A Physical Selection Paradigm for Ubiquitous Computing

Heikki Ailisto, Johan Plomp, Lauri Pohjanheimo, and Esko Strömmer

VTT Electronics, P.O.Box 1100, FIN-90571, Oulu, Finland
Heikki.Ailisto@vtt.fi

Abstract. More natural communication with ubiquitous digital devices requires new ways of interaction between humans and computers. Although the desktop metaphor and the windows, icons, menu, and pointing device (WIMP) paradigm work well in the office computer, different means of interaction might be more suitable for mobile terminals and their communication with ambient devices, objects and services. We present three cases where physical selection[1] may prove advantageous over more traditional ways of interaction. Also, we suggest different ways of realising physical selection and compare their characteristics. Finally, we give an example of physical selection in the case of activating and reading a temperature sensor wirelessly. In the future, we shall investigate the possibility of implementing the physical selection paradigm with mobile phones and Personal Digital Assistants.

1 Introduction

The vision of ubiquitous computing inherently includes natural interaction between humans and digital devices embedded in their environment. The desktop metaphor [12] works well in the office, but it is not so well suited to ubiquitous and mobile computing [15].

Myers et al. describe how the advances in computing will set new requirements for user interface (UI) development [8]. Current interaction with (desktop) computers is implemented by means of an interface paradigm generally referred to as WIMP (Windows, Icons, Menus, Pointing device). This paradigm finds its roots in the windowing and direct interaction system developed at Xerox PARC and used commercially first in the Apple Macintosh (from 1984), soon to be followed by similar implementations by Microsoft (Windows) and by MIT for Unix (X-windows) [2]. The current implementations have a remarkable degree of commonality, which has allowed for easy use of different computer systems after the basic principles of WIMP have been mastered.

[1] The term *physical selection* used here covers both *physical pointing* and physical selection based on *proximity*.

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When small mobile terminals, such as PDAs (Personal Digital Assistant) and smart mobile phones, appeared on the market, they were largely deriving from this successful WIMP paradigm. However, the small display has too little space for windowing solutions or large menus to be displayed. Pointing by means of the touch screen is not very precise and the amount of concurrent information displayed is necessarily limited. Browsing a large amount of information, or selecting an item from a large list, are very tedious tasks with the interface provided by a mobile terminal. The lack of a keyboard has also called for alternative text-input methods like handwriting and speech. Research on finding new ways for post-WIMP interaction is broad and will probably contribute significantly to the natural interaction with mobile terminals.

There is another important observation one needs to make with respect to the use of mobile terminals in a ubiquitous computing setting. The interaction will no longer be limited to the applications within the mobile terminal. Instead, the mobile terminal will be used as a mediator between the user and services and devices in the environment. The mobile terminal will negotiate with the environment, convey the available services to the user, and facilitate the interaction with this service. As in the case of the direct interaction metaphor, interaction involves the selection of a target and the subsequent manipulation of that target. Now the targets are not just found on the screen, but also in the real-world environment of the user and his hand-held mobile terminal. Therefore extending the selection to the real-world by means of a pointing action is a natural step. Interaction with a service is initiated by means of a real-world selection action (physical selection), followed by manipulation facilitated by the mobile terminal. This "manipulation" may just mean the presentation of information, but also displaying a complete user interface for further interaction, or invoking an action in the environment.

Ideas close to physical selection have been suggested [14],[16],[5],[11]. Ulmer and Ishii [14] developed the idea of Phicons, which serve as physical icons for the containment, transport and manipulation of online media in an office environment. Their paper does not discuss the role of mobile personal terminals, such as smart phones or PDAs, but instead relies on fixed devices, such as digital whiteboards, projectors, and printers. Kindberg and co-workers study infrastructure to support "web presence" for the real world [5], their main idea being connecting physical objects with corresponding web sites. Infrared (IR) beacons, electronic tags or barcodes are suggested for creating the connection.

In this paper physical selection as a means of human computer interaction by using mobile personal terminals communicating with the ambient smart devices and services is suggested. The employment of widely used and increasingly popular mobile terminals as a tool for physical selection is estimated to have high potential with a much wider application than accessing web pages associated with physical places or objects. It can be seen as a building block for fulfilling the ubiquitous computing vision. We describe three examples of using physical selection, analyse the implementation issues, and give an implementation example. Finally, the potential of physical selection as well as the future direction of the research is discussed.

2 Using Physical Selection

In this section the possible usage of physical selection is considered. First different characteristics are identified and then three examples are presented.

