An Experimental Comparison of Physical Mobile Interaction Techniques: Touching, Pointing and Scanning

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Abstract. This paper presents an analysis, implementation and evaluation of the physical mobile interaction techniques *touching*, *pointing* and *scanning*. Based on this we have formulated guidelines that show in which context which interaction technique is preferred by the user. Our main goal was to identify typical situations and scenarios in which the different techniques might be useful or not. In support of these aims we have developed and evaluated, within a user study, a low-fidelity and a high-fidelity prototype to assess *scanning*, *pointing* and *touching* interaction techniques within different contexts. Other work has shown that mobile devices can act as universal remote controls for interaction with smart objects but, to date, there has been no research which has analyzed when a given mobile interaction technique should be used. In this research we analyze the appropriateness of three interaction techniques as selection techniques in smart environments.

1 Introduction

Mobile devices have become pervasive; most people carry one, have them turned on almost continuously and use them in different contexts. So far they are mostly used for interaction between a user, mobile device and a service. In such situations the context of use, which is one of the focuses of this work, is generally not considered. In the last decade there has been an increasing interest from industry and academia in using mobile devices for interactions with people, places and things in the real world [1]. This paper focuses on mobile interactions between a user, a mobile device, and a smart object in the real world. We call this specific mobile interaction technique *physical mobile interaction*. In this approach the user interacts with the mobile device and the mobile device interacts with the smart object.

The most popular and promising physical mobile interaction techniques are *touching*, *pointing* and *scanning*. As the name suggests, for the first two of these the user has to touch or to point on a smart object to indicate that she is willing to interact with it. For scanning, the user simply uses the mobile device to discover what controllable devices are available. As mentioned earlier, to date, there has been no

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research that has analyzed in which context a given interaction technique is preferred by a user and which interaction techniques should be supported by the smart objects. The location of the object, the distance between object and user, the service related to the object, the capabilities of the mobile device and the preferences of the user are important factors for the selection of an interaction technique.

The primary results of the work described in this paper are findings and guidelines for when to use or to prefer a particular physical mobile interaction technique. In this work we have focused on the usage of mobile devices for interactions with objects in smart environments. There are numerous scenarios in which such an interaction makes sense including additional services such as reading the manual of a microwave after touching it with the mobile device or requesting direct support for a specific device. Other examples are the provision of interaction functionalities for devices without an interface (e.g. power consumption of electronic devices) or remote control of objects (e.g. requesting the current status of the washing machine while watching TV). To address these and other questions, we conducted a comprehensive online survey; developed and evaluated a paper prototype; implemented the interaction techniques *touching*, *pointing* and *scanning*; and evaluated this prototype in a real world setting. This development process was based on user centred design, to set the user at the focus so as to retrieve as much user feedback as possible.

The paper is organized as follows. The next section relates our work to existing approaches whereby the interaction techniques *touching*, *pointing* and *scanning* are discussed in detail. Following this we present the results of our analysis which are based on an online survey with 134 participants. We then discuss a paper prototype which was developed based on the findings of the analysis phase and which was evaluated in a small user study. After that we describe the implementation and evaluation of the three interaction techniques and their usage in a demonstrator. Finally, we discuss the findings and guidelines for physical mobile interaction techniques based on the results of our analysis, the evaluation of the paper prototype and a user study based on the high-fidelity prototype.

2 Related Work

Our research is related to physical mobile interactions in general but focused on the usage of techniques for interaction with objects in smart environments. Therefore, we first discuss smart environments in general before discussing mobile interactions within smart environments. Following this, we conduct an analysis of *touching*, *pointing* and *scanning* interaction techniques.

A smart environment is an environment fitted with a variety of sensors and electronically operated devices which allow the occupants to customize the functionality of their living environment (e.g. a domestic home). Using the system, it is possible to e.g. monitor light level, temperature, window and door status and who is currently in a house [2]. Most research related to smart environments currently focuses on context aware systems which adapt according to contextual information. In [22] the authors describe the Easy Living project providing an overview of interaction modalities in such context-aware smart environments. Such environments are usually equipped with a set of smart objects which are augmented by sensors or actors to interact with their physical environment and which often provide a user interface [3]. One issue is how to interact with and control these objects. One solution is to use mobile devices as remote controls. Examples include the Home Automation System [4] and the Pebbles Research Project [5]. However, so far, the literature reports very little work on the evaluation of physical mobile interaction techniques in general and in particular in smart environments. The only comparable analysis of mobile interaction techniques was done by Ballagas et al. [6]. Unlike our work they focused on the classification of interaction techniques based on previous work and personal experience. Furthermore they did not run a questionnaire or user studies to compare the mobile interaction techniques.

The following subsections analyze the physical mobile interaction techniques *touching*, *pointing* and *scanning* in detail.

