# Using While Moving: HCI Issues in Fieldwork Environments

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"Using while moving" is the basic ability fieldwork users require of a mobile computer system. These users come from a wide range of backgrounds but have in common an extremely mobile and dynamic workplace. We identify four specific characteristics of this class of users: dynamic user configuration, limited attention capacity, high-speed interaction, and context dependency. A prototype is then presented that was designed to assist fieldworkers in data collection tasks and to explore the HCI design issues involved. The prototype was used in an extensive field trial by a group of ecologists observing giraffe behavior in Kenya. Following this trial, improvements were made to the prototype interface which in turn was tested in a subsequent field trial with another group of ecologists. From this experience, we have formulated our resulting ideas about interface design for fieldworkers into two general principles: Minimal Attention User Interfaces (MAUIs) and context awareness. The MAUI seeks to minimize the attention, though not necessarily the number of interactions, required from the user in operating a device. Context awareness enables the mobile device to provide assistance based on a knowledge of its environment.

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## 1. INTRODUCTION

This article presents some findings and proposals for new research that have arisen from our work on the "Mobile Computing in a Fieldwork

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Environment" project (http://www.cs.ukc.ac.uk/projects/mobicomp/Fieldwork/index.html) at the University of Kent at Canterbury, a project that is sponsored by JTAP (JISC Technology Applications Programme—http://www.jtap.ac.uk/). Our main research interest is in the development of novel software tools for the mobile fieldworker that exploit existing handheld computing and sensor technology. The work described in this article concentrates on examining the special needs and environment of the fieldworker, reflecting on the HCI features required for a successful PDA (Personal Digital Assistant) for use in the field.

First, we examine the nature of fieldwork and its inherent mobility, and then present the prototype fieldwork tools that we have developed for use in this dynamic environment. The remainder of the article is devoted to the discussion of minimal-attention user interfaces and context awareness, the two general principles that have aided in the prototype tool's success.

## 2. THE VERY MOBILE NATURE OF FIELDWORK

Handheld computing appliances are typically envisioned as tools within the businessperson's domain, where the executive is accompanied by a subset of their business data stored on a PDA. During a meeting at the office or whilst commuting to work on the train, the PDA allows them to work with their data at a location of their choice. However, the world of the businessperson is far removed from the environment of the fieldworker. Perhaps one of the most striking differences can be seen in terms of usage patterns. The businessperson will normally be seated at a desk to use their PDA, or perhaps with the PDA rested on their lap. We could, therefore, describe this as portable computing rather than truly mobile computing because, although the user can roam anywhere with their PDA, it is generally with the intention of bringing computing resources to use within a static workplace rather than to use them whilst on the move. The fieldworker's environment, however, is a much more dynamic one, where the PDA will be utilized throughout the course of the user's work, often spread over a wide geographic area. That is, the usage of the PDA is truly *mobile*.

*Static usage* of PDAs poses HCI challenges centered around the problems arising from the ever diminishing size of the hardware, e.g., examining how software displays can be adapted to the dramatically smaller PDA screens as in Kamba et al. [1996], Sarkar et al. [1993], and Scholtz et al. [1997]. However, at least the environment of use is still in common with traditional desktop or laptop PCs. Mobile usage of PDAs offers even more challenges, as not only do the issues of miniaturization have to be addressed but also the completely different user environments. We believe that the requirements of computing hardware and software intended for mobile usage are significantly different from that of their statically used counterparts, and it is these different requirements and how to satisfy them that we are interested in.

Kristoffersen and Ljungberg [1999b] suggest three categories of mobility: wandering (where the user wanders around with no one specific destination as part of their day to day work), traveling (where the user spends some time traveling in a vehicle in order to get to a particular location), and visiting (where the user may spend some time in different locations). They also classify the technology used into mobile, portable, and desktop categories. However, these classifications focus on the mobility of the *user* and *device* respectively, whereas we are more interested in the mobility of the activity. We believe it is the amount of mobility that the user requires whilst simultaneously using a device that is the primary factor in influencing its design: hence our classification of static usage and mobile usage.

We have concentrated our efforts in the areas of ecological and archaeological fieldwork in particular, as two members of the project have backgrounds in these areas, and we have a number of contacts who are keen to trial our prototypes. However, the ideas and prototypes we have been developing are intended to be widely applicable and are not solely aimed at these areas. Indeed, much of our work is valid for applications that require mobile usage but are outside of the fieldwork arena altogether, e.g., PDA tourist guides [Cheverst et al. 1999], tools for a field service engineer [Kristoffersen and Ljungberg 1999a], etc.

## 3. FOUR CHARACTERISTICS OF THE FIELDWORKER USER

The nature of fieldwork has been described in general terms as highly mobile, where the fieldworker will use the PDA throughout a variety of environments during the course of some work. More specifically, the most common form of fieldwork carried out is data collection. The aim of this activity is to record data about the environment that the user is exploring. The unique nature of mobile usage requirements within this context can be identified by four characteristics:

—*Dynamic User Configuration*. The fieldworker will want to collect data whenever and wherever they like, but it is extremely unlikely that there will be any chairs or desks nearby on which to set-up their computing apparatus. Nevertheless, the fieldworker will still want to record data during observations whether they are standing, crawling, or walking (all of which would be quite normal in fieldwork conditions).

