

No wires attached: Usability challenges in the connected mobile world

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Mobile computing platforms combining small, lightweight, low-power devices with wireless network connectivity enable the performance of familiar tasks in new environments and create opportunities for novel interactions. Since mobility imposes significant cognitive and ergonomic constraints affecting device and application usability, ease of use is central to devices in the fully mobile wirelessly connected (FMWC) world. In this paper, we consider mobility as an attribute both of the computer and the user. We explain the differences between transportable and fully mobile devices, and we contrast applications that are essentially FMWC applications, those that can be adapted to the FMWC context, and those that are unsuitable for it. We discuss the unique challenges to usability for mobile users and devices and their interaction, and we point out the increasingly critical role of usability in the mobile environment.

Mobile devices supported by wireless connectivity can dramatically change the ways in which people interact with computers. On the one hand, tasks that have been traditionally undertaken in a fixed setting, such as an office, can be performed in arbitrary locations (at least in theory.) On the other hand, many types of field work that had not been previously assisted by computers can benefit from instantly available computational and informational resources. Furthermore, the connected mobile world opens up numerous possibilities beyond the realm of work—expanding our leisure, entertainment, and informal

communication activities. The field of mobile wireless computing is continuing to develop rapidly, not only in the range of mobile devices (for example, personal digital assistants [PDAs], mobile phones, and wearable computers), but also in the range of available communication technologies (for example, the Wireless Applications Protocol [WAP], Bluetooth** wireless technology, and IEEE 802.11 wireless standards).

Attempts to understand the design and usability implications of the connected mobile world started more than a decade ago. These included the construction of taxonomies of mobile computers¹ as well as identification of some broad issues in mobile user interfaces.² At first, the intrinsic constraints of mobile devices were identified with technological limitations, such as poor computational resources (compared with static computers), limited energy sources, and less reliable network connections.³ Later, various aspects of human interaction with mobile computers came under scrutiny, including ergonomic constraints,⁴ properties of ubiquitous access,⁵ and collaboration in mobile environments.⁶ In the last few years, particularly intensive debates have focused on the problems of input and output mechanisms for mobile devices.

It is now clear that the goal of “anytime, anywhere, anyhow access for anybody”⁷ presents more chal-

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lenges to its inventors and designers than had been originally anticipated. While many existing technological restrictions may be only a few steps away from being resolved, a large number of environmental constraints and some limitations on the human side will remain. For a mobile solution to be successful, everyone involved in the development of various components must focus on the total user experience in general, and on usability in particular. This calls for technical specialists to attend meticulously to the impact of mobility on usability, and for usability experts to be well informed about one of the fastest growing segments of the human-computer-interaction (HCI) domain.

This paper presents a detailed analysis of the field of mobile wireless computing. Most contemporary mobile devices feature wireless connectivity. Typically, *mobile* is used as an attribute of a computing device; it implies that a device can be easily transported to a location where the user wants to interact with it. However, mobility in its usual sense conveys nothing about the user and the type of interaction. In this paper, we consider mobility an attribute of both the user and the device; we classify an interaction as mobile if both the user and the device can relocate during the interaction. Only those devices that support mobile interactions are fully mobile; devices that can be moved to a different location but require the user to remain stationary during the interaction are no more than transportable. To distinguish the specific case of fully mobile computing combined with wireless connectivity, we introduce the concept of fully mobile wirelessly connected (FMWC) computing, and apply it to devices, applications, and contexts of use. On the usability side, we see some critical differences between stationary interactions, where user movement is restrained, and mobile interactions, where various degrees of body movement are allowed, particularly, walking. Placing the interaction into a freely moving context, we face a whole new world of environmental and cognitive challenges that affect usability of devices and applications. Within applications that can be considered for FMWC devices, we distinguish three types: essentially FMWC applications, applications adapted for the FMWC context, and applications that are unsuitable for it. We describe the salient characteristics of each type and their impact on application usability.

The paper is written for both the technical and broad HCI communities. Both groups can benefit from the analysis of the FMWC field (see the section “Defin-

ing the space of mobile wireless computing”) that examines various classes of mobile devices and the three types of FMWC application. The section “Contexts and interactions in the FMWC world” also targets both reader audiences and describes two major types of mobile interaction context: the mobile office context and the field context. The following section, on implications for technical and HCI communities, emphasizes the importance of User-Centered Design (UCD) for creating easy-to-use FMWC products. Essential usability implications of the FMWC world that need particular attention from hardware and software engineers are then presented, followed by a discussion targeted for the HCI community focusing on methodological issues of UCD in the FMWC environment.

Defining the space of mobile wireless computing

The following section describes the spectrum of FMWC devices and how these devices, the applications that run on them, and interactions with them can be characterized.