2.1 Touching

Touching relates to selecting a smart object by bringing the user's mobile device into contact with the object the user wishes to interact with. For this the user must be nearby the object and aware it is augmented with a touch capability. In the next step the user has to touch the object which results in the related services being presented to the user on their mobile device. Through this, additional services can be accessed that are not provided by the device itself. This interaction technique is seen as natural because it conforms to our everyday physical interactions as we often touch objects with our hand or fingers to support the comprehension of the listener when talking about it. Want et al. [7] were among the first to present a prototype for the *touching* interaction technique which incorporated RFID tags and a short range RFID reader in a mobile device (in this case a tablet computer). They used their prototype to demonstrate the augmentation of books, documents and business cards to establish links to services such as ordering a book or picking up email addresses. Another implementation was described by Välkkynen et al. [8] who developed an interaction technique called *TouchMe* that uses proximity sensors to sense the distance between the augmented object and the mobile device. Common technologies for implementing this interaction technique are Radio Frequency Identification (RFID) and Near Field Communication (NFC) [9] which means objects need not be touched directly, rather circa 0-3 centimetres is sufficient for the selection.

2.2 Pointing

Using the *Pointing* interaction technique the user can select a smart object by aiming at it with a mobile device. This interaction technique is regarded as natural as it reflects one of our everyday physical interactions such as pointing at objects with our finger when we speak to support the comprehension of the listener. This interaction technique can be realized by several technologies such as visual markers, optical beams or image recognition technologies. Fitzmaurice [10] was one of the first who described the concept of using mobile device pointing for interaction with smart objects, which involved getting information from a map augmented with a computer based library. Rekimoto and Nagao were among the first to present an implementation of this interaction technique based on their *NaviCam* [11] system which consisted of a mobile device with an attached camera that interpreted visual codes on physical objects. They used this prototype to obtain additional information about entities such as pictures, an active paper calendar and an interactive door. In the last decade, several projects or standards such as QR code [12], Semacode [13] or visual codes [14] have focused on further development of visual markers and their interpretation on mobile devices. Other projects have used *pointing* based on cameras and object recognition approach rather than visually augmented objects [15]. Välkkynen and Tuomisto [8] for example implemented p*ointing* using light sensors on the object which are illuminated using laser or infrared beams attached to the mobile device. IrDA is built-in to many mobile devices and can be seen as an example of interaction via *pointing*. Typical mobile device support distances range from 0 to 60 cm. For example, such system is used by *Mobipoint* [16] which is a commercial installation provided by the *Deutsche Post* to receive codes from a poster. The system can be used to download ring tones for free from a webpage. When the pointing distance is less than 10 cm, IrDA might be seen as one way of realizing *touching* interaction technique.

2.3 Scanning

S*canning* allows user to get a list of nearby smart objects by using a wireless mechanism. Selecting one item from the list of discovered smart objects results in the listing of its services. The advantage of this type of interaction technique is that the user does not need to be aware of the augmentation of a smart object nor must this object be visually changed to get the attraction of a person. The idea of using a mobile device for scanning the environment was first seen in the early Star Trek television series (1966-1969) where a *tricorder* [17] was used to scan unknown environments. There exist several implementations of this interaction technique; most are based on radio frequency communication such as Bluetooth phone services.

3 Analysis

The goal of this phase was to analyze the needs of potential users and to deduce which services are useful when interacting via a mobile device with a smart object. The analysis and the prototypes are based on mobile phones because most people own this special kind of a mobile device and already know how to interact with it. Furthermore we were interested in which locations and contexts potential users would interact with smart objects, and which interaction techniques they prefer. We utilised a three step process of evaluation. At the outset of our work we sought to get an initial unprejudiced user opinion via an online questionnaire which we then verified through the evaluation of our low and high fidelity prototypes. Thus the recognised weaknesses of users not being good at speculating about how they may or may not use systems was not a significant issue as the findings were tested via prototype evaluation.

Thus we conducted an initial web based questionnaire at the beginning of our work in November 2005. 134 people participated, 40% of the participants were female and 60% were male. The participants were between 17 and 59 years old with an average age of 28. 41% of the participants had a university degree and 95% of them owned a mobile phone.

At the beginning of the questionnaire we explained what intelligent environments were and solicited their opinions about various aspects of such environments. The findings revealed that the respondents had high expectations for the benefits such environment would bring to their life. For example, they described a smart environment as an interesting, practical and comfortable way to live, in particular they foresaw the possibility of saving time, energy and money. Many respondents mentioned benefits for older or handicapped people. In contrast some respondents were afraid of losing too much control. Many users mentioned a fear of a power blackout of the smart environment or were worried about the dependence on technology and a loss of human control.

We then asked about their general feeling regarding the usage of the mobile device for interacting with objects in smart environments. The corresponding feedback was positive. The respondents pointed out that mobile phones were widespread and familiar. They mentioned the benefit in interacting with their smart environment whilst away from home which provided a confident feeling of being able to regularly check the status of their home, whilst away. Additionally security issues were raised and it was apparent that there was no proper trust in the security of mobile phone technology.