2.1 Main Characteristics of Physical Selection

The main characteristics of physical selection are
- selection characteristics,
- data transfer characteristics and
- data handling and storage characteristics.

Conceptually physical selection can be based on proximity or pointing. In the case of proximity, physical selection occurs when the mobile terminal[2] ("selection device") is within a certain distance of the target object ("tag"), say closer than 5 cm. In the case of pointing, selection is initiated by the mutual alignment of the pointing device and the target object. For example, the pointing beam may need to be aimed at the target object (within its field of view) within a margin of 5 degrees. Choosing between these two concepts influences not only the usage of physical selection but also its implementation.

The data transfer characteristics determine whether the selection initiates uni- or bidirectional communication between the mobile terminal and the tag. They also cover issues like data rate, latency time and communication range between the mobile terminal and the tag. The amount of data to be transferred may vary from one-bit on/off data to files of Java code. In some cases, physical selection only initiates data transfer using some other communication channel [10], e.g. via a wireless local area network.

The data storage and handling capacity of the tag varies widely according to application needs. The data content of the tag may be fixed, such as in barcodes or passive RFID tags (Radio-Frequency Identification), or it may be dynamic as in sensors or systems with embedded processors. The processing power in the tag ranges from dumb processor-less to smart systems which act as the front ends for sophisticated applications such as heating systems or burglar alarms.

In the following subsections three use-cases exemplifying these characteristics are given.

2.2 Updating the Context Profile of a Mobile Terminal

Developing context sensitivity [3] of devices and services has been seen as one of the main goals of ubiquitous computing research. Although some successful demonstrations and applications have been presented, two key problems seem to hinder the

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[2] The word *mobile terminal* is used for the selection device held by the user. Usually the terminal has means of input and output. Practical examples of a mobile terminal are a PDA and a smart phone. A "*tag*" is the target object to be pointed at. A tag can be a fixed information storage (e.g. barcode), an interface to an ambient device (e.g. smart temperature sensor), or to a system (e.g. a computer controlled heating system).

progress in this area: 1) the methods for automatically and reliably assessing the context, e.g. location, task at hand or situation, has proven to be much more difficult than expected; and 2) more fundamentally, the answer to the question "Does the user really want automatic context sensitivity?" is not always "Yes". As a solution to both of these problems in the specific case of updating the context profile of a mobile terminal we suggest physical selection. This approach seems to be highly potential: it resolves the ambiguities and uncertainties related to context reasoning and at the same gives the user a notion of control over her/his digital environment by allowing the user to update and change the context deliberately but in a fashion more natural than using keys or mouse.

The context profile of a mobile phone or a PDA should relate to the current location, task or social situation. The location specific context could be e.g. office, meeting room, car or home. Changing or updating the context profile of a mobile terminal could be done as shown in Figure 1 by physically selecting a Context Tag with the mobile terminal and accepting the new profile. A natural place for Context Tags would be near door posts of rooms. In a similar way, the task or situation context could be chosen by selecting physical symbols of each named context with the mobile terminal.

Fig. 1. Changing the context profile of a mobile terminal by physically selecting a Context Tag

Updating the context profile of a mobile terminal requires only unidirectional data transfer, namely from a Context Tag to a mobile terminal. The amount of data to be transferred is small, and thus there is no need for fast communication. The data content of a Context Tag can be either static or semi-static. The activity required by the user is easier, more subtle and faster than selecting the context profile through menus with small keys or by voice commands.

2.3 Activating a Function by Physical Selection

Physical selection can be used to activate functions, either in the tagged device or in the mobile terminal. The former case is the familiar way of using remote controllers to control TV, VCR and audio appliances or to operate car locks and garage doors. The latter case is a more novel idea, which again is associated with mobile terminals. Examples of this kind of activating functions might include activating a phone call to a person by selecting her/his picture or starting a game or an operation in the game in a mobile terminal by selecting a corresponding physical tag. It is also easy to envisage applying tags as URL-addresses [5],[10], where by the user could receive more information, such as maps, manuals, product data etc. via the Web.

Unidirectional data transfer with moderate bit rate and short latency time are typical requirements for this type of application. The data content of the tag may be fixed and there is no need for smartness in the tag. The selection activity may be based either on proximity or pointing.