Mobile, pervasive, ubiquitous or wireless? As in any new area of technology, the terminology of mobile wireless computing is still unsettled. Every now and then, the term *mobile wireless computing* is used in conjunction or interchangeably with *ubiquitous* or *pervasive* computing. Ubiquitous computing, first introduced at Xerox PARC (Palo Alto Research Center) in 1988, is “the method of enhancing computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user.”⁸ Some attributes of ubiquitous computing, such as instant availability to the user, may be similar to those of mobile computing, but the two are not synonymous. While the notion of a computer being with the user at all times is essential for mobile computing, ubiquitous computing emphasizes the invisibility of the computing environment; that is, the notion of computers being widely available and inconspicuous. Pervasive computing aims to “manage information and reduce complexity for a mobile workforce and a mobile society.”⁹ Pervasive computing emphasizes the networking capabilities of computers and, as IBM’s Pervasive Computing initiative defines the term, is about “everything [being] wireless, mobile, and voice.”⁹

Most often, however, computers that feature network connectivity on the move are described simply as mobile or wireless computers (the term *portable*

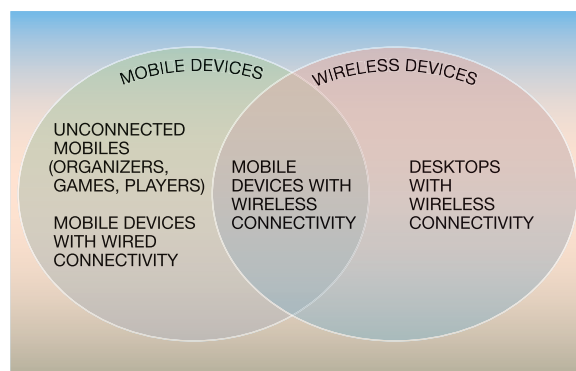
is also occasionally used.) Although common, each definition captures only part of the meaning of mobile connectivity. Not all mobile devices are enabled as wireless, and not all wireless devices are mobile. Figure 1 gives a more accurate view of the mobile and wireless categories. As a generic term for mobile wireless computing, *pervasive computing* seems most appropriate. However, for the purpose of evaluating usability of mobile wireless products, this definition is imprecise, as we shall see in the following sections.

Device mobility and modes of interaction. From the usability point of view, it is not the qualities of a computing device that are paramount, but the qualities of the interaction between the user and the device. A continuum of existing personal computers, of varying degrees of mobility, is shown in Figure 2, and this figure assists us in analyzing how the degree of device mobility determines possible interaction modes. Figure 2 presents the five major types of personal computers in existence today, with degree of device mobility increasing from left to right. This is an extension of a classification of personal computers by portability introduced by Weiss.¹⁰ We may characterize each device by two attributes: form factor (including dimensions and weight), and surface support requirements (whether or not the device needs to be held against any fixed surface outside of the user's body, or if the user's body is used to support the device).

Desktops. Desktop computers are large and heavy objects that require a fairly constrained physical arrangement of their components. Their input and output mechanisms are placed on firm horizontal surfaces for normal operation. In the mobility spectrum, we classify such computers as fixed. The only possible mode of interaction with a desktop is for the user to be 'glued' to the device's location. We call such an interaction mode stationary, as both the user and the device are stationary during the interaction.

Laptops. Laptop computers (including subnotebooks) are much smaller and lighter than most desktops. Similar to desktops, they need to be supported by a fairly firm, fairly horizontal surface while in operation (that is, a desk or the user's lap). Due to their smaller form factor, they can be moved to various locations and thus are classified as transportable in the mobility spectrum. Despite the fact that laptops can be moved from place to place, in operation both the user and the device must remain in one location. Consequently, the interaction mode is stationary.

Figure 1 Mobile and wireless devices



Palmtops. The design of palmtop computers¹¹ (sometimes known as clamshells) is similar to that of laptops, but the former are significantly smaller and lighter, and can often fit into a large pocket (such as the Psion Revo** Plus or the Hewlett Packard Jornada**). For very short interactions (no longer than few minutes), palmtops can be held in the user's hand, but even small palmtops must be placed on a table or another flat surface for efficient prolonged operation. Similar to laptops, in the mobility spectrum, palmtops are classified as transportable. The prevalent mode of interaction is stationary, despite the occasional non-stationary usage.

Handhelds. Handheld devices such as PDAs, pagers, and mobile phones, are small and lightweight and are best operated while held in the user's hand. According to Weiss,¹⁰ a computer must pass three tests to qualify as handheld: (1) it must be easily used while in one's hands, not resting on a table; (2) it must operate without cables, except temporarily, while recharging or synchronizing; (3) it must either allow the addition of new applications or support Internet connectivity. Similar to laptops and palmtops, handhelds can be easily relocated. Unlike palmtops, however, handhelds do not require surface support outside the user's body nor does the user need to remain in one location during the interaction. Therefore, in the mobility spectrum we classify handhelds as fully mobile. Since both the user and the device can change location while the user interacts with the device, handhelds afford their users a mode of interaction fundamentally different from the stationary mode. We call this mode mobile interaction.

