this scenario and feel free to change their location and posture.

Visibility plays an important role for the interaction with remote displays. Using our prototype, participants are able to edit text directly on the handheld screen. Thus, the distance between participants and the edited text is reduced, and therefore visibility is enhanced. Regarding this matter, we conjectured that subjects would prefer the interaction with handheld devices.

In order to predict the outcome of the experiment, we also took into account factors like specific characteristics of the handheld device employed during the study, a MDA Vario II. The device lacked a proper joystick and we used instead its central navigation button that allowed only up-down-right-left movements. Thereby, we expected that participants would rather use the stylus pen interaction since they can freely move the cursor in all directions.

Assuming that participants would have a greater experience using the wireless keyboard and mouse, we expected them to be slightly faster performing the tasks in this modality.

4.2 Experiment Design

We conducted a repeated-measures experiment, where the same subjects were used for each condition. Only one independent variable, i.e. the type of interaction, was manipulated. The following dependent variables were measured:

User Acceptance: Analyze which type of interaction meets the most requirements for this particular setting.

Task Completion Time: For each task, measure the time participants need to complete it.

Error rate: Measure the number of errors made by each participant when using the different types of interaction. An error is considered to be any failed attempt to hit or select an intended target.

4.3 Participants

11 graduate and PhD Computer Science students, 3 female and 8 male, volunteered to participate as subjects. Participants were between 20-35 years old and were all right handed. All had from high to expert experience with computers and owned mobile phones at the time of the study. 9 out of 11 described their experience with mobile phones as medium or high. Most subjects sent less than 20 messages per week using the mobile phone; only two send more. Only one subject owned a PDA, and 8 out of 11

subjects claimed to have poor experience with such a device, and just had some exposure occasionally through friends.

4.4 Tasks

Participants were given two different tasks presented in written form under each condition. Both tasks were related to web browsing activity which requires complex and rich combination of mouse and keyboard input. In the first task, participants were asked to browse a video sharing website and search for a specific title. Thus, we focused on the mouse movement and click actions. The second task consisted in writing an email using a mock email account, which allowed users to experience a longer insertion of text. They were asked to log in, write the body of the email (50 characters), add the receiver address, and send the email.

4.5 Questionnaires

In the style of the IBM Post-Study questionnaire [12] we developed a questionnaire consisting of 10 items corresponding to the system usefulness. The items were 7-point graphic scales, anchored at the end points with the terms "Strongly agree" for 1, "Strongly disagree" for 7, and a "Not applicable" (N/A) point outside the scale. Some space was left at the end of the questionnaires for positive and negative aspects, and for further comments.

4.6 Interviews

At the end of the experiment, participants were interviewed. They were asked about their age, occupation, and experience with computers and handheld devices. In order to measure their familiarity with text input in handheld devices we noted the approximate number of text messages that subjects send per week.

4.7 Captures

Every session was video-taped and audio-recorded so that we could observe the body language and study the subject's attitude towards the three interaction techniques. A screen video capture tool was used to record the user input in the remote screen. Thus, we could trace the cursor and detect any errors approaching and selecting targets.

4.8 Procedure

Participants were first introduced to the course of the experiment and encouraged to make themselves comfortable imagining they were sitting in their living room rather than in the cold library. Participants had no prior exposure to the device and were given only a basic introduction and a few minutes to play with the device.

Under each condition, participants were given two written tasks and left some time to go through the tasks and ask questions. To prevent an order effect systematically affecting the dependent variables, we randomized the order in which conditions were presented to participants, as well as the tasks within each condition. If participants were unfamiliar with the websites interface, they were introduced to them before starting the experiment. After completing the tasks, participants filled in a condition-adapted questionnaire. When they had gone through the three conditions, participants were shortly interviewed.

4.9 Results

For every dependent variable, we calculated descriptive statistics. Because of the relatively low number of participants, we did not run sophisticated statistic analysis. Illustrated in the bar-charts in the next sections we will derive indicators for each of the criteria mentioned above.

4.9.1 User Acceptance

The results of the study indicate that user acceptance was highest for wireless mouse and keyboard (Figure 5). On average, this combination was marginal higher accepted than the handheld devices. Mutually contradictory, the maximum value is lower for the PDA with pen and virtual keyboard than for the wireless peripherals. We therefore calculated standard deviation and standard error, which are both lower for the PDA with pen and virtual keyboard (std. deviation 1,3, std. error 0,4) than for wireless mouse/keyboard (std. deviation 1,9, std error 0,6)

For the interaction with the PDA, user acceptance was higher using it with pen and virtual keyboard than with joystick and keypad.