2.4 UI for Devices and Services without Display and Keys

Physical selection could be used for activating - and even downloading - the User Interface for devices without display or keys. This kind of applications can of course be implemented with, for example, Bluetooth radio communication, but we assume that it can be made much easier and more natural when the UI of a device or service is activated by selecting it - or its physical icon - instead of a complicated series of menu selections. Figure 2 illustrates the principle. Potential applications include burglar alarm systems, home appliances, cars, and industrial systems.

Fig. 2. Activating the UI for a device without a display and keyboard

Activating and using the UI via physical selection requires bidirectional communication, moderate or reasonably high data rate (in the case where the UI is first downloaded), and short latency time. The device to be controlled must contain some data processing capability, otherwise the whole concept is meaningless. The main advantage over more standard approaches, such as using a wired terminal or Bluetooth connection, is seen to be the easy and natural way of establishing the connection by physical selection, and consequently the speed of operation.

3 Implemetation of Physical Selection

This section analyses the practical implementation of the physical selection. In addition to the selection function, the data transfer function is also considered, because these two functions are often implemented by the same technology, even though this is not necessary. Three major alternatives for wireless physical selection exist:

- visual codes, e.g. barcode,
- electromagnetic technologies and
- infrared (IR) technologies.

Vision based solutions as used for augmented reality are excluded in this study, since they often rely on modelling the environment and use a fixed infrastructure, which are not feasible for the mobile usage we envision.

3.1 Visual Codes

The common barcode is the best known visual code. Barcode is a one-dimensional code consisting of vertical stripes and gaps, which can be read by optical laser scanners or digital cameras. Another type of visual code is a two-dimensional matrix code, typically square shaped and containing a matrix of pixels [9]. Optical Character Recognition (OCR) code consists basically of characters, which can be read by people and machines.

The introduction of mobile terminals with embedded digital cameras has made visual codes a feasible solution for physical selection. A code can be read with the camera and analysed by image recognition software.

Visual tags are naturally suitable for unidirectional communication only, as they are usually printed on a paper or other surface and the data in them can not be changed afterwards [6]. When printed on paper or adhesive tape, the tag is very thin, and it can be attached almost anywhere. The most significant differences between barcode, matrix code and OCR lay in the information density of the tag and the processing power needed to perform the image recognition. Barcodes have typically less than 20 digits or characters, while matrix tags can contain a few hundred characters. The data content of an OCR is limited by the resolution of the reading device (camera) and the available processing power needed for analysing the code. Visual codes do not have any processing capability and they do not contain any active components, thus their lifetime is very long and they are inexpensive. The reading distance ranges from contact to around 20 centimetres with hand held readers and it can be up to several meters in the case of a digital camera, depending on the size of the code and

resolution of the camera. By nature, visual codes are closer to the pointing class than the proximity class.
Barcodes are widely used for labeling physical objects everywhere. There are already myriad of barcode readers, even toys, on the market. Commercial image recognition software is also available.

3.2 Electromagnetic Technologies

The following electromagnetic technologies can be applied for physical selection especially in applications based on the proximity concept:

- RFID technologies based on inductive coupling,
- short-range communication technologies based on inductive coupling and
- short-range technologies based on RF (Radio Frequency).

RFID systems incorporate small modules called tags that communicate with a compatible module called a reader [4]. The communication is usually based on a magnetic field generated by the reader (inductive coupling), but with very short operating ranges it is also possible to apply capacitive coupling. The tags are typically passive, which means that they don't operate or produce signals independently from the reader. Instead, the passive RFID tags receive the energy needed for the operation from the magnetic field generated by the reader module, eliminating the need for a separate power supply. In addition, there are active RFID tags that incorporate a separate power supply for increasing the operating range or data processing capability. RFID technology can be applied for physical selection by integrating a tag in the ambient device and a reader in the mobile terminal or vice versa.

Typically the tags incorporate an antenna and one IC (Integrated Circuit) chip providing data transfer, storage and possibly also processing capability. Usually the data transfer is unidirectional from the tag to the reader, but also bidirectional tags exist. The operating range is typically from a few millimetres to several tens of centimetres depending on the antenna, operating frequency, modulation method, operating power and bit rate. Examples of operating frequencies typically used are 125 kHz and 13.56 MHz. The basic advantages of the inductive RFID technology compared to other electromagnetic technologies are low price, small size, operation without a power supply and good commercial availability. These advantages make the inductive RFID technology very attractive from the viewpoint of physical selection applications based on the proximity concept.

Originally the RFID tags were aimed at the electrical labelling of physical objects, replacing visual barcodes. Currently, the RFID technology has established itself in a wide range of applications, e.g. automated vehicle identification, smart cards, access systems and toys. There are several manufacturers providing RFID ICs, tags and systems.