Figure 2 Device mobility continuum



Table 1 Characteristics of personal computing devices

Device Type	Form Factor	Highest Degree of Mobility	Mode of Interaction	Modularity
Desktops	Large	Fixed	Stationary only	Fully modular input/output mechanisms
Laptops	Medium	Transportable	Stationary only	Single unit device with optional external output mechanisms (audio)
Palmtops	Small	Transportable	Stationary, with minor exceptions	Single unit device with optional external output mechanisms (audio)
Handhelds	Medium to small	Fully mobile	Mobile interaction enabled	Single unit device with optional external input/output mechanisms
Wearables	Small	Fully mobile	Mobile interaction enabled	Fully modular input/output mechanisms

Some ambiguity exists in categorizing tablet-type computers that do not have a keyboard and rely on a touch-sensitive input. While small tablets such as PDAs are a clear case of handheld computers, Weiss does not include larger tablets such as Microsoft TabletPC** or Stylistic** in the handheld category, “simply because of [their] size.”¹⁰ In contrast, we do consider larger tablets handheld computers because their mode of interaction is closest to that of handhelds.

Wearables. Wearable computing devices, or *wearables*, are essentially modular computers whose components are small and light enough to be worn on a user’s body for convenient operation. The input and output components of wearables are worn close to the user’s sensors (eyes and ears) and actuators (hands and mouth). By definition, wearables do not

need any support other than the user’s body, and this classifies them as fully mobile. Similar to handhelds, wearables enable mobile interaction. Incorporating input and output components and processing modules into the typical user’s personal items (for example, an inch-sized display projector that clips onto a user’s glasses or a keyboard that wraps around the user’s wrist) brings near invisibility to the wearables and makes them both mobile and ubiquitous.

Table 1 lists the form factor, degree of mobility, interaction mode, and degree of modularity for the continuum of personal computer types.

Within the group of devices classified as fully mobile, there are varying degrees of freedom of movement for the user. With handhelds, the freedom of movement is simply the ability of the user to walk

about while using the device. Some handhelds, like mobile phones, permit one-hand device operation. With some handhelds and wearables, freedom of movement extends to the whole body, including hands-free interaction and, in some cases, eyes-free interaction. Eyes-free mode is the ultimate in freedom of movement during interactions, as interaction requiring visual attention still constrains free body movement.

The focus of the rest of the paper is on fully mobile, wirelessly connected (FMWC) devices, the applications running on them, and their usage environments. The difference between stationary and mobile interaction modes has significant implications for usability of FMWC computers in different usage contexts. Consideration of the effects of mobility should influence not only the design of FMWC hardware, but also the choice of applications appropriate for a fully mobile environment. This consideration is discussed in detail in later sections.

Network connectivity continuum. Networks can be either wired or wireless, and a network connection can be either permanent or intermittent. Table 2 lists various types of personal computers according to the connection configuration they support on the move, if any.

Transportable and fully mobile communicating devices inevitably have to deal with circumstances where communication is not available for a period of time. These intermittently connected devices and their applications need to compensate for the lack of an available connection. In this case, some applications will require that the information necessary to perform a task be obtained in advance when a connection is available and retained for operation when disconnected. Similarly, applications may need to store information obtained when disconnected and transmit it after a connection becomes available.

Classifying applications. Usability in a mobile environment is influenced both by the effects of mobile interaction and by the nature of applications running on FMWC devices. These may be communication applications (for example, e-mail and Web browsing) or non-communication applications (for example, word processors and spreadsheets). Dornan¹² provides a comprehensive guide to wireless communication applications, describing in detail the underlying technologies and emerging services.

Table 2 Network connectivity and device types

	Wired	Wireless
Permanent	Desktops	Desktops
Intermittent	Laptops, palmtops	Laptops, palmtops, handhelds, wearables

Table 3 classifies applications (communication and non-communication) based on how appropriate they are for the FMWC hardware and environment. We distinguish the following types of applications:

- Essentially FMWC applications, which must be both mobile and wireless,
- “Adapted for FMWC” applications, which may be enabled on a FMWC device, and
- “Unsuitable for FMWC” applications, which are inappropriate for the FMWC environment.

In Table 3, a cell is marked with “No” if a particular application cannot exist on a particular hardware type, with “Yes” if it does or can, and with “Conditional” if it exists conditionally (see the section “Applications adapted for the FMWC context” for further detail on conditional applications).

Essentially FMWC applications. Essentially FMWC applications offer solutions that are unique to the wireless connectivity environment and can be delivered mainly through FMWC devices. On-the-spot communication and context-aware mobile computing characterize the two branches of these applications. Many current on-the-spot communication applications are voice-based, such as mobile telephony; text-based, such as Short Message Service (SMS); or multimedia-based, such as Multimedia Messaging Service. In the future, on-the-spot communication applications may expand to include messaging through other human senses, such as touch or smell.