—*Limited Attention Capacity*. Data collection tasks are oriented around observing a subject. Depending upon the nature of the subject the user will have to pay varying amounts of attention to it. "Snap-shot" observations require little more than recording the current state of the subject at a particular point in time. However, many observations are carried out over a more prolonged period of time during which the fieldworker must keep constant vigil on the subject to note any changes in state, e.g., observing animal behavior. In these situations the user needs to spend as much time as possible in observing and to minimize the time devoted to interacting with the recording mechanism.

—*High-Speed Interaction*. The subjects of some time-dependent observations are highly animated or, more commonly, have intense periods or "spurts" of activity. The fieldworker is normally a passive observer whose work is subject-driven; therefore, during these spurts of activity they need to able to enter high volumes of data very quickly and accurately, or it may be lost forever.

—*Context Dependency*. The fieldworker's activities are intimately associated with their context or, if different, the subject's context. For example, in recording an observation of a giraffe, its location or the location of the observation point will almost certainly be recorded too. In this way the data recorded is self-describing of the context from which it was derived. Further applications of the data often involve analyzing these context dependencies in some form, e.g., plotting giraffe observations on to a map if location is part of the context.

The relative importance of these four factors can vary with different fieldwork. For example, in testing our prototype software we have been involved with two projects: a giraffe observational study in Kenya [Pascoe et al. 1998] and an archaeological survey near Sevilla, Spain [Ryan et al. 1997] (we refer mainly to the Kenyan work in this article). The giraffe behavioral study strongly exhibited all four of the above characteristics, whereas in the archaeological study the characteristics of limited attention capacity and high-speed interaction were not so pronounced. The differences lie in the nature of the data collection subject; giraffe are very animated whereas Roman pottery is quite static. However, these attention and speed factors are still of importance in archaeological fieldwork because, although the pottery may well be fixed in absolute terms, the archaeologist will walk around an area and note any interesting subjects they pass by. Therefore, relative to the observer, the focus of observation is changing quite rapidly, and the amount of attention that can paid to observations and the speed of recording them are limiting factors as to how quickly the fieldwork can be completed.

As an example of parallel research to ours, the work of telecommunication service engineers and maritime consulting staff is examined in Kristoffersen and Ljungberg [1999a]. These mobile workers exhibit many of the same characteristics as our fieldworkers; indeed, climbing up a telegraph pole to fix a telecommunications installation is not so different to climbing up an acacia tree to observe a giraffe in terms of the mobility requirements of a PDA, except perhaps for the high-speed interaction requirement. However, the authors have chosen to focus on identifying the general characteristics of the work context rather than the general characteristics of the user as we have done. We believe that the different approaches are complementary, and both highlight the limited attention capacity and dynamic configuration of the user, though our work also addresses the typically context-dependent nature of mobile work.

## 4. THE FEATURES OF A PROTOTYPE FIELDWORK TOOL

We have constructed some prototypes to experiment with providing fieldworkers with mobile computing technology that aims to satisfy these requirements. We have concentrated on developing novel software applications that utilize existing low-cost hardware rather than employing custom-made or expensive equipment, making it more attractive for our user groups to consider deploying. However, we have carefully examined the available devices and evaluated their suitability for fieldwork environments through the following criteria:

—*Pen User Interface*. We found that the flip-open "clam-shell" pocket computers equipped with miniature keyboards were not suitable for fieldwork environments, where the user is typically standing or walking whilst operating the device. Although ideal for static situations where they can be rested on a work-surface, in-hand use of these devices requires both the user's hands and often involves a clumsy method of typing with one's thumbs. Pen-based interfaces on a pad-like device provide a more ergonomic solution that can be held in one hand if simply viewing data; they generally use some form of handwriting recognition for entering data. They provide a natural substitute for the fieldworker's paper notebook: similar in size and operation, and suitable for use by the user in many different dynamic situations (e.g., whilst walking).

—*Small and Unencumbering Form Factor*. Given the nature of some of the work it is important that the equipment does not encumber the user's body or senses in any way. For example, in searching for an elephant in dense bush the user will use their sense of sight and hearing to the full and, should the elephant give chase, will need to be able to run to the best of their ability! Therefore, we have limited our equipment selection to small handheld computers, ideally of a size that would unobtrusively fit into a trouser pocket when not in use.

—*Battery Life*. A typical fieldworker will spend a day in the field before returning to a base camp. Therefore, a device that can be used for at least a whole day without requiring replacement batteries is desirable.

—*Robustness*. The very nature of the environment makes it necessary to have devices that are able to cope with knocks, drops, and the general conditions of outdoor life, including heat, dust, rain, etc. In short, a very durable device is required.