The next section of the questionnaire presented three different application areas for mobile applications interaction with smart objects. The first one concerned getting information related to an object, such as getting online instructions for a device (e.g. washing machine), opening a web page related to a device (e.g. fridge), opening other websites related to the devices (e.g. recipes related to the microwave) or an online guide for the television or radio. The participants had mixed opinions about these application areas as one can see in the following Figure 1.

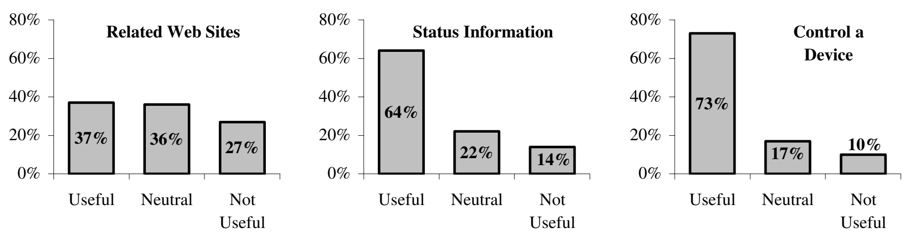

Fig. 1. Results of the online survey regarding the usefulness of predefined application areas for mobile interactions with objects in smart environments

37% saw retrieving information on related websites as a useful thing whilst 27% thought it was not useful. The next application area was about retrieving status information about physical appliances such as the status of the coffee machine (switched on/off) and the time a washing machine needs to complete a wash. Here 64% regarded such a service as useful. The last application was about controlling a device remotely such as the heating. Again this scored well with 73% of the participants considering such a service useful.

Subsequently the participants were asked when they would use the mobile phone for interactions with objects in smart environments. Figure 2 shows that most of the respondents (43%) would use such a system independently of their location. A third of the respondents (34%) would use it only remotely. 13% would use it only when at home. 10% of the respondent would refuse to use such a system at all.

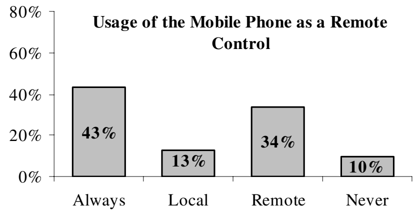

Fig. 2. Preferred location of the user when interacting via the mobile phone with smart objects

Next we explained the principle of the mobile interaction techniques and asked if they would use *scanning*, *pointing* or *touching* when interacting with smart objects in various contexts. Figure 3 and 4 summarise the overall findings and shows that, in general, users would prefer *pointing* and that they were almost equally split on the use of *scanning*, but they disliked *touching*. *Pointing* performs best because many participants saw it as an intuitive interaction technique with little physical effort. *Scanning* was preferred in situations in which a physical distance between the user and the target object existed. *Touching* proved unpopular because mostly respondents did not see any added value; rather it was seen to entail more unnecessary physical effort. The only reported merit was in situations where touching helped avoid ambiguity.

The advantages of *touching* were seen in the accuracy and uniqueness of the selection process especially when devices are small and close together. The most common complaint was the need for a physical closeness to the device which requires a high level of user motivation to make the effort of moving closer. The technique was classified as very intuitive and moreover the technique was seen as the most secure and trustworthy approach.

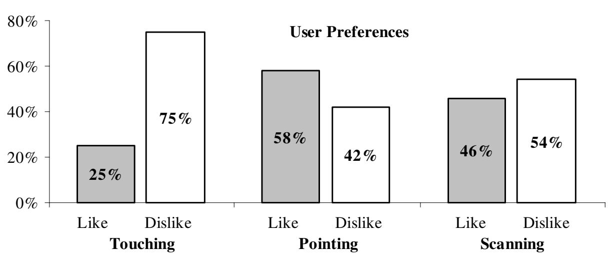

Fig. 3. Preferences (like, dislike) of the participants regarding the interaction techniques *touching*, *pointing* and *scanning* in general

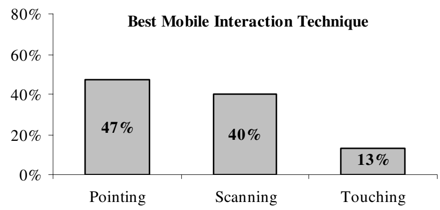

Fig. 4. Direct comparison of the three physical mobile interaction techniques touching, pointing and scanning

The benefits of *pointing* are seen as being natural, easy to use and quick for addressing the target device directly. In addition, the respondents mentioned that *pointing* avoids a complex user interface. However, ambiguities in the selection process were possible, especially if devices are close together or small.

A frequently mentioned benefit for *scanning* was that it operates at a distance and does not require proximity to the device and therefore requires less physical effort. Moreover the listing of all devices was seen as an advantage. Respondents mentioned that the mobile device becomes a mnemonic device for all available and usable smart objects. However, a drawback was that information must be displayed even when it is unimportant, although this is more an implementation issue.

Whilst this survey allowed us to scope the breadth of the issues to be investigated, by its nature there remained ambiguities that needed a more realistic context to resolve; thus we developed a low-fidelity and the high-fidelity prototype to refine our findings and to evaluate the interaction techniques in a more practical context.