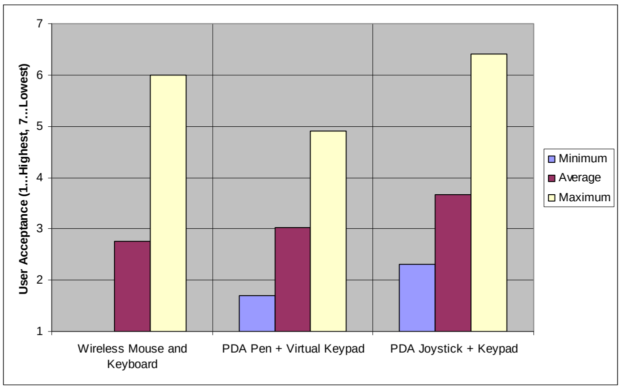

Figure 5. User acceptance

4.9.2 Task Completion Time

Task 1 (Browsing a website). Using the wireless mouse and keyboard, subjects were fastest completing task one (Table 2). On average, they needed 0:46 minutes to browse the website and start the video, which is even faster than the minimum value of both variants of the handheld device. The best absolute time was 0:22 minutes set with the wireless peripherals.

Regarding the handheld device, they were slightly faster using the PDA with pen and virtual keyboard (average of 1:10 minutes) than using it with joystick and keypad (average of 1:24 minutes).

	Min	Average	Max
Wireless mouse and keyboard	22	46,00	96
PDA with pen and virtual keyboard	52	70,45	112
PDA with joystick and keypad	63	83,55	115

Table 2. Completion time in seconds for task 1 (Browsing)

Task 2 (Writing an email). As for task 1, participants were fastest using the wireless mouse and keyboard to perform the second task (Table 3). On average, they needed 1:39 minutes to log in, write the text and send the email. Again, even the average was lower than the best attempt with the handheld device. The best absolute value, set with the wireless peripherals, was 0:50 minutes.

Like for the first task, subjects completed this task slightly faster using the PDA with pen and virtual keyboard (average of 3:11 minutes) than using it with joystick and keypad (average of 3:23 minutes). For both, the slowest person needed more than 5 minutes to complete the task of entering a text of 50 letters.

	Min	Average	Max
Wireless mouse and keyboard	50	99,18	212
PDA with pen and virtual keyboard	114	191,36	313
PDA with joystick and keypad	138	203,18	305

Table 3. Completion time in seconds for task 2 (Writing)

In total, both tasks were fastest performed with wireless mouse and keyboard. Beside the assumption that users are more experienced in operating mouse and keyboard, both PDA styles revealed conceptual limitation:

- With the pen, users had to move the pen across the virtual keypad to reach one letter after the other. With the keypad, the low number of physical keys required intensive use of shift- and meta-keys. Both styles slowing down typing speed tremendously.
- Sharing the touch-sensitive surface of the PDA for both controlling the cursor and clicking required to lift-up the pen from the surface, perform click, and put-down the pen back on the touchpad for moving. Moving the mouse with a four direction joystick slowed down the movement of the cursor.

Looking at the error rate we were quite surprised that the input with wireless mouse and keyboard was fast – but not efficient.

4.9.3 *Error Rate*

The obtained results reveal that users made substantially more errors using the wireless mouse and keyboard than using the handheld device during the interaction with the remote display. Subjects made fewer mistakes using the PDA with pen and virtual keyboard than using it with joystick and keypad (Figure 6).

On average, users made 10 times more mistakes using the wireless mouse and keyboard than using the PDA with pen and virtual keyboard! The minimum number of errors with the wireless peripherals (6 errors) was equal to the maximum with PDA and pen – nobody did more errors using PDA with pen and virtual keyboard than the best user was able to perform with wireless mouse and keyboard.

This results show that the usage of mouse and keyboard was clear to be applied quickly, but transferring it to the special setup of operating the graphical pointer on the display from a larger distance dramatically decreased precise usage. This result is also supported from the interviews and our observation of the body language (see below).

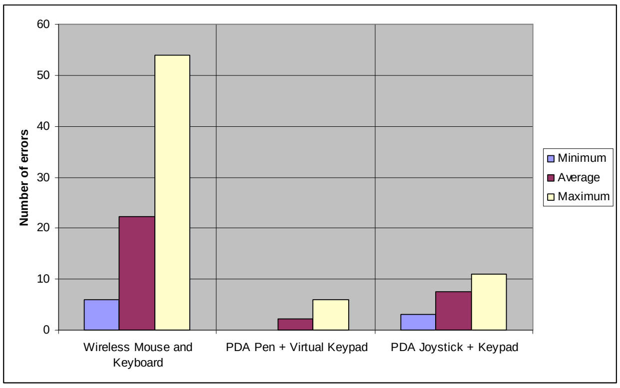

Figure 6. Error rate

4.9.4 *Results from the questionnaires*

The next paragraphs show the preferred interaction for some items of the questionnaire, i.e., the condition with the lowest average. The scale used in the questionnaires ranked from 1 to 7, where the lower values represent the higher agreement with the statement of the question.