—*Connectivity*. Sensors may be used to automatically obtain some data values if there is a way of connecting them to the main device. However, the process of data collection is not an end in itself. The collected data will need to be downloaded to a desktop computer for analysis and detailed study once the fieldwork has been completed. Therefore, it is necessary to have a device that can be easily connected to both a PC and various sensor devices.

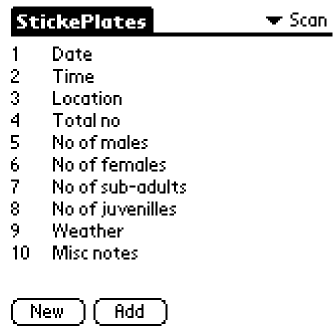


Fig. 1. Using the StickePlates program to create a template for giraffe observations.

Based on these criteria, we chose the 3Com PalmPilot as the most suitable device. There are a number of specialized manufactures of ruggedized mobile computers, but we wished to select a device that was reasonably priced, widely available, and suitable for a variety of mobile environments, not just in fieldwork.

In developing the first software prototype we wanted to provide some easy-to-use tools that allowed the fieldworker to collect data in electronic form. These would provide us with a platform for experimentation of our ideas to make data collection easier and quicker by the provision of various forms of assistance on the PDA.

The tools took the form of a suite of three prototype programs based on the stick-e note metaphor [Brown et al. 1995], similar in concept to Fitzmaurice's situated information [Fitzmaurice 1993], in which electronic notes can be attached to a context. For example, a description of a shard of Roman pottery could be tagged to the location of the find. However, rather than just recording simple textual notes, fieldworkers can record quite elaborate sets of data such as behavioral descriptions. To accommodate this requirement, we extended the stick-e note metaphor by eliminating the distinction between context and content. The resulting stick-e notes consist of a variable number of elements that can be viewed as both data and context (due to the self-describing contextual nature of field observations). Employing this new notion of stick-e notes we developed the following three prototype programs:

—*StickePlates*. Most data collection work involves recording observations as standard sets of data (e.g., recording the date, time, location, pottery type, and description, for each archaeological find). The StickePlates program allows the user to define a number of note templates in advance for such data. See Figure 1.

—*StickePad*. This program provides the recording facilities with which the user can create new notes, based on a predefined template, or modify existing ones. The StickePad will be the most frequently used tool, so it is especially important for this program to be designed in harmony with the fieldworker's mobile usage characteristics. See Figure 2.

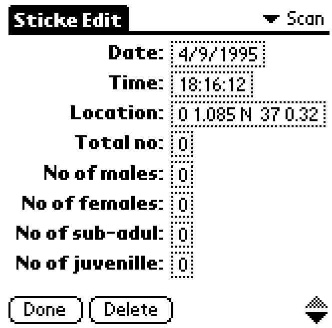


Fig. 2. Recording a new giraffe observation note in the StickePad.

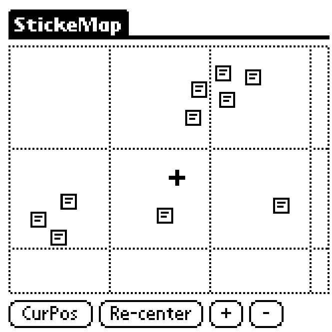


Fig. 3. Viewing the user's location (the cross-hair) in relation to the recorded notes (the note icons) in the StickeMap.

—*StickeMap*. A map screen is provided that offers an alternative method of visualizing and selecting notes to the StickePad's simple sequenced list. Icons denoting notes are overlaid onto the map and can be selected in order to view or edit their contents. See Figure 3.

We have tested the system in a number of environments, the most rigorous of which was a two-month behavioral study of giraffe in Kenya [Pascoe et al. 1998]. In this trial a willing ecologist, Kathy Pinkney, replaced her paper notebook with our prototype for the entire period of her fieldwork, using it for all of her data collection tasks. The focus of her research was to investigate the feeding behavior of giraffe in order to assess their impact on the vegetation within the Sweetwaters game reserve. To do this effectively she needed to collect a large amount of raw observational data of giraffe feeding. For each nibble of the branch that a giraffe took Kathy would have to record the location, time, tree species, feeding height, and number of bites taken, in addition to any other activities the giraffe indulged in in-between nibbles. The giraffe's voracious appetite for acacia and general restlessness make recording the observations very difficult, especially considering that the ecologist will need to look through a telescope and operate a stopwatch at the same time. In fact, such tasks are so difficult in traditional paper-notebook recording methods that an assistant note-taker is normally required. Our aim was to provide a computer-based solution that would allow the ecologist to collect all the necessary data single-handedly.

We are aware of one other project that aims to utilize fieldwork tools in African ecology work [Bailey 1997]. However, their interests lie in allowing illiterate trackers to accurately record the location of animal sightings through a simple pictogram interface, rather than assisting the ecologists to record large and complex data sets.