4 Low-Fidelity Prototype

The second phase of the user centred design process was to create and evaluate a low fidelity paper prototype of the application. Figure 5 shows some examples of the paper prototype. The test was conducted by eight people whereby everybody performed both tasks described below to verify the assumptions of the analysis phase.

Before every test we explained how the interaction techniques work and how they could be used (taking into account it was a paper prototype).

In the first task the participants were asked to open a web page containing cooking recipes by selecting the fridge. In that situation the testers had line of sight to the fridge, but were too far away to perform *touching*. Six of the eight participants used *pointing* to select the fridge. They argued that, in the case of having a line of sight, *scanning* is too time-consuming. Furthermore, they were not motivated to move closer to perform *touching*. They mentioned they would use *touching* if they were already close enough to the smart object. Just two of the testers used *scanning* but they realized during the selection process that *scanning* was more time-consuming than using *pointing* or *touching*.

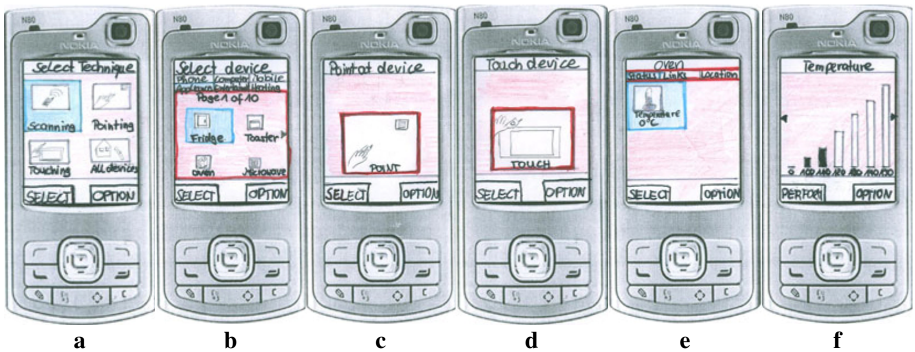

Fig. 5. Scans of the paper prototype: Selecting of a physical mobile interaction technique (a), interfaces after the selection of an interaction technique (b – d), selected smart object (e) and usage of a service provided by the smart object (f)

In the second task the users were asked to set the timer of the microwave to 5 minutes. In this case several devices were close together and a selection via pointing could be ambiguous. Seven of the test people used *pointing*; as long as *pointing* was in any way possible they preferred it. They mentioned that if there was no line of-sight and *pointing* was impossible they would switch to *scanning*. *Touching* was only an option if they were already close enough to the device.

Subsequently, we asked the participants which physical mobile interaction technique they would use if the smart object was in another room. All of them responded that they would use *scanning*. They did not show any motivation to move closer to perform *pointing* or *touching*.

Finally the users were asked which techniques they associate with the following features or attributes:

A. **Security:** All eight users mentioned *touching*. They trusted this technique because they subconsciously think it is the most secure one. They would use this technique if the smart object had some critical role in their life (e.g. a security observation camera or oven).
B. **Intuitive:** Four test people mentioned *pointing* because they compared it to the TV remote control metaphor. The four other mentioned *touching* because they liked the easy selection process.
C. **Speed:** Five of the participants mentioned *touching* because of the unambiguousness of the selection process. They thought that *pointing* needed more time because of the danger of selecting a wrong device and because of the pointing activity itself. The other three mentioned *pointing* because of the fact that they do not lose time while getting closer. Furthermore, they all mentioned that the process of *scanning* for and selecting one device takes more time than touching.
D. **Least error-prone:** All mentioned *touching* because they associated this interaction technique with attributes like error resistance and security.
E. **Highest cognitive effort:** Six participants mentioned *scanning* because they saw a high cognitive effort in finding the device and performing a mapping

from name of the device to the device itself. Two mentioned *pointing* because they saw a cognitive effort in hitting the target.

F. **Highest physical effort:** All users mentioned *touching* because it requires more physical effort than the other interaction techniques.

5 High-Fidelity Prototype

After the analysis, the development of the low fidelity prototype and its evaluation, we started to implement a high-fidelity prototype to evaluate our previous findings in a more practical context. For this we used a previously existing smart environment which is a domestic apartment that includes a range of smart objects which can be addressed via UPnP to receive and perform services.

Such a practical evaluation is very important for the analysis of these interaction techniques because several physical or technical constraints could be not simulated with a paper prototype or in an online questionnaire. Examples include the time needed for a scanning process, the time needed until the mobile device points exactly on an object or the correct touching of a smart object.

5.1 Architecture

Figure 6 gives an overview of the architecture of our high-fidelity prototype which consists of the following five components: The smart objects in the previously existing smart environment, the mobile phone, a web server, a pointing recognition server and an UPnP server.