4.9.4.1 *User Satisfaction*

With the first question, we evaluated the user satisfaction. Most people strongly or moderately agreed on the satisfaction of the combination PDA with pen and virtual keyboard. For this combination, no user moderately disagreed or stated "not applicable". Nobody strongly agreed on the satisfaction of the PDA with joystick and keypad, which is on average (i.e. 3,6) clearly behind the others. The first column of Figure 7 summarizes the answers of the users.

Because the difference in the average between the other two interactions is minimal (2,9 for PDA with pen; 3,2 for wireless peripherals), we looked at the standard deviation (2,1 for mouse and keyboard; 1,5 for PDA with pen and virtual keyboard), which also supports the conclusion that the PDA with pen and virtual keyboard have highest user satisfaction.

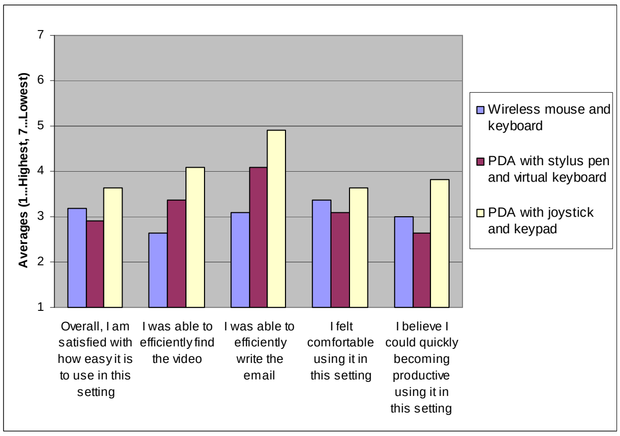

Figure 7. Averages for selected questions

4.9.4.2 Navigation

With the next questions, we evaluated how efficient the users were able to use the devices for navigation. We asked the users to navigate with the mouse pointer to find the video and start the playback.

In the questionnaire, we differentiated between three criteria: Simple to find the video, able to find it quickly, and personal statement about efficiency. The first was most agreed in favor of the PDA with pen and virtual keyboard, whereas the latter two most were in favor of the wireless mouse and keyboard. Most people (8 out of 11) strongly or at least slightly agreed for the wireless mouse and keyboard. The average of 2,5 is clearly lower than for the PDA with pen (3,4) and PDA with joystick (4,1) (cf. second column of Figure 7).

Comparing the PDA styles, 7 out of 11 persons at least slightly agreed that the pen is efficient. On average, the pen is clearly seen to be more efficient than the joystick.

4.9.4.3 Text Input

With the next questions we did the same to analyze the use of the devices for text input. In summary, the mouse-keyboard setup was seen as the most simple, fastest and efficient method.

The personal impression of efficiency was only strongly agreed for the wireless keyboard. In summary, most people at least slightly agreed for this setup (7 out of 11); most people disagreed for the keypad of the PDA (3 strongly disagreed, 5 at least slightly disagreed). Looking at the average values in the third column of Figure 7 puts the devices in clear order: 2,9 for wireless keyboard, 4,1 for PDA with pen, and 4,9 for PDA with keypad.

4.9.4.4 Most comfortable

Beside the efficient use, the comfort is a major usability factor in home environments. The configuration yielding highest results for comfortable navigation and text input was the PDA with pen, and virtual keyboard (8 out of 11, though never strongly agreed, average of 3,1; shown in fourth column of Figure 7). The other two have the same amount of nominations for agreement (7 out of 11), but the distribution to only slightly agreement puts the PDA with joystick and keypad (average of 3,6) behind the wireless mouse and keyboard (average of 3,4).

4.9.4.5 User Habituation

In the last question, we evaluated the personal meaning about the ability of getting familiar with each setting. The average is illustrated in the last column of Figure 7.

In summary, most users agreed that they believe to quickly become productive with the PDA with pen and virtual keyboard (10 out of 11, none disagreed, with an average of 2,6). With the highest amount of strong agreements (5 out of 11, average of 3,0), the wireless mouse and keyboard was put in the middle of the two PDA versions. The PDA with joystick and keypad was seen to represent the combination most difficult to apply (average of 3,8).