There are also technologies particulary aimed for short-range communication that are based on magnetic induction, but contrary to the RFID technologies incorporate an active transmitter at both ends of the communication link, which also makes the tags able to operate and produce signals independently from the reader. When compared to the inductive RFID technologies, the disadvantage of these technologies is that the tags always require a separate power source for operation. The advantages are longer operating range and increased data processing capapility of the tag due to the separate power source. When compared to RF based technologies, magnetic induction has some advantages in short-range (below 3 m) wireless communication such as power consumption, interference and security [1]. There are also some commercial components available which are applicable in physical selection applications.

Longer operating ranges than by magnetic induction can be achieved by RF-based technologies such as Bluetooth, other wireless personal area network (WPAN) technologies and long-range RFID technologies. WPAN based tags are always active in the sense that they require a separate power source and can produce signals independently from the reader. However, the backscattering technology used in the long-range RFID tags makes them able to operate without a separate power source. On the other hand this means that they can operate and produce signals only when being in the operating range of the reader. The operating range of all these RF-based technologies is typically several meters, which is too long for most of the physical selection applications. However, it is possible e.g. to reduce the operating range by external shielding or to use received signal strength indication (RSSI) if available. Examples of the operating frequencies of WPANs and long-range RFID tags are 868 MHz, 915 MHz or 2.45 GHz. One possible disadvantage of Bluetooth, concerning especially ambient devices, is the high power consumption. Bluetooth, other WPAN and long-range RFID components and modules are available from several manufacturers.

3.3 Infrared Technologies

Infrared (IR) is widely used in local data transfer applications such as remote control of home appliances and communication between more sophisticated devices such as laptops and mobile phones. In the latter case, the IrDA standard is widely accepted and it has a high penetration in PC, mobile phone and PDA environments. Due to the spatial resolution inherent to the IR technology, IR is the most obvious technology for implementing physical selection applications based on the pointing concept.

An IR tag capable of communicating with a compatible reader module in the mobile terminal would consist of a power source, an IR transceiver and a microcontroller. The size of the tag depends on the implementation and intended use, but the smallest tags could easily be attached practically anywhere. The data transfer can be unidirectional or bidirectional. The operation range can be several meters, but a free line-of-sight (LOS) is required between the mobile terminal and the ambient device. In the IrDA standard, the specified maximum data rate is 16 Mbit/s and the guaranteed operating range varies from 0.2 to 5 meters, depending on the version used. One possible problem of IrDA, concerning especially the ambient device, is its high power consumption. For reducing the mean power consumption and thus extending the lifetime of the battery, if used, the IR tags can be woken up by the signal from the reader module [7],[13]. It is also possible that the tag wakes up periodically for sending its identification signal to the mobile terminal in its operating range.

In general, IR technologies are very commonplace. Many home appliances can be controlled by their IR remote controller. Several mobile phones and laptops incorporate an IrDA port, and with suitable software they could act as tag readers. Components and modules are also available from several manufacturers.

3.4 Comparison of the Technologies

The three most potential commercial technologies for implementing physical selection are compared in Table 1. Bluetooth is included for reference since it is the best known local wireless communication technology. Obviously, exact and unambiguous values are impossible to give for many characteristics and this is why qualitative descriptions are used instead of numbers. When a cell in the table has two entries, the more typical, standard or existing one is without parenthesis, and the less typical, non-standard or emerging one is in parenthesis.

Table 1. Comparison of potential commercial technologies for physical selection (Bluetooth included as a reference)

	Visual code	**IrDA**	**RFID, inductive**	**Bluetooth**
Selection concept	proximity/ pointing	pointing	proximity	none (proximity)
Data transfer type	unidirectional	bidirectional	unidirectional (bidirect.)	bidirect.
Data rate	medium	high	medium	high
Latency	very short	medium	short	long
Operating range	short-long	medium (long)	short	medium (long)
Data storage type	fixed	dynamic	fixed (dynamic)	dynamic
Data storage capacity	limited	not limited	limited (not limited)	not limited
Data processing	none	yes	yes, limited	yes
Unit costs	very small	medium	low	medium-high
Power consumption	no	medium	no (low)	medium-high
Interference hazard	no	medium	low-medium	medium-high

In the *Updating the context profile of a mobile terminal* use-case tags are used in a variety of places, usually without easy access to a power supply. To create sufficient infrastructure, a large amount of tags is needed. This suggests that the optimal technical solutions are based on visual codes or electromagnetic tags although it is not impossible to use infrared tags.