Contextual awareness in mobile environments is often perceived as critical for a successful FMWC application. There is a large body of research that has been done recently in this area, the discussion of which is outside the scope of this paper. However, one of the seminal projects in this area is worth mentioning here. The Remembrance Agent¹³ is a program that augments human memory by displaying a list of documents relevant to the user’s current context. Augmentation of the user, through extending both memory and perception is often seen as the path

Table 3 Classification of FMWC applications

Type of Application	Hardware Mobility			Sample Applications
	Fixed	Transportable	Fully mobile	
Essentially FMWC	No	No	Yes	On-the-spot product guide, voice communication, field engineering applications
Adapted for FMWC	Conditional	Yes	Yes	Field data logging
Adapted for FMWC	Yes	Yes	Yes	Web browsing, spreadsheets, calendar, simple drawing
Adapted for FMWC	Yes	Yes	Conditional	E-mail, word processing
Unsuitable for FMWC	Yes	Conditional	No	Complex design and image processing applications, for example, AutoCAD** or Photoshop**

by which the next generation of devices (which are mostly wearables) will become one with the user.

In general, contextual awareness can be categorized as follows:

Location awareness—Used in location-based services, this is the ability to track users' whereabouts at each moment and provide them with the information relevant to the current location. This includes, but is not limited to: offering maps and road guidance, supplying details about specific objects and places close by (for example, retrieving extended product descriptions while shopping), or flagging the presence of other users in the area, according to the user-specified "buddy list." Location-based applications may also provide data management services according to user-defined preferences, for example, managing incoming personal and business calls depending on the present whereabouts of the user.

Environmental awareness—The ability to read the specifics of the interaction setting, such as a noisy crowd, a one-to-one conversation, or an enclosed space.

Mobility awareness—The ability to decode a user's movements and body posture at each moment, for example, knowing whether the user is currently sitting, standing, walking, or running.

Health awareness—The ability to measure various physical conditions of the user, such as heart rate, body temperature, and blood pressure.

Activity awareness—The ability to understand current high-level activities of the user, for example, reading, watching TV, or writing.

In the mobile environment, there are two possible interpretations of location that are important to wireless applications. We define them as the "absolute context" and the "relative context." In the absolute context, the user's location consists of his or her geographic or spatial coordinates at each moment in time. In the relative context, the user's location is linked to another entity, moving or stationary, for example, a car or a building. The absolute context of the user in a moving car is changing, but the relative context will stay the same until the user steps out of the car. Different location contexts call for different location-based applications; understanding the difference between the contexts will help to deliver usable wireless applications when they are needed and in the way the user wants them.

Applications adapted for the FMWC context. In contrast, applications adapted for the FMWC context are exclusive neither to the wireless connectivity nor to the mobile environment, and exist in a different form elsewhere. Examples include most office applications that originally existed on desktop computers and were later enabled first on transportable and then on fully mobile devices, as lighter versions of the original application. These include e-mail programs, calendars, Web browsers, word-processing programs, spreadsheets, and similar applications. Most of these adapted applications exist on all three types of hardware: fixed, transportable, and fully mobile. Some,

such as field-data-logging applications used by medics, field engineers, or surveyors, have been developed to automate tasks that were not performed on computers previously. Although these applications can exist on desktop computers as well, they are primarily used on mobile and transportable computers.

Within this group of applications, most afford mobile interaction with an FMWC device through either text-based or natural language input. These applications are mainly based on interaction styles involving direct manipulation, menu selection, and the use of forms.¹⁴ Certain applications (marked “Conditional” in Table 3) afford mobile interaction predominantly through natural language interfaces. These are applications that typically presume a sizeable text input. In most cases when text needs to be entered by hand, the interaction becomes stationary, as either both hands are engaged with a typical keyboard, or text is entered more slowly with one hand, via a stylus or a chord keyboard. For these applications, an FMWC device acts as a de facto transportable device.

Applications unsuitable for the FMWC context. These applications are inappropriate for FMWC devices because they cannot overcome the challenges posed by the mobile environment. Although these applications normally require substantial memory, processing power, and large screen size, it is not the technology that makes them unsuitable for the mobile world. What prevents these applications from being ported to FMWC devices is the complexity of the FMWC environment, not the complexity of the applications themselves. Applications unsuitable for the FMWC environment demand intense concentration, extremely high visual attention and, often, very accurate manual input. All these requirements are impossible to meet during mobile interaction, since it assumes relatively short interaction time; high-degree of attention sharing between the interaction and background activities; and lower concentration on each activity that is going on in parallel (see more detail about mobile contexts in the section “Mobile work contexts”). Thus, most computer-aided design (CAD) applications, complex modeling tools, and image processing applications are unsuitable for FMWC devices. We classified this type of application as conditionally suitable in Table 3, even for transportables; this is because certain parameters of the environments in which transportables may be used come close to those of the mobile settings, particularly for palmtops.