The simple form-based interface of our prototype software embodied the design philosophy of PalmPilot software: "if it needs a manual then it's too difficult to use." Rather than providing a radically new interface design from what the ecologist may have previously encountered, we instead sought to provide innovative features set within a familiar interface metaphor. This approach allowed Kathy to quickly learn how to use the system on the plane flight from England to Kenya. Once in the field, she created a number of templates to define data sets for observations, including vegetation surveys, giraffe behavioral observations, and giraffe feces records. The prototype software proved itself indispensable in the recording of giraffe behavioral observations. Through a combination of automation and optimized modes of interaction, more data were recorded at a much faster rate than would otherwise have been possible with a single observer using a manual recording medium.

Each day of the two-month study the PalmPilot software was used to record giraffe observation data, which was then downloaded to a laptop computer at the research center each night. This data would be electronically shipped back to England every two weeks when collecting supplies from the nearest town (which also happened to have a doctor's surgery offering an email service). At the end of the study approximately 6000 observations had been recorded. Apart from a few minor bugs in the code, the prototype performed at a level that allowed the ecologist to complete more work, in a way that was both faster and easier, than is possible in a manual system. The HCI factors in the prototype that led to this success can be formulated into two general principles:

—*Minimal Attention User Interfaces.* Providing interface mechanisms that minimize the amount of user attention, though not necessarily the amount of user interaction, that is required to perform a particular task.

—*Context Awareness [Schilit et al. 1994].* Imbuing the device with the capability to sense its environment.

The remainder of this article describes in detail how both of these principles were applied in the prototype system and discusses our work on further enhancements and research arising from our experiences in the field.

Fig. 4. The ecologist observes the giraffe whilst simultaneously recording data on the PalmPilot using the MAUI.

## 5. THE MINIMAL ATTENTION USER INTERFACE (MAUI)

MAUIs seek to satisfy the needs of the fieldworker with respect to their characteristics of dynamic user configuration and low attention capacity. An example of a task in the Kenyan fieldwork that illustrates both of these characteristics particularly well is the detailed giraffe observation. During one of these observations the ecologist was often hiding behind vegetation, walking through the bush, or crouching over a telescope (see Figure 4). Data needed to be recorded in any of these circumstances. Additionally, observing a giraffe's detailed feeding behavior (such as the number of bites taken from a particular acacia tree) required a great deal of attention. This is especially true when observing from a distance through a telescope, where, unless the user pays constant attention, the giraffe can quickly move out of the field of view.

Conventionally, handheld computers require the direct attention of the user for the whole duration of a particular task. During this period all of the user's attention is focused onto the device. For example, to select a document the user will hold their PDA in one hand, select the document with the pen held in the other, and all the time be looking at the device in order to correctly operate the interface. In a fieldwork environment this distracting process can negatively affect the quality of the work. Note that it is not the number of interactions occurring that is the important factor, but the amount of attention that they require from the user.

A MAUI attempts to remedy this situation by transferring interaction tasks to interaction modes that take less of the user's attention away from their current activity. In effect it is about shifting the human-computer interaction to unused channels or senses, and in a way that is not so cognitively demanding to distract the user from the task at hand. As a small experiment of this idea, our prototype software overloaded two of the hardware buttons of the PalmPilot device with a configurable increment and decrement function. These buttons could then be used to manipulate sequential data with less attention from the user because the buttons provided enough tactile feedback without requiring the user to actually look at the device. The user could configure the amount decremented or incremented by these buttons for particular types of data (e.g., tree height may increment in units of five meters and giraffe bites in steps of one). This feature was most usefully employed in counting giraffe bites from a tree: here the ecologist could keep a running total of the number of bites taken—just by clicking a button for each bite—whilst simultaneously observing the giraffe through the telescope. In effect, this is an eyes-free form of human-computer interaction.

We are exploring other methods to optimize the eyes-free MAUI of our prototype. The touch-sensitive screen provides one opportunity. If it is divided into selectable areas, say four quadrants, a particular function or data value can then be assigned to each of the quadrants, e.g., a tree species selector where top-left = acacia, top-right = uclea, bottom-left = scutia, bottom-right = other. The user can easily identify the four corners of the screen with their thumb and hence operate the interface in eyes-free mode (especially if some form of audio feedback is given). Although we may not be able to divide the screen into enough areas to support all functions or data types, we can certainly implement the most frequently required options to optimize for an eyes-free mode of operation. However, lack of tactile feedback from the touch screen may be of concern.

Our interest in MAUIs is not limited to eyes-free forms of interaction but also covers other methods that attempt to minimize the amount of distraction caused to the user's activity. One-handed operation is such a method. Although the user may need to occasionally look at the screen, one-handed operation allows them to operate the device with one hand whilst continuing to perform tasks with the other. Such a facility is useful in many diverse situations, not just in fieldwork. For example, consider the businessperson who wishes to consult their diary and to-do lists for the day whilst walking to work with their briefcase in one hand and their PDA, retrieved from their pocket, in the other. In such circumstances the hand that holds the device also has to perform the interaction tasks. Small devices such as the PalmPilot are ideally suited to this type of activity as they can be easily held in one hand whilst leaving the thumb free for manipulating the screen or buttons.