The smart objects and the services they offer can be accessed via Universal Plug and Play (UPnP). A heating system for instance could offer a service called *temperature*. Every service has a certain status which can be retrieved and changed via UPnP. Through this the mobile device is able to read the status of a smart object and to use a service provided by it. To identify an element in an UPnP network a Unique Device Name (UDN) number is required which is needed for addressing the devices in such a network. The physical mobile interaction techniques *touching*, *pointing* and *scanning* are used to select one of the UDNs through which a specific smart object is selected. For *pointing,* every smart object is augmented with a light sensor, which recognizes when the laser pointer attached to the mobile phone is pointing at it. For the implementation of *touching* we used Near Field Communication (NFC) [9] technology whereby the smart objects are augmented by Mifare NFC tags which can be sensed by the mobile phone. The physical mobile interaction technique *scanning* is implemented by using Bluetooth access points which provide information about nearby smart objects. Thus, for every object to be identifiable by all three interaction techniques, it must be an element of the UPnP network, be represented by at least one Bluetooth access point and be augmented with a solar cell and an NFC tag.

The mobile phone application which we call *Mobile Interaction Application* (MobileIA) is implemented using the Java 2 Micro Edition (J2ME) and communicates via a web server running on top of an UPnP framework to retrieve information and to perform services in the smart environment. MobileIA uses the Nokia NFC & RFID

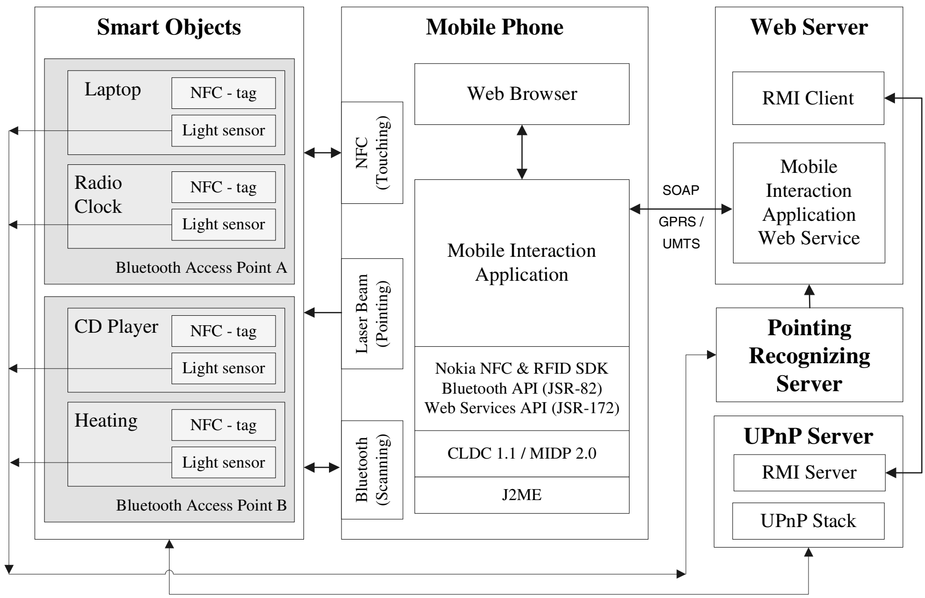

Fig. 6. Architecture of the high-fidelity prototype including smart objects, mobile phone, web server, pointing recognizing server and UPnP server

SDK 1.0 [18], the Bluetooth API (JSR 82) and the Web Services API (JSR 172); and is based on CLDC 1.1 and MIDP 2.0. MobileIA provides support for the interaction techniques *touching*, *pointing* and *scanning*. Whenever there is a need for information, requests are sent to the *Mobile Interaction Application Web Service* (MobileIA Web Service). The MobileIA Web Service offers a WSDL interface to the mobile phone clients. The MobileIA uses the Web Services API to send a Remote Procedure Call (RPC) to the web server. The messages are sent using the SOAP protocol.

After the identifier of the smart object is known, the mobile phone client requests its description. This description includes all services provided by the object and the current state of the smart object with respect to those services. From this, the mobile phone client generates a representation of the object. A user interface is generated that lists all available services, shows a graphical representation of the state and provides the means to invoke the service with parameters that can be specified. When the user changes the status of a device service, i.e. invokes the appropriate service, a request containing all relevant information is sent to the web server.

The web server gets the request and forwards it to the UPnP server. Since the web server and the UPnP server are separated, they communicate using Remote Method Invocation (RMI) from the RMI client (web server) to the RMI server (UPnP server). This RMI interface includes three operations. It allows a request to be sent to all available devices. Thus, the web server can continuously update its list of available devices providing immediate feedback if devices fall out. Moreover it allows a request to perform an action. The third method can be used to check if the status of a device has been changed.

The UPnP server can then execute the service passed from the web server. The result of this service call can then be transferred back to the web server which can communicate it back to the mobile phone. The UPnP service execution can be quite time consuming. To avoid a time-out in the communication between the mobile phone and the web server, the communication is closed after the service has been invoked. The result is stored in the database and can be queried by the mobile phone through the web server. This communication path can be used to send arbitrary results from the service back to the phone.

The following subsections discuss the implementation of *touching*, *pointing* and *scanning* in detail.