Contexts and interactions in the FMWC world

User experiences in the FMWC world are dramatically different from those in the traditional computing environment and present a number of technical, environmental, and social challenges¹⁵ in the usability of FMWC devices and applications. Some technical challenges relate to network connectivity, such as dealing with an evolving infrastructure, coverage and feedback concerns, security hazards, and complex integration issues for a wide variety of devices. For example, the intermittent nature of wireless connectivity and changing connection speeds affect the overall usability of many applications because these applications fail to respond to the user as expected. Other technical challenges are posed by device design constraints which are imposed by trade-offs between size and functionality, or between weight and battery life.

A fully mobile computer is prone to enormous variations in the environment and work contexts in which it operates. Environmental variations pose the largest and most diverse group of usability challenges in the FMWC context. They include: fluctuation of temperature and lighting conditions, varying levels of noise and distractions, mobility of the user, competition for attention in multitask mobile settings, and the need to manipulate other physical objects during interaction. While most of the resulting technological challenges will be dealt with in the coming years, the burden of environmental constraints cannot be reduced significantly. Many of them are inherent in mobile interaction, such as the work context, weather conditions, physiological limitations of the human body, and cognitive restrictions; all of these will continue to put the usability of FMWC devices or applications to a serious test.

Social challenges of mobile experiences include personalization,¹⁶ comfort, acceptance and adoption issues, and privacy concerns, especially for location-based applications. The ability to monitor a user's whereabouts creates an opportunity for a great number of convenient context-aware services and is particularly valuable in emergency situations. At the same time, some users will consider revealing their location a serious infringement of their privacy. This may adversely influence the overall user satisfaction with a location-based application, especially if employees are required to run such applications on their FMWC devices; some users may even perceive this as a disadvantage of the device itself.

Mobile work contexts. The FMWC world broadens the space of traditional computing settings and allows office workers to become more mobile, connected and, as a result, flexible. It also brings computing power to areas and occupations where it has been rarely, if ever, applied before. The more advanced FMWC devices and wireless technology become, the more areas will exploit and rely on the benefits of FMWC computing. We distinguish between two types of FMWC environments, with fundamental differences between them: the mobile office context, in which traditional office-type computing is made mobile, and the field context, to which traditional computing has not been applied, and where FMWC devices are the only computing devices used.

Understanding the differences between the two contexts is of great consequence to both technical and usability specialists, as each context requires a specific approach to the design of FMWC devices, applications and interactions.

Mobile office context. In the mobile office context, FMWC devices are used similarly to desktops and laptops in a traditional office-based computing environment, with most tasks and applications aiming to duplicate those enabled on stationary computers. In this context, the assumption is that, while interacting with an FMWC device, the user performs familiar work in circumstances which are less familiar for that type of work. For a considerable time, stationary computers are expected to remain the primary platform for most office applications, with FMWC devices acting as auxiliary devices.

In the office context, most tasks performed while interacting with a computer are internal to the operation of the computer, that is, the task itself takes place in the computer, such as creating a spreadsheet or a Word** document, sending e-mail or browsing the Internet. In the mobile office context, the internal computing tasks are likely to dominate during the interaction with a FMWC device, with the tasks taking place outside the computer (for example, walking or manipulating other physical objects) being secondary.

Field context. In the field context, FMWC devices are used in a non-traditional computing environment for tasks unrelated to the stationary use of computers. The field context is much more diverse than that of the mobile office, and we believe that in the near future the number of FMWC devices in the field context will largely outgrow the number of FMWC de-

vices in the mobile office context. The field context covers a broad range of tasks and occupations, such as service engineering, law enforcement, medicine, social work, and surveying. It also includes nonprofessional activities for which computers have not been previously used, for example, store shopping and travel. Often in the field context, tasks that are currently enabled on FMWC computers have been previously facilitated by a different medium, for example, pen and paper or telephone. In some cases, present field activities had no equivalent in the non-FMWC world, such as on-the-spot communication. In the field context, the user remains in familiar circumstances but applies a less traditional tool to facilitate the work.

Kristoffersen and Ljungberg¹⁷ point out four important features of mobile interaction that they identified for telecommunication service engineers and maritime consulting staff. We believe that the same features apply to most field contexts:

Task hierarchy—While interacting with an FMWC device, tasks external to operating the device (for example, fixing wires or examining a patient) are central; the tasks taking place in the computer (for example, reporting status) are supplementary.

Visual attention—Visual attention of the user is largely directed to events occurring outside the computer, to avoid danger or to monitor the progress of the primary task.

Hand manipulations—During the interaction, the user's hands are commonly engaged with a variety of physical objects unrelated to the interaction with the FMWC device (for example, other equipment).

Mobility—Directed by the nature of the dominant task outside the computer, some users may be required to remain highly mobile during the task.

