

# Mobile computing in outdoor environments

Massimo Ancona, Gabriella Dodero, Vittoria Gianuzzi

DISI - Università di Genova

Via Dodecaneso, 35 - 16146 Genova (Italy)

{ ancona,dodero,gianuzzi }disi.unige.it

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## Abstract

The paper originates from, and describes as well, an experience in developing and using a system for on-site support, in real time, for archaeological excavations. The experience is made possible by joining two new technologies: wireless mobile computing and pen-based man-machine interfaces. The respective impact on system hardware and software structure is described and implications for outdoor mobile applications are discussed.

**Paper category: Long paper - 2. Report on innovative computing application**

## 1 Introduction

With the term *mobile computing* we indicate the possibility of using computing resources in a mobile environment, i.e. not being constantly in the same place. This activity is made possible by recent technology advances, and it is intrinsically different from usage of laptop computers, which support a stationary working environment at different locations (such as both home and office). Mobile computing refers to a different kind of devices, usually called hand-held palmtop computers. Like all new technologies, mobile computing provides new challenges to hardware and networking, and mostly of all, to software design. The reduction in size, and the need of being operational in outdoor environments has important consequences on user interfaces and packaging. True mobility needs wireless communication, such as radio or infrared connections. High costs and low bandwidth/reliability tradeoffs have important consequences on traditional networking support, like client/server program execution, distributed file systems and data bases, and so on. Software challenges lie both in adapting and redesign of existing pieces of software, and in design of novel applications especially addressing needs of mobile users.

One such application is the outdoor field: earth sciences are natural candidates for benefiting of this new technology. Applications like wildlife monitoring in Kenya's natural parks have already been operational for a while, though still in prototypal phases. Other experiences are now being collected in the archaeological sector, where field survey and excavations are just starting to make use of mobile devices. Like most other outdoor computing environments, field archaeology is an extremely hostile computational environment. Besides mobility, a computer should be operational in the open air, in any possible weather including heat, dust or perhaps rain. Most laptops are often non-operative under such conditions. In contrast to what might happen in urban areas, electric power supply and telephone cable connections is seldom possible on an archaeological site: no wires can cross it, but perhaps there could be a nearby building (where archaeologists live during the campaign) where such facilities could be found.

All earth sciences, like field archaeology and geology, are now employing various computer-based methodologies for analysis and retrieval of research results. Stationary computers are being increasingly used, for cataloging stratigraphic data and finds, for photogrammetry and topography, for teledetection (from satellite to low flights). Computing technologies and tools which have proven to be useful in a posteriori analysis of field data include DataBases, CAD, GIS, Remote Sensing: such tools have not been specifically developed for supporting archaeology, nevertheless they have proven useful in such fieldwork. Special purpose programs have been developed too, which support the archaeologist work off-line, during the data analysis phase, and the development of Internet provides an easy way for remote database access.

Computing technologies are accessible by archaeologists in every University or Museum laboratory. On the other hand, fewer tools have been made available to support field work on laptops; and real-time cooperation between field scientists and those at Universities, Museums

etc. is still to be achieved. It should be noticed also that a campaign is usually very limited in time, and that a large part of excavation is done by qualified personnel, coming from University or Museum research units, rather than by local, less-qualified personnel. The latter consideration focuses on the aim of optimizing the archaeologist's work in the field, where there usually is a significant delay between excavation and study of finds. Communication possibilities such as those currently offered by Internet and related services like email are not currently available in the field.

The consequences of both data processing delay and lack in communication could become relevant. Since the duration of an excavation campaign is limited, and transportation costs could be relevant, it is important to take the right decisions on the spot, with the availability of archaeological databases and possibly consulting specialists who are in some far away Museum or University. Contextual analysis of finds, in the field, at present cannot rely on adequate computing support, which is usually available at later phases only, that is during the synthesis phase. Similar considerations hold for most outdoor research activities in all earth sciences, and for outdoor activities far from urban areas as well.

The system described in this paper aims at reducing this gap as far as possible by making use of wireless mobile computing. The project results from on-going interdisciplinary cooperation among archaeologists, architects and computer scientists, and it makes advantage of combined advances in computer technology, such as wireless communication and computing, together with visual data management. In the next Section we shall introduce two technological innovations being employed in our outdoor application, that is wireless mobile computing and pen-based man-machine interfacing, which are well suited for combined use. Then, we shall discuss on how software to support field work can be designed, **and which lessons can be learned to be applied in other outdoors environments** . Two subsystems, one on a mobile computer and the other on a fixed workstation, are briefly described. Description of present project status concludes the paper.

## 2 Wireless and Pen-based: the solution for outdoor computing

Advances in cellular communication, wireless LAN and satellite services shall soon support an increasing number of mobile users, as described in [1, 6, 7]. In the next future, millions of people shall connect to information sources while moving for their job by means of their personal digital assistants. These devices provide the computing power of a workstation in a smaller, light package called palmtop or hand-held computer. Such tools include advanced user friendly interfaces based on electromagnetic or passive pens which "write" on shock-proof liquid cristal screens.

Palmtop computers cannot input from keyboards for reasons of space and weight; instead, user interface is based on a pen. A pen immediately replaces a mouse (or other pointing devices) in menu-driven software; when a complex command or a text has to be input, some handwriting recognition software has to be used. Such software should recognize at least block letters; of course, advances in recognition techniques are always welcome by users.

This technology, to which an introduction can be found in [2], has been introduced to the market some time ago, among great expectations on the users side. Unfortunately, the first enthusiastic forecasts were often followed by corresponding disillusiones for the limited possibilities offered by commercial systems, and the low bandwidth available in cellular communication.

In retrospect, pen-based computer users now constitute a specialized market niche, that of applications for which these devices cannot be substituted with laptops etc. in contrast to early forecasts where palmtops were assumed to substitute keyboard-based inputs in all