5.2 Touching

Touching is realized with Near Field Communication (NFC) technology [9]. The technology is based on RFID but combines it with chip card technology so there is no difference between readers and tag anymore. For our prototype we used a Nokia 3220 with an attached Nokia NFC shell [19] and Mifare NFC tags. If users want to use the *touching* technique, they first initiate the corresponding interaction mode. The NFC reader then starts looking for available tags in its reach. When the mobile phone is in the proximity of the smart object the NFC shell establishes an electromagnetic field to create a radio frequency connection. Thus, it can read data from the tag. A UDN identifier can be extracted form these packets.

Fig. 7. The Nokia 3220 with integrated NFC chip, usage of the NFC phone for reading a Mifare NFC tag, a Mifare NFC tag attached to an smart object and a user who is using the NFC phone to touch the NFC tag

Communication between our Nokia 3220 and a tag is only possible in a range of 0 - 3 centimetres whereby just one tag can be read at the same time. To get the device identifier (UDN) from the Mifare NFC tag, the MobileIA uses the Nokia NFC & RFID SDK 1.0 [18]. Once the user has moved the mobile phone close enough to the Mifare NFC tag, the SDK triggers an event and notifies the MobileIA of the data packet. The UDN stored in the packet can then be read. As described above, the device description is retrieved through the infrastructure and can be used by the application running on the phone.

5.3 Pointing

Pointing is realized by a light beam from a laser pointer attached to a Nokia N70 that is sensed by light sensors on the smart object. This is equipped with a micro-controller on which a recognition algorithm is implemented. As the micro-controller we chose the Particle Computer platform [20]. Particle Computers are small wireless sensor nodes. The node's hardware comprises a microcontroller, a radio transceiver (125 kbit/s, with a range of up to 50 meters), a real-time clock, additional Flash memory and LEDs and a speaker for basic notification functionality. It can be powered using a single 1.2V battery and consumes on average 40mA. The particle computer can easily be extended by additional boards. For our prototype we added off-the-shelf light sensors (FW 300) with an active area of about 0.77 square centimetres. Each pointing sensor for the pointing action consists of three such light sensors to achieve a larger active area (about 2.3 square centimetres). A small LED is added to provide basic feedback if the pointing action was successful. This setting is enough to detect whether or not a light source like a laser pointer is aimed at such a sensor. However, a change in the ambient light can give exactly the same result, especially if the surroundings are rather dim and the main light is switched on. There is no way to distinguish these two cases by merely looking at the magnitude of the signal change. Therefore we added a chip to make the pointer pulse in a specific frequency. Using hardware, or (as in this prototype) software analysis directly on the Particle computer, it is possible to determine whether changes in the sensor values are caused by a pointer or just from changes in ambient light. This technique was also applied in [21] where the authors showed that it is even possible to transmit an ID through the laser beam.

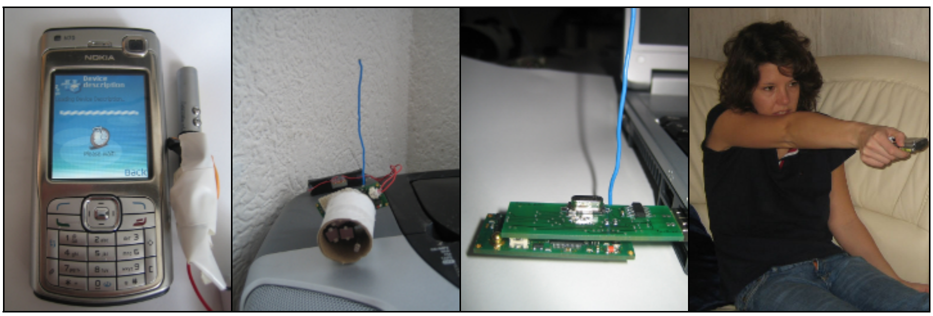

Fig. 8. Nokia N70 with attached laser pointer, smart object with attached light sensor connected to a particle, particle message receiver attached to a USB port and usage of the interaction technique pointing

After the Particle computer has detected that the laser pointer points to one of its sensors, a message is sent to a receiver connected to a USB port of the pointing recognizer server. This communication is performed using its radio frequency communication facility. On the pointing recognizer server side, the UDN sent with the message is retrieved. Upon reception of such a message, the UDN is passed to a Java Servlet on the web server where it is stored in a database together with time information.

The moment the user starts the pointing technique mode on the mobile phone, it periodically sends requests to the web server. Whenever there is an UDN available in the database that is not older than a specified time, this UDN is returned to the phone. As described in the previous section, the device description is then requested.