Consider, for example, an aircraft service engineer who typically installs, tests, or repairs aircraft equipment and wiring. In addition to a toolkit, a torch, and some spare materials, the engineer may carry an FMWC device to substitute for such traditional companions of aircraft engineers as aircraft schematics, a notebook, and a pencil. The FMWC device may provide new functionality, previously not available during inspections, such as the capability of checking stock and placing spare part orders.

A closer look at the engineer's working environment points out factors such as the small spaces inside an

aircraft among which the engineer moves during the inspection, inferior lighting conditions, and little room for body maneuvering within each space. During most of the inspection, both hands of the engineer are occupied with measuring equipment, cables, repairing tools, and other objects.

Recently, handhelds with touch screens, keyboards, and additional stylus input have been promoted for field use (for example, the customizable Panasonic Toughbook** wireless handhelds). With touch-screen handhelds, direct manipulation remains the leading interaction style, supported by menu selection and the use of forms.

For the engineer, there are two ways to approach operating his FMWC device: he may 'make place'¹⁷ for interacting with the device, that is, interrupt the main task of inspection, log the data or read them off the device, and then resume the main task; or he may try to arrange for the interaction to 'take place,' that is, to operate the FMWC device while executing the main task. In the 'make place' case, the interaction with an FMWC device is not significantly different from interaction with a paper notebook. It can even be less efficient since the engineer has to perform some extra actions, such as locating and saving files or navigating through menus. Attempting the 'take place' interaction, the engineer faces a number of problems at once: where to place the device, how to operate it with both hands busy, and how to keep visual attention focused on the main task while following on-screen instructions.

It is highly unlikely that the 'take place' interaction can happen in the aircraft engineer's case if he uses a handheld. Handhelds afford a very particular mode of interaction—the engineer has to focus on the device when reading or entering data. However, 'take place' FMWC interactions are desirable in all field contexts, and essential in some, for example, in the area of public and emergency services. Recently, police departments started introducing FMWC devices as part of officers' toolkits to allow the officers to exchange information with control rooms and headquarters quickly and efficiently. For instance, officers can see emergency calls on their FMWC devices along with the map of the area and operator's comments,¹⁸ or match fingerprints of an offender against the police database.¹⁹ A huge demand for FMWC devices and applications is predicted for other service professionals, such as firefighters and paramedics.²⁰ With FMWC devices, an emergency crew would be able to transmit the patient's data to the hospital,

where the doctors could monitor the patient's condition, advise the crew, and prepare to begin the correct treatment immediately after the patient arrives at the hospital. With 3.1 million emergency journeys reported in England alone last year, of which about a third were life-threatening,²¹ the benefits of such services will be massive. It is also clear that in none of the above examples, can the FMWC users afford to make place for the interaction; the FMWC activities should instantly and effortlessly take place in the situation at hand.

Comparative characteristics of stationary and mobile interactions. As described in the preceding discussion, mobile interactions are not homogenous. Within the mobile interaction type, we can now distinguish between (1) mobile interaction in the mobile office context and (2) mobile interaction in the field context. Table 4 contrasts and compares the features of the two types of mobile interactions and stationary interaction. For mobile interaction, the values of certain parameters, such as the environment, device size, time of interaction, and user mobility, are the same for the mobile office and field contexts. The values of other parameters, such as competition for attention, task hierarchy, parallel manipulation of other physical objects, and interaction style, vary not only between stationary and mobile interactions, but also between mobile-office and field contexts.

Usability implications of FMWC complexities for technical and HCI communities

Designing for the world of connected mobility is a huge challenge for a wide range of experts, from hardware engineers to software developers and HCI specialists. More than any other area of computing, the FMWC world in its complexity and diversity calls for a thorough understanding of its users, rigorously of the design process, and meticulous attention to the usability of both devices and applications.

The importance of User-Centered Design (UCD) for creating easy-to-use products and systems is argued for in this issue²² and elsewhere.^{23,24} Unlike other design methods that focus on the product itself, UCD focuses on the product in use and the total user experience; this requires more rigor in the design process than other approaches. The FMWC world is still in its infancy, and it is natural that attention is often paid to the feasibility of an idea or technology more than to anything else. This frequently makes designers and developers adopt the trial-and-error ap-