4.9.5 Body Language

Video records were extremely useful to observe body language. Figure 8 represents three video-captures from the same participant using the three interactions during the experiment. In the first capture the subject is holding the wireless mouse and keyboard on her lap. The second capture corresponds to the interaction with the PDA and stylus pen, and it can be observed how the participant changes her posture crossing her legs and putting an arm over the backrest of the chair. For the last interaction, she maintains her legs crossed.

Most participants adopted the lap-approach to cope with the lack of a hard flat surface. Figure 9 shows how some subjects had difficulties using the mouse on their lap and tried using their hands, the chair, or the undersurface of the chair as a surface.

Figure 8. Participant of each setting

Figure 9. Participant using the wireless mouse

4.9.6 Comments from the interviews

Questionnaires asked participants for positive and negative feedback, as well as further comments or suggestions. Table 4 contains feedback collected for each interaction. One participant expressed for instance his comfort when using the PDA and joystick "It was the most comfortable way to interact; you can also relax in your chair"; whereas a different participant valued negatively the difficulty of using the same method: "I would prefer a touchpad rather than a joystick". In fact, this free-text section emphasizes the importance of comfort in the presented scenarios. Participants dedicated further comments at the end of the experiment to express their satisfaction in terms of comfort.

	Wireless mouse and keyboard	PDA with pen and virtual keyboard	PDA with joystick and keypad
Positive Aspects	• It is a well known interface • The best among the three methods. Quite easy my lap to use the mouse • It is almost the same as working with my desktop	• A bit more comfortable because I didn't have to carry so many things • Mouse function is good, fun to play with • Easy to use, intuitive	• Mouse-Keyboard in one device • Very easy to use and to type the message • High accuracy • Handy device • More flexibility, not only restricted by keyboard
Negative aspects	• Mouse very hard to use in this setting • Very uncomfortable due to keyboard size • Very uncomfortable if not support surface available, tiresome.	• Need more practice to get used to PDA and to the stylus pen • Typing is not as easy, virtual keypad • Movement limited by PDA screen's size	• Joystick of PDA hard to use • The mouse sometimes was too fast • I would prefer a touchpad rather than a joystick
Comments	• At home, in my living room, I would not use the big keyboard and the mouse on my legs • The email task is more difficult than the video task	• Once you get used to the PDA and the stylus, it is a nice method to use • Better, but need to practice more. • I still prefer to send an email from my PC	• It was the most comfortable way to interact; you can also relax in your chair • Easy to learn but difficult to use efficiently

Table 4. Comments from the interviews

5. SUMMARY AND CONCLUSIONS

In this paper, we illustrated our developments of a remote interaction device for home environments. Based on the two user scenarios and the requirements to such a system, we described the implementation of the first prototype based on web-service technology. Using the prototype we conducted a small user study employing handheld devices to overcome the problem of carrying mouse and keyboard for remote interaction with graphical user interfaces.

The results provide as expected clear evidence for advantages of keyboard and mouse as most study participants are very experienced in their usage. Surprisingly performs the mobile device just slightly worse when it comes to task completion time, has comparable results when considering usability satisfaction and performs much better when considering the error rate.

With the prototype presented in this paper, users were successful in their use of handheld devices to control internet and multi-media services from the distance. Handheld devices are ready for use in home environments, in particular when mouse and keyboard are not usable because of the missing surface for operation. So far, the study indicates potential for releasing computer input from its current close association with mouse and keyboard.

Considering these results, one can argue that mobile devices should be considered as a replacement for mouse and keyboard in a home scenario context, that they are applicable for multi-user scenarios such as collaborate web browsing and that they are in general an interesting option for the interaction with remote displays, such as the ones installed in public environments such as airports and office buildings.

Overall, the usage of mouse/keyboard and PDA with pen and virtual keyboard are on a similar level regarding user acceptance, satisfaction, and comfort; mouse/keyboard outscored the others in terms of speed and (personal meaning of) efficiency. In fact, the error rate was dramatically increased with mouse/keyboard in comparison with the other approaches. From the comments we conclude, that the PDA with pen was most fun and easy to use, but precisely operating a computer application would need more practice.

Comparing the two PDA-styles we conclude, that using the pen and virtual keyboard were more accepted, satisfying, efficient, error-free, comfortable and easy to learn than using the joystick and keypad. There was no indicator where the latter one could be preferred.