Thus far we have only discussed operating on individual portions of a complete data set or task. We also inherently need a minimal-attention method of navigating between these individual features. This was the area of the prototype interface that proved least successful in the first Kenyan trial. For example, to edit a note the user had to decide which field of the note to select, perform the editing operation using the type-specific controls, return to the list of fields, and then decide the next field to edit.

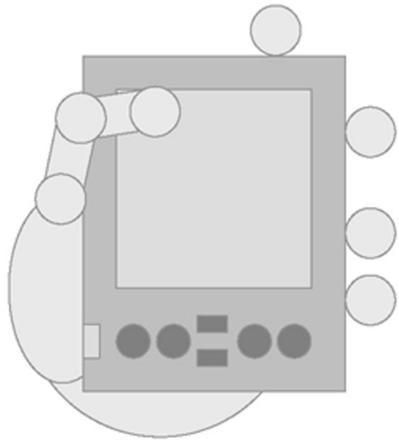

Fig. 5. Most comfortable grip for one-handed operation.

Although this was easily executed, a problem arises when the user's concentration is directed elsewhere, such as toward a giraffe: the number of decisions and manipulative processes involved in selecting and modifying the data appropriately become a distraction to the main task at hand. To improve this situation the form-filling interface could be structured as a set of "layered" screens, one for each data element. The user would then be presented with a sequence of these screens that are optimized for minimal attention, much like filling in a questionnaire question by question. Note that, as with many of the features presented, this would be an optional enhancement to the existing system rather than a replacement, because if the user's attention is not pressed then they may prefer to work with the data in the "bigger picture," e.g., viewing the whole form whilst editing a small field within it.

We have attempted to combine our ideas of layered sequential screens with those of eyes-free or one-handed controls in the second generation of the prototype fieldwork tools in order to provide a better MAUI (i.e., one that can be operated with even less distraction to the user's activity). This has been tested in another field trial with the ecologists in Kenya. This time the fieldwork requirement that drove our designs was the need for rapid data collection carried out in parallel with other manual activities. An example that illustrates this need is elephant dung pile counting. In this task the ecologist briskly walks a 10-kilometer transect recording the location and number of elephant dung piles on each 500-meter leg of the journey. They may also record any other animal sightings of interest along the way and will often be using their binoculars. We concentrated on providing a one-handed mode of operation for such activities so that the fieldworker could easily operate the prototype whilst walking, looking through binoculars, tracking animals, etc.

The first design decision in developing our one-handed MAUI for the second-generation fieldwork tools was to find the most comfortable fit in the hand for the device and to select the control surfaces we would use.

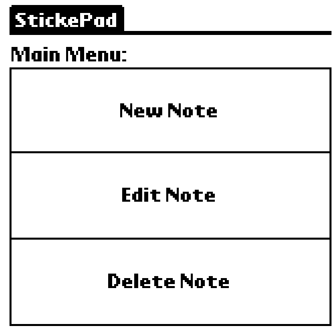


Fig. 6. StickePad main screen in one-handed mode.

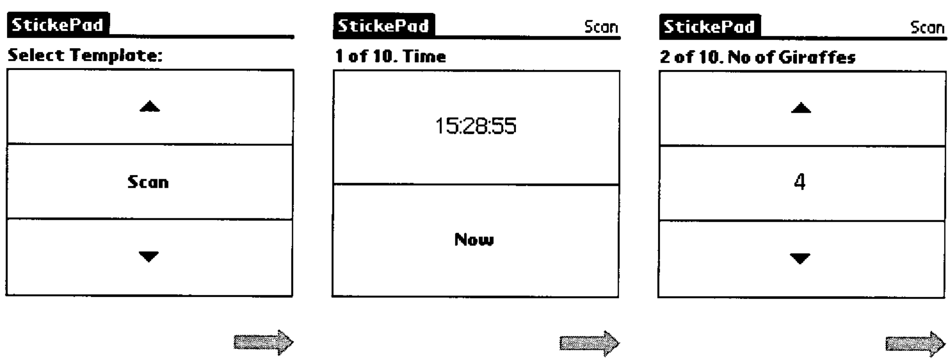


Fig. 7. The first three of a sequence of one-handed controls to enter a new note.

Figure 5 shows the most comfortable and secure method we found to hold the device with one hand, which leaves the thumb free to operate the device. However, the touch screen and hardware buttons cannot be used together, as the hand can only be positioned to place the thumb exclusively on either control surface: the thumb is not extensible enough to be able to use both surfaces from the same hand position. We decided to use the hand position that favors the touch screen, as this control surface offers much more flexibility in the design and presentation of the MAUI controls.