All suggested technologies apply to the *Activating a function by physical selection* use-case. Several sub-cases of this use-case seem to be easier to use from a distance and that makes infrared as a pointing based technology more suitable than others.

The *UI for devices and services without display and keys* use-case is the most demanding of the three cases presented. Bidirectional communication, and a demand for data processing capabilities on the tag side rule out the visual code option. Of the two remaining alternatives, infrared seems to be more compelling because of the standardised bidirectional communication and the ability of the tag to act as a front-end for the device in question.

4 Example of Physical Selection in Sensor Reading Case

This section illustrates as an example a communication system with physical selection facility and its demonstration (a more detailed description can be found in [13]). The communication system is based on IR technology. In addition to demonstrating the usefulness of the physical selection paradigm, the goal was to develop a communication system for interconnections between mobile terminals and ambient devices enabling ultra-low power consumption, a very low price and a small size of the ambient devices. The requirement for ultra-low power consumption concerns especially ambient devices, because they are typically fixed installations and thus difficult to recharge, their battery difficult to replace and power supply from the mains impossible to arrange or would increase the installation costs dramatically. Whereas the batteries of mobile terminals can typically be recharged even daily, the power supply of the ambient devices must be based on a small battery lasting for several months or even years. Another possibility is to scavenge the power from ambient light, RF-field, temperature gradient, mechanical energy etc. Typically all these power supply methods call for the mean power consumption of the ambient device far below one milliwatt. [13]

The architecture of the communication system is presented in Figure 3. The communication system consists of a terminal interface unit (TIU) integrated into the mobile terminal and a micropower communication tag (TAG) integrated into the ambient device (Application object in Figure 3).

The communication protocol, architecture, electronics, and software of the TAG and the TIU were designed taking into account the requirement for ultra-low power consumption of the TAG. To evaluate the results, a macroprototype demonstrator was implemented. The mobile terminal in the demonstrator was a PDA, and the ambient device a temperature sensor readable by the PDA. According to the evaluation, the power consumption of the IR-tag can be reduced down to a few microwatts in typical applications, where the TAG is most of the time in ready-for-communication state. In spite of the reduced power consumption, the data rate during the communication can be close to the IrDA standard [13].

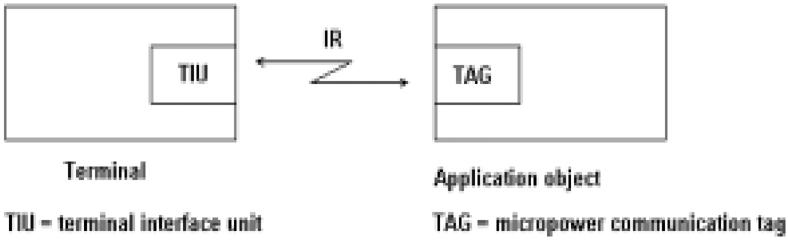

Fig. 3. Demonstrated IR based system.

5 Discussion

Physical selection offers a new way for human computer interaction in many applications of mobile and ubiquitous computing. Since smart phones and other mobile terminals, such as PDAs, are becoming very common place, it is most tempting to use them as tools of interaction between the user and the ambient intelligent devices and services. We identified some important characteristics linked to physical selection: the selection method (proximity or pointing), the data transfer characteristics, and the data handling and storage characteristics. Three use cases were analysed with respect to these characteristics. We assume, that physical selection is perceived more natural than current methods in many cases like the ones discussed here. This hypothesis remains to be tested by future research.

The three main alternatives for implementing physical selection are visual codes, electromagnetic and infrared technologies. Each of these alternatives has its benefits and drawbacks making them suitable for certain applications. For example, implementations based on infrared technology offer bidirectional communication with dynamic data content and high data rate at moderate cost. Furthermore, IR inherently supports pointing and is more privacy preserving than RF. For these reasons, we decided to build our first physical selection experiment, the reading of a temperature sensor, using IR communication and a mobile terminal.

Since the experiment showed the concept to be feasible and since IR communication is supported in hundreds of millions of existing mobile terminals by their IrDA ports, the use of IR communication technology has a good foundation and will be elaborated in our future work. The open platforms of PDAs and new Symbian® based smart phones offer the possibility for realising physical selection in mobile terminals existing today and those to come during next years. Therefore, we intend to implement physical selection with IrDA equipped mobile terminals (smart phones) and experiment with new use cases.

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