5.4 Scanning

Scanning is realized using Bluetooth access points which provide information about smart objects in its proximity. To implement this technique, we used the Nokia N70 phone since it provides Bluetooth support. The mobile phone user first chooses the scanning mode on the mobile phone. Then, the user explicitly starts a Bluetooth scan for all available Bluetooth enabled devices that can connect to the phone and selects one. This includes all access points in the user's proximity. The list of found access points can be used to get an approximation of the location of the user which could potentially be used to reduce the number of devices close to the user. The mobile phone sends the list of access points to the web server. There is a description in the infrastructure that maps each access point to devices that are located close to it. From that description the web server retrieves all available devices. The UDN and a human-readable name of each of the devices are sent back to the phone. The mobile phone application generates an appropriate graphical representation (for unknown devices, a standard representation including the name) for each of the devices and displays it. Now the user can select one of the smart objects from the list and its device description is retrieved in the same way as with the other two techniques.

5.5 User Study

The experiment based on the prototype previously described was conducted with 20 participants. The users were aged 9 to 52 with an average age of 28 years. 35% of the participants were male and 70% had an academic education. 55% of the participants did not have a technical background in their job or field of study. In the first part of the experiment the users had to perform different tasks using the high-fidelity prototype. The tasks had to be performed under different context of location and activity. In all of the following scenarios the participants were located in a living room. All scenarios were subdivided into the three activities sitting, lying and standing to cover most casual activities. We assumed that lying is related to activities like relaxing or laziness, sitting is related to talking or writing, and standing is related to working and hurry. All participants performed all tasks of the four scenarios while sitting. Afterwards we asked them about their behaviour and preferences when lying or standing.

In the first scenario the participants had to select a CD player and then had to turn it on. There was a distance of three meters between the participant and the device. The users had a line of sight to the smart object. 95% of all participants used pointing to select the CD player. This decision was independent of their activity. Just 5% of the participants used scanning.

In the second scenario the participants had to open a website related to a radio show. This link was available through the radio which was close to the participant.

All participants used touching in that situation. The decision was independent of the activity. The users mentioned that in that situation touching is the best and fastest technique because they do not need to spend physical effort because they were already in touching range.

In the third scenario of the experiment the participants had to select the heating of the bathroom, switch it on and set on 25 degrees. 100% of the participants used scanning to select the smart object. There were no differences when lying, sitting or standing. No participant was motivated to move to the other room and to use pointing or touching.

In the last scenario the participants had to select the laptop to access a Wikipedia link which was stored on it. The testers were not able to point on the laptop because there was no line of sight to it at the given position. The users had to move one meter for pointing and about four meters for touching. Unlike the first three scenarios, the activity of the user (sitting, lying or standing) in this scenario was an important factor for the selection of an interaction technique. When the users were lying or sitting, all participants used scanning to select the smart device. In contrast to that, in the case where the users were standing just 5% of the participants used scanning, 25% pointing and 65% touching. They refused to use *scanning* since this interaction technique takes more time than the other two. The reason for the high acceptance of touching was that the participants thought that if they are already standing they could move the short distance to the touching range as well.

6 Findings and Guidelines

This section summarises the results of the analysis phase described in section 3, the evaluation of the low-fidelity prototype described in section 4 and the practical evaluation of the high-fidelity prototype described in section 5.5. Based on these we discuss guidelines which should help application developers when designing systems that take physical mobile interaction techniques into account.

6.1 Advantages and Disadvantages of *Touching*, *Pointing* and *Scanning*

One general result from our observations was that *touching* and *pointing* are the preferred techniques if the user has line of sight to or is close to the device. The reason for this is that these techniques are based on our everyday interactions. For instance, we often point with our index finger at products in a shop to indicate what we want to buy or we touch things to feel their surface. *Scanning* is seen as a very technical interaction technique which is more complex to use because of its indirectness. Older users in particular prefer direct mobile interaction techniques because they want to avoid as much input on the mobile device as possible. *Touching* is regarded as an error resistant, very secure, very quick, intuitive and non-ambiguous selection process which can require physical effort. It is typically preferred when the smart device is in reach of the user. *Touching* often requires the users' motivation to approach the smart device. This motivation increases if the benefits of *touching* outweigh the necessary physical effort. *Pointing* is seen as an intuitive and quick technique but requires some cognitive effort to point at the smart device and needs line of sight. It is typically used when the smart device and its tag are in the line of sight of the user and the smart device cannot be grasped directly by the user. In the users' minds *pointing* makes most sense because it combines intuitive interaction with less physical effort.

The indirect mobile interaction technique *scanning* is avoided as much as possible. If there is a line of sight, the user normally switches to a direct mobile interaction technique such as *touching* or *pointing*. Indirect interaction is mainly used to bridge a physical distance and to avoid physical effort. Scanning is seen as the technique with the least physical effort. A disadvantage is that the user has to select the intended device after scanning; this process is more time-consuming than directly interacting when standing close to a smart object. Furthermore the cognitive effort is higher compared to *pointing* or *touching*. It is typically used when the smart device and its tag can not be seen by the user and when the smart device is in scanning range. Generally, if a movement is necessary the user tends to switch to scanning.

Table 1 summarizes the findings described in this subsection.