Table 4 Comparative characteristics of stationary and mobile interactions

Interaction Parameters	Stationary Interaction	Mobile Interaction	
		Mobile Office Context	Field Context
Environment	Largely indoors, few fluctuations in the environment	Indoors and outdoors, with frequent fluctuations	Indoors and outdoors, with frequent fluctuations
Device Size	Medium to large	Small	Small
Time of Interaction	Medium to long	Short to medium	Short to medium
User Mobility	Fixed, mainly sitting position, restricted body maneuver	Any position, various degrees of free body movement allowed	Any position, various degrees of free body movement allowed
Competition for Attention	Little	Some	Significant
Task Hierarchy	As a rule, interaction-related tasks are the primary activity	Interaction-related tasks may be a secondary activity	Interaction-related tasks are mainly a secondary activity
Parallel Manipulation of Physical Objects outside Interaction	Rare	Occasional	Frequent
Interaction Styles	High dependence on direct manipulation; other styles are complementary	Greater reliance on forms and menu selection, supported by direct manipulation and natural language	Natural language is of prime importance, supplemented by menu selection and forms

proach, where bringing the product to life quickly is seen as more beneficial than bringing the product to life carefully. As the field matures, the viability of FMWC technologies will become more important than their feasibility. In these circumstances, UCD is no longer simply a highly desirable design approach, but a vital mechanism for ensuring that the FMWC products are capable of being useful and usable.

Usability implications for designers and developers of FMWC applications. There are several usability implications of FMWC complexities that are particularly important to application designers and developers. These include understanding the nature of and differences among applications that are suitable for the FMWC context and those that are not. Clearly, porting FMWC-unsuitable applications onto FMWC hardware is unlikely to succeed. Difficult environmental conditions, as well as the intrinsic human constraints of mobile interaction, will prevent most users from effective use of this type of application in mobile settings.

There are very few or no benchmarks for applications which are essentially FMWC applications, or al-

ternatives to them; users, therefore, are likely to be tolerant of their imperfections. In contrast, the vast majority of FMWC users have experienced applications adapted for FMWC outside the FMWC environment, in traditional computing settings. In these circumstances, the users have benchmarks for application performance in their minds and will be more critical of the FMWC implementations.

Most applications used in the mobile office context are those which have been adapted for FMWC. Because the majority of users continue to use applications in both mobile and traditional office contexts, these adapted applications should aim to preserve as much of the look and feel of the original applications as possible. If the same application differs significantly in the two contexts, the user-perceived usability and satisfaction with the FMWC version of the application may suffer. Mastering a new version while using the old one would be more difficult than mastering a new version while unlearning the previous one.

The nature of the field context in most cases insists that the interaction take place as the user cannot sus-

pend his or her primary task. Because direct-manipulation interaction style suggests the make place interaction, relying on direct manipulation in the field context can be a dangerous option. Instead, the application should aim to support other interaction styles as well, particularly, natural language. In the field context, the user should be able to choose which interaction style is appropriate for the situation at hand. A robust well-thought-out field application would support both visual and audio output modalities, as well as natural language and manual input.

Implications for designers and developers of FMWC hardware. FMWC hardware should account for mobility of both computers and their users. Not all devices usually classified as mobile enable mobile interactions. As argued in the section “Defining the space of mobile wireless computing,” full mobility is determined by both the form factor of the device and by its surface support requirements. Most current FMWC hardware has been designed primarily with mobile office applications in mind and is not appropriate for the field context. Most single-unit handheld devices, both with touch screens and keyboards, suggest that the user will make place for the interaction and keep visual attention on the screen or have both hands free of other physical objects. Because in the field context the take place interaction is the natural and often the only option, the ultimate goal of hardware designers should be making field FMWC devices both mobile and ubiquitous. We believe that modular hardware that consists of various devices and input/output components would work best in the field context. The user should be able to pick and mix components for his personal device network, similar to the way he can pick and mix blocks from a construction kit. Single-unit multifunctional devices are useful because of their generality, but are rarely the best option for any particular function.

Field contexts are complex and often hazardous, and interaction with a FMWC device is predominantly a secondary task. Therefore, efficiency requirements in the field are higher than anywhere else. For the personal device network, all components should be fully compatible and able to communicate with each other.

UCD challenges in the FMWC world. The complexity of the FMWC world presents serious challenges not only in the design process, but equally, in the design methodology. We strongly believe that UCD

is the most efficient design approach for FMWC products. It is also clear, however, that UCD itself will need to undergo certain transformations and find new solutions to become an effective and efficient FMWC design method. We do not have these solutions at the moment; they do not exist, to our best knowledge. In this last section, our goal is to highlight the critical points in the UCD process that need particular attention and adjustment. We invite both HCI experts and technology specialists interested in UCD to join us in discussing and developing the comprehensive UCD methodology for the FMWC world.

The most obvious challenge is dealing with the requirement for mobility itself. In the FMWC context, not only does the user influence the method of interaction with the device, but the context itself often defines the interaction. Users may interact with the device differently, depending on the situation at hand. Context-aware applications may significantly alter the user experience. In order to fully understand how a user interacts with the FMWC device, it is not sufficient to simply examine the user’s direct interaction with the device—the evaluator must also be aware of the external context in which the interaction takes place, that is, the evaluator must perceive the context the way users perceive it themselves. One of the first attempts to design a general reusable tool that would aid the researcher in studying interactions with mobile (particularly, wearable) computers in the field environment is presented in Reference 25.