In such a hand grip the thumb is more easily maneuvered in the vertical plane than the horizontal, so the one-handed MAUI constructs its control elements as a series of stacked lateral bands, equally suited to both left- and right-handed users. The main screen of the MAUI-enabled StickePad, as shown in Figure 6, consists of three buttons that can be activated with a tap of the thumb to select the appropriate function. Selecting the "New Note" button invokes a sequence of one-handed controls through which the user progresses to create a new note, as shown in Figure 7. In the first control (a list selection control) the user chooses a note template by scrolling through the possible choices using the up and down arrow buttons, then pressing the central button when it displays the desired template name. The remaining controls in the sequence allow the user to enter data as appropriate for the note. The example used in Figure 7 shows

Table I. Two Example Uses of Multiple Taps

| Taps | Sequence Navigation | Number Editing |
|---|---|---|
| 1 | Next field/control in sequence. | Increment or decrement (depending on which button pressed—up or down arrow) by 1. |
| 2 | Previous field/control in sequence. | Increment or decrement by the number-specific step amount. |
| 3 | Jump to the first field/control in the sequence. | — |
| 4 | Jump to the last field/control in the sequence. | — |

a time control, which can be updated with the current time, and a numeric control that can be incremented and decremented using the arrow buttons. As with the list selection control, once the desired data value is shown it is tapped with the thumb to select it. Controls exist to manipulate all the Stickepad's data types except for textual data. A control does exist to display the textual data, but it uses a normal text editing dialog box if it needs to be edited, as editing text with this one-handed method is probably too cumbersome to be useful.

In addition to designing an optimal layout of controls for one-handed operation we have also investigated the use of multiple taps. Using this technique a button may have more than one function assigned to it depending on the number of taps of the user's thumb on the touch screen. This is equivalent to the single- and double-clicks commonly executed on mouse buttons. A single and double tap can be easily performed on the touch screen, and even treble and quadruple taps. However, both the physical operation and cognitive load of remembering the number of taps for different functions make it prohibitive to exceed quadruple taps. In the prototype MAUI, we commonly make use of single and double taps, and use treble and quadruple taps more sparingly for functions that are used less often. One of the most useful examples of using the multiple taps in the StickePad is to navigate through the sequence of controls used to edit or enter each field of a note, as shown in the examples given in Table I.

The multiple taps operate on the particular part of the control to which they are applied, e.g., double clicking on the number control's up arrow for incrementing is obviously different to clicking on the number control's down arrow for decrementing. In sequence navigation, multiple taps are directed at the data display part of a control, e.g., the number displayed in the numeric control.

There is one other one-handed input technique: the thumb stroke. This involves running the thumb from the top of the screen down past the halfway mark and the reverse action starting from the bottom of the screen. This is a very fast and fluid motion and is used in the StickePad program to quickly flip between one-handed mode and normal mode (where the user may be interested in looking at the overview of collected data displayed on the main screen). The thumb stroke is available to the user whatever the current mode. Importantly, this allows the user to effortlessly

Table II. Interaction-Mode Characteristics for the Ecology Fieldwork Activity

| | Visual | Audio | Tactile |
|---|---|---|---|
| Environment (African bush) | | Restricted. Cannot make much noise in case animals are disturbed. | |
| User (ecologist) | | | |
| Task (giraffe observation) | Prohibited. Ecologist will need to keep her eyes on the giraffe under observation. | | |
| Tools (PalmPilot and data collection software) | Small screen (160 × 160 pixel). | No microphone. Very limited audio output through internal speaker. | Four tactile hardware push buttons. Touch screen. |

switch to one-handed mode using a one-handed operation rather than needing to activate the menu and then select the option from a menu item in normal mode (which would require two hands).

In general, we are designing interfaces based on a model of the fieldwork activity, not on a model of the fieldwork data. Although some interface elements are created to manipulate particular types of data, it is the user's activity that shapes the design of our interface. Identical data may have completely different interfaces, depending on the user's activity. For example, in the field the ecologist may want a simple and direct interface that is oriented to recording data quickly, whereas back in the laboratory the user will likely view the same data in a much more rich and complex form, such as in a GIS (Geographical Information System). It may be tempting to encode the visual interface into the logical template descriptions (as is often the case with HTML documents), but this severely limits the flexibility and portability of the data model. Therefore, we have been careful to keep interface and data models distinct in our prototypes.

One final opportunity in developing MAUIs for fieldwork lies in the new hardware capabilities that are becoming available in-built on PDAs or available as attachments. For example, microphones are becoming more prevalent with handheld computers and provide opportunities for voice recognition, whilst small vibrating units (typically used by pager software) offer the developer another means of providing feedback to the user. Other innovative forms of hardware interface mechanisms are explored in Harrison et al. [1998], which investigate how various tilt and touch sensors can be employed to manipulate the device through physical movements.

The design of our MAUIs is strongly influenced by the characteristics of the ecology fieldwork activities. In particular, the interaction modes that the MAUI utilizes are selected to best fit the characteristics of the fieldwork activities. In order to assist in a more general understanding and comparison of how different activities affect the choice of interaction modes

Table III. Interaction-Mode Characteristics of our MAUIs

| | | Visual | Audio | Tactile | Data Types |
|---|---|---|---|---|---|
| Eyes-Free Push-Buttons | Input | | | Hardware buttons. | Numeric. |
| | Output | | | | |
| One-Handed Oversized Controls | Input | | | One-handed thumb-driven input via touch screen. | Numeric, picklist, location, time, date, bearing, data series. |
| | Output | Easy-to-read oversized controls. | | | Numeric, picklist, location, time, date, bearing, data series. |

in a MAUI, we can construct a table of the activity's interaction-mode characteristics, as the example in Table II illustrates.