Table 1. Comparison of properties of the physical mobile interaction techniques

	Touching	Pointing	Scanning
Natural Interaction, Intuitiveness	Good	Good	Average
Felt error resistance, non-ambiguous	Good	Average	Bad
Performance (within interaction distance)	Good	Average	Bad
Cognitive Load	Low	Medium	High
Physical Effort (outside interaction distance)	High	Medium	Low

6.2 Which Interaction Technique in Which Context?

Based on our research as described in the previous sections we formulated the following basic guidelines:

1. Users tend to switch to a specific physical mobile interaction technique dependent on **location**, **activity** and **motivation**.
2. The **current location** of the user is the most important criterion for the selection of a physical mobile interaction technique.
3. The user's motivation to make any **physical effort** is generally low.

Next, the most important factors for the selection of an interaction technique will be discussed.

Location: In general the following three different situations exist.

A. The smart object is within the reach of the user. In this case, users prefer *touching* because in this context it is more intuitive and faster than the others techniques.

B. The smart object and its tags can be seen by the user but it is not in close reach. In this situation users mostly prefer *pointing* because they have to expend physical effort to use of *touching*. In addition, they avoid *scanning* because it is more time consuming and complex.
C. The smart object is in *scanning* and *pointing* range, but there is no line of sight between the user and the smart object. In this situation users mostly prefer *scanning* because they have to spend physical effort to use *touching* and *pointing*.

Activity: Besides the location, activity is another factor in the selection of a physical mobile interaction technique. In our research we considered three different activities *lie*, *sit* and *stand*. The results of the user tests showed that in the context of lying or sitting, the location context is much more important than the activity context. The situation when the user is standing is completely different. In this situation the motivation to move and to use *touching* or *pointing* is much higher. Another aspect of activity is the kind of occupation. If the user wants to relax, she does not want to make any physical effort, whereas she is more motivated to move when she is busy.

Motivation: Basically, the user is not willing to make any physical effort and chooses the physical mobile interaction technique mostly according to the location and activity context. Nevertheless, the motivation to approach a smart device can be increased. In particular the following aspects increase the motivation to move:

A. <u>Security Issues</u>: Users are willing to make a physical effort when they are highly motivated, e.g. when the smart device plays some critical role in their life. In these cases, the testers are prepared to get closer to perform a selection via *touching*. Examples include interaction with the security system of a smart environment or the oven. The reason is that users are convinced that this interaction technique is most secure. They think that because of the short distance between the mobile device and the smart object it is not possible to interrupt or eavesdrop on the connection, or to manipulate the transferred information. Furthermore, they think that the risk of selecting the wrong device is very low.
B. <u>Speed</u>: In some cases, the selection process must be performed very quickly. Here, the motivation is increased to move closer to use a fast direct interaction technique. An example for this is the control of the lights in the room. In this case the users are not willing to use a time-consuming scanning procedure, they prefer to point to or touch the object to quickly switch it on or off.
C. <u>Intuitiveness</u>: The intuitiveness of the direct interaction techniques can increase the motivation to approach an object for interaction. Older people in particular who are not used to mobile phones are more motivated to make a physical effort to prevent a more complex and time consuming indirect selection technique.
D. <u>Maximum Physical Effort</u>: The previously mentioned aspects to increase the motivation are only appropriate if the required physical effort is not too high, e.g. implies movement of up to 10 meters. The further the smart devices are away the less important are the motivation aspects.

These guidelines could help application designers in the future when developing systems that take physical mobile interaction into account. When looking on the results it must be considered that we did not run a long term study within the people's home environment. Based on these results we hope developers can better decide which interaction techniques should be provided in which context.

7 Conclusion

In this paper we have presented a comprehensive analysis of the physical mobile interaction techniques *touching*, *pointing* and *scanning*. First we conducted an online questionnaire asking the participants about their opinion with regard to mobile interactions in smart environments in general, and in particular which services they would use. Additionally, we asked them about their preferences regarding the three interaction techniques. Following this, we developed and evaluated a low-fidelity and a high-fidelity prototype which supported *touching*, *pointing* and *scanning*. Finally, we summarised all these findings and defined guidelines for which context a particular interaction technique is preferred or should be supported.

We analyzed the influence of the user's location, her activity and her motivation on the preference for a physical mobile interaction technique. We observed that location is by far the most important factor for the selection of *touching*, *pointing* or *scanning* within a given context. In addition to this, we analyzed how the activity of the user (standing, sitting, lying) related to the same decision. Generally it can be said that if the user is sitting or lying, she prefers an interaction technique which is possible without changing the location, even if the interaction might take more time. Furthermore, we deduced that factors such as security issues, speed and intuitiveness can also influence the preference for an interaction technique within a given context.

In short; people prefer to touch things that are near. If they're not near, and there's a clean line of sight, they prefer pointing. Only if all else fails they prefer scanning

In our future work, we will investigate further physical mobile interaction techniques in our smart environment. We also plan to conduct long term studies with residential users in the environment to learn more about the interplay between location, activity and motivation in relation to the choice of selection technology. In particular, for pointing we plan to investigate alternative implementation options based on cameras built into the phone.

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