For writing emails it is remarkable that the (physical) keypad of the PDA were even behind the virtual keyboard on the PDA's display. From completion times for entering 50 characters of an email-body we can say that entering larger text is still an issue. Obviously, there is more effort needed in developing new entry techniques, like the EdgeWrite text entry [19], and more sophisticated keyboards and joysticks are contributing to enormously decrease the disadvantages that handhelds had comparing to common keyboards in terms of speed and ease to learn.

Based on the outcome of the first prototype, we are aiming at two major improvements in the near future: (1) we would like to add more mobile input methods, and (2) we would like to conduct a larger user study. In case of the former aim, we will add other mobile devices to be integrated. The goal is to provide a platform integrating as different input devices and modalities as available today. For the future, we will work on the goal of overcoming the problem of carrying any device by integrating gesture recognition or speech control. For evaluation, we plan to conduct a more sophisticated user-study, specifically with larger user groups, to reveal the benefits for users of different ages and physical capabilities.

6. ACKNOWLEDGMENTS

This research was supported by the European Commission within the InterMedia Network of Excellence (project No. 038419).

7. REFERENCES

[1] M. Abrams, C. Phanouriou, A. Batongbacal, S. Williams, and J. Shuster. UIML: An appliance-independent XML user interface language. In *Proc. WWW8*, 1999.

[2] F. Ahmad and P. Musilek. A keystroke and pointer control input interface for wearable computers. In *Proc. PerCom 2006*, pages 2–11, 2006.

[3] R. Ballagas, F. Memon, R. Reiners, and J. Borchers. iStuff Mobile: Rapidly prototyping new mobile phone interfaces for ubiquitous computing. In *Proc. CHI '07*, pages 1107-1116, ACM Press, 2007.

[4] R. Ballagas, M. Rohs, J. Sheridan, and J. Borchers. (2006). The smart phone: A ubiquitous input device. *IEEE Pervasive Computing*, 5(1), 70-77.

[5] R. Ballagas, M. Rohs, and J. Sheridan. Sweep and Point & Shoot: Phonecam-Based Interactions for Large Public Displays. In *Proc. CHI'05*, 2005.

[6] K. Eustice, T. Lehman, A. Morales, M. Munson, S. Edlund, and M. Guillen. A universal information appliance. *IBM Systems Journal*, 38(4):575-601, 1999.

[7] L. Iftode, C. Borcea, N. Ravi, P. Kang, and P. Zhou. Smart phone: An embedded system for universal interactions. In *Proc. FTDCS 2004*, 2004.

[8] H. Jiang, E. Ofek, N. Moraveji, and Y. Shi. Direct pointer: direct manipulation for large-display interaction using handheld cameras. In *Proc CHI'06*, pages 1107-1110, ACM Press, 2006.

[9] B. Johanson and A. Fox. The event heap: A coordination infrastructure for interactive workspaces. In *Proc. WMCSA 2002*, page 83, 2002.

[10] R. Kjeldsen. Improvements in vision-based pointer control. In *Proc. Assets 2006*, pages 189–196. ACM, 2006

[11] T. Koskela and K. Väänänen-Vainio-Mattila. Evolution towards smart home environments: empirical evaluation of three user interfaces, *Personal and Ubiquitous Computing*, 8(3-4), 234-240, 2004.

[12] J. Lewis. IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use. *International Journal of Human-Computer Interaction*, 7(1):57-78, 1995.

[13] B. A. Myers. Mobile devices for control. In *Proc. Mobile HCI '02*, pages 1-8, Springer-Verlag, 2002.

[14] J. Nichols. Using handhelds as controls for everyday appliances: A paper prototype study. In *Extended Abstracts CHI '01*, pages 443–444, 2001.

[15] J.-Y. Oh and W. Stuerzlinger. Laser Pointers as Collaborative Pointing Devices. *In Proc. Graphics Interface'02*, 2002.

[16] D. R. Olsen, S. Jefferies, T. Nielsen, W. Moyes, and P. Fredrickson. Cross-modal interaction using xweb. In *Proc. UIST 2000*, pages 191-200, ACM Press, 2000.

[17] D. R. Olsen and T. Nielsen. Laser Pointer Interaction. In *Proc. CHI'01*, 2001.

[18] C. Roduner, M. Langheinrich, C. Floerkemeier and B. Schwarzentrub. Operating Appliances with Mobile Phones - Strengths and Limits of a Universal Interaction Device. In *Proc. Pervasive '07*, pages 198-215, Springer-Verlag, 2007.

[19] J. O. Wobbrock. A robust design for accessible text entry. Accessibility and Computing. *SIGACCESS Accessible Computing*, No. 84, pages 48-51, 2006.