In order to more precisely describe exactly where in the activity the interaction-mode characteristics originate, we have divided activity into environment, user, task, and tools. Each of these aspects of the activity may prefer, restrict, or prohibit the use of a particular mode.

In the ecology fieldwork activity in Table II we can see that the use of the audio mode in a MAUI would not be a particularly good choice given the restriction imposed by the environment and the very limited audio capabilities of the tools. Additionally, the giraffe observation task requires the full attention of the user's eyes, prohibiting the use of the visual mode in a MAUI. However, there are no restrictions imposed on the tactile mode by any aspect of the activity: in fact the tools even offer a few methods of exploiting this mode. Therefore, in selecting or designing a MAUI for this activity, we would seek to choose one that primarily exploits the tactile mode.

Comparing the interaction-mode characteristics of our MAUIs (Table III) with that of our activity (Table II) enables us to select the eyes-free push-button MAUI as the best interface for the ecology fieldwork activity. However, we also need to make sure that the data types that need to be entered and conveyed in the activity are supported in the chosen MAUI (in the fieldwork example, the majority are).

Complex activities may span more than one environment, user, task, or tool. If these present incompatibilities in interaction-mode characteristics, then the activity needs to be divided into subactivities in which the interaction-mode characteristics are compatible. An appropriate MAUI can then be designed or selected for each subactivity. Additionally, if the MAUI designer is able to choose the tools that are used in the activity, then they will be selected to suit the chosen MAUI rather than the MAUI chosen to suit the tools. The tools only appear on the activity's interaction-mode

Table IV. Interaction-Mode Characteristics for Navigating for the Blind

| | Visual | Audio | Tactile |
|---|---|---|---|
| Environment (urban area) | | | |
| User (blind person) | Prohibited. No visual sense. | Restricted. Do not want to interfere with the person's awareness of their environment. | |
| Task (navigation) | | | Restricted. Person may be carrying shopping, a cane, etc. |

characteristic table if they are a fixed part of the activity, as the PalmPilot effectively was in our case due to our development investment in it. If we could have chosen any tools, then perhaps a device with a chording keyboard would have been our selection, since it allows a more sophisticated use of the tactile mode.

In summary, the "minimal attention" in the "minimal-attention user interface" is achieved through the effective use of modes of interaction that least distract or interfere with those that the user is employing in their current activity. This complementary use of interaction modes is the key to successful MAUI design.

MAUIs tend to be constructed for specific activities rather for general-purpose use, in both our work and others: for example, in developing navigation aids for the blind [Strothotte et al. 1996] and assistants to field service engineers [Kristoffersen and Ljungberg 1999a]. By constructing tables of interaction-mode characteristics for these activities, we are able to more rigorously compare them with other activities, as well as to select or design an appropriate MAUI that uses complementary interaction modes. For example, considering the navigation aid to the blind, a table can be constructed (Table IV).

Note that the table includes no tools aspect to this activity because we have assumed that we have a choice of technology. On comparison with the table for the ecology fieldwork activity we can see that the prohibition of the visual mode is shared. However, in this activity the audio mode is less restricted than the tactile one, which could be prohibited altogether in certain situations (e.g., when carrying a lot of shopping). Therefore, a MAUI that primarily utilized the audio mode, with perhaps some auxiliary use of the tactile mode, would be best suited for a navigation aid for the blind. Similarly, Table V shows that the activity characteristics of the telecommunications service engineer also make an audio-based MAUI the best selection, though for different reasons.

We hope that by explicitly identifying interaction-mode restrictions and their origins in this way will enable developers to more easily and accurately identify similar activities in terms of their interaction-mode usage

Table V. Interaction-Mode Characteristics for Telecommunications Field Servicing

| | Visual | Audio | Tactile |
|---|---|---|---|
| Environment (up a telegraph pole) | | | Restricted. User needs at least one hand free to hold on to the pole. |
| User (field engineer) | | | |
| Task (field servicing) | Restricted. The user will wish to keep her eyes on the facility under repair for most of the time. | | Restricted. May be carrying lots of other equipment. |

(the applications could appear quite different in other ways). It should also assist in quickly identifying existing MAUIs that can be successfully deployed for a particular activity, or in specifying the interaction-mode requirements or limitations for the design of a new MAUI.

## 6. CONTEXT AWARENESS

The fieldworker is generally equipped with a plethora of equipment to assist in the observation process. In the Kenyan study, for example, a map and compass would have been required to pinpoint location and a stopwatch required for recording time series data such as giraffe behavioral observations. However, rather than taking more equipment out into the field, we believe that a fieldworker endowed with a PDA will actually take out less. The reason for this apparent paradox is that we wish to assimilate as many of the other equipment interfaces into the PDA as possible and to automate their operation. In addition, instead of providing an electronic "copy" of the device, we aim to embed the appropriate function within the task it is related to: for example, automatically entering the current location into a new observation note. This is achieved by making the PDA aware of its context through various attached or embedded sensors so that it is able to supply context information when needed. This concept of context awareness in the form that we know it today was pioneered by Schilit et al. [1994].