On the methodological side, the “anytime, anywhere” attribute of mobile interaction lets the environment variability genie out of the bottle, and makes some UCD stages extremely difficult and significantly different from current procedures. The affected stages are task analysis, prototyping, and design evaluation and validation.

Task analysis. Task analysis for a mobile product is significantly more complex than such analysis for a non-mobile product. The first challenge of task analysis is accounting for all possible usages of the product. The mobility paradox is that the more convenient the FMWC device in a particular setting, the bigger the chance that the user will try to use it in a completely different setting as well. We doubt that the designer of the first laptop seriously thought of using it on the beach, but the laptops did find their way there eventually. With fully mobile devices, the number of previously unthought-of usages jumps.

Obviously, if an FMWC device or application has not been designed with the new task or context in mind, the product may be difficult to use there. However, for the user it is natural to quickly get used to the power of the product in one context and assume that product should cope with another context with equal success.

Consider, for example, the case of mobile phones. The primary usage (at least as it had been believed for a long time) is for voice-based communication. When SMS was introduced in the past decade, it was seen as a minor application, and few designers would have considered conducting task analysis for SMS in the design of a new phone. Nowadays, with 45 million short messages sent in the U.K. alone every day,²⁶ a mobile phone that has the easiest interface for voice communication is likely to fail the user satisfaction test if it does not provide a reasonably good SMS interface. PDAs are another example of this. Originally designed with office-type applications in mind, they are now considered almost universal FMWC devices, although they are definitely not universally usable.

The second challenge of task analysis also comes from the variability of the usage environments and affects the course of task analysis in specific settings. Consider the difficulties of observing the details of how a worker in the field context tackles a task. This may be as simple as following a delivery driver around or as complex as observing how an aircraft service engineer goes about maintenance of components inside a jet engine. In some cases, task analysis may be performed in a simulated environment of a jet engine, for example, but a realistic simulation is difficult for the case of the delivery driver, where environmental conditions of the operating environment are very important. The nature of the environment may vary over the span of a single task, but it may also vary based on other considerations, for example, the time of year or weather conditions that will affect light levels and temperatures in the operating environment.

The third challenge of task analysis stems from the multitasking nature of mobile interaction. In most cases, especially in the field context, FMWC applications require the user to interact with them while simultaneously undertaking other tasks. These parallel tasks may be as simple as following directions while walking or as complex as operating in a hazardous environment and applying the appropriate level of attention to both the FMWC-based part of

the task and whatever work it supports. Task analysis, therefore, should carefully consider the whole variety of parallel activities.

Prototyping. UCD includes prototyping at various stages. Prototypes for FMWC products will need to have a high degree of fidelity and exhibit the key characteristics of the finished product for some of the evaluations, for example, size and weight constraints or robustness, as in the aircraft service engineer example. Because operation of the product is typically secondary to the main task, successful testing of a prototype can only be performed in conjunction with a realistic simulation of the primary task. This may significantly increase the cost of prototyping. Similarly, the limited capabilities of the FMWC device may constrain the ability to instrument the device and hence make monitoring more difficult.

Design evaluation and validation. Design evaluation and validation will share most of the same difficulties that were encountered during task analysis. In particular, designers need to evaluate the FMWC product in a realistic environment, where the realism may include different periods during a day, different lighting and noise levels, or even different seasons. Evaluating an FMWC device for a delivery driver on a perfect summer day tells us little about the ease-of-use characteristics of the device on a frosty January morning, where the driver may wear gloves or the device may not function properly due to weather conditions. More than any other environment, the FMWC world calls for sustained evaluation to assess the viable lifespan of the product. Mobility, however, makes sustainable observation of an FMWC product even more difficult than that of a non-FMWC product because it introduces far more factors to record and evaluate.

Finally, the connected nature of FMWC products and the flexibility of the users in the FMWC environment intensely stimulate collaborative work. Significant efforts of application designers have been dedicated to developing a wide variety of mobile collaborative applications. UCD is difficult enough for non-mobile collaborative applications, and it will certainly become more difficult for mobile collaboration.

Conclusion

Living in a mobile connected world opens up numerous opportunities for both work and leisure activities and makes our daily conduct both more effi-

cient and more exciting. These opportunities, however, pose challenges to the technical and HCI communities. Although mobility has been one of the hottest topics of the last decade, mobility is most often considered an attribute of a computing device or a user in general, not as an attribute of a user and a device during the interaction. In this paper, we focused precisely on the latter and showed that there are a number of critical differences between interacting with a mobile computing device and interacting with a computing device that can be taken to an arbitrary location and used there in a stationary mode.

**Trademark or registered trademark of Bluetooth SIG Incorporated, Palm Incorporated, Psion PLC, Hewlett-Packard Company, Microsoft Corporation, Fujitsu PC Corporation, Autodesk Incorporated, Adobe Systems Incorporated, or Matsushita Electric Corporation of America.

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