In our prototype we made our programs aware of two elements of their context that are useful in a wide array of activities: time and location. Knowledge of time is easily obtained through the unit's own internal clock, and this can be used to provide various timing functions that eliminate the need for a stopwatch. Location was provided through an attached GPS (Global Positioning System [Herring 1996]) receiver that could pinpoint the user to within 100 meters anywhere in the world (given an unobstructed view of the sky). The GPS receiver was a separate unit attached via a serial cable, but we expect GPS receivers, or an equivalent technology, to be integrated with PDAs in the near future. However, decisions on the nature of the physical hardware integrated with the device need not limit context-aware technology, as from a few basic sensors a number of software-derived

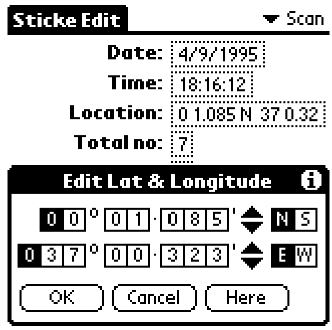


Fig. 8. Editing a location field in the StickePad illustrates how context awareness can be used to expedite data collection, in this case by automatically entering the user's location (derived from an attached GPS receiver) and allowing it to be easily updated via the "Here" button.

context elements can be generated. For example, a tide-level context element can be computed from the location and time context elements. Similarly, a "dominant vegetation" context element can be derived from a location and GIS vegetation map. In fact, the wealth of potential context information has spurred us into developing a Context Information Service (CIS) in a related research project [Pascoe et al. 1999]. The same general experience in developing electronic tourist guides has led Georgia Tech in a similar direction [Salber et al. 1999].

One of the characteristics of the fieldworker described earlier was the need for high-speed interaction. Context awareness can help in this area by automating some aspects of the fieldworker's activities. In the prototype software the StickePad automatically defaulted any time or location fields of a newly created note to the current clock or GPS reading respectively (see Figure 8). Even such a seemingly minor enhancement made the ecologist's job much easier. For instance, recording giraffe feeding behavior through a telescope would normally have required two people, one to dictate the observations being made through the telescope and the other to use the stopwatch to record the times and details of the rapidly occurring events. However, the prototype system allowed a single person to perform both tasks by automatically completing the timing information as soon as the user indicated a new event had taken place, leaving them to simply enter a code for the behavior.

Another characteristic attributed to the fieldworker is their context dependency. As mentioned earlier, the data being collected are effectively a description of various elements of their context, and at a later date the complete collection of data will be compared and analyzed from the perspective of one or more of these context elements. For example, the collected notes could be plotted in a GIS in order to visualize and analyze the data from a location context element perspective. Equipped with a PDA we can effectively bring cut-down versions of these context visualization tools into the field, where not only can we view the various notes that have been recorded but also our presence relative to them. In the prototype we implemented a StickeMap program to demonstrate a form of context visualization by plotting the recorded notes and user's current position on to a configurable map (see Figure 3). Visualizing data using context information provides a powerful mechanism that allows the user to gain an overview of the data from a particular contextual perspective, to filter information that they are interested in, and to look for patterns in the data.

## 7. CONCLUSIONS

We have introduced the environment of the fieldworker as one that is significantly different from the typical business user and have presented our belief that this different environment should fundamentally affect the approach taken in the provision of PDA resources. In order to qualify these differences, four characteristics peculiar to the fieldworker have been identified from which a selection of hardware criteria and a prototype software system have been developed.

Based on successful trials of the prototype in different fieldwork projects, we have attempted to identify the essential HCI features of PDAs for the field and have defined two important principles. Firstly, the MAUI that, through the appropriate utilization of interaction modes, seeks to provide an interface that minimizes the amount of distraction from the user's activity as possible. Secondly, context awareness provides a method of automatically recording, presenting, and filtering information through a knowledge of the user's current environment. We have found that a combination of these two principles can deliver very effective solutions for the fieldworker and, in many cases, the mobile user in general.

## 8. FUTURE WORK

We intend to create more specialized applications, in particular a rhino tracking and identification tool and a rapid vegetation/dung survey tool, in our continuing collaboration with the Kenyan ecologists. With these applications we will explore the use of a variety of different context elements such as weather, habitat, footprint signs, etc., building on our context awareness work that has been primarily location oriented thus far. We will also experiment with triggering: the process of automatically making available the electronic resources that are of interest to the user in the present context. For example, the observational history of a rhino could be associated with its radio-collar in order for that information to be automatically made available to the ecologist when approaching the animal.

We will also develop the initial framework proposed in this article for comparing and matching MAUIs and activities. Our work thus far has concentrated on the development of MAUIs for one particular type of activity characteristics. However, we also intend to explore MAUI design for the many other general types of activity characteristics. There are also interesting possibilities in using context awareness to dynamically build the interface from reusable MAUI components that are most appropriate for the current conditions of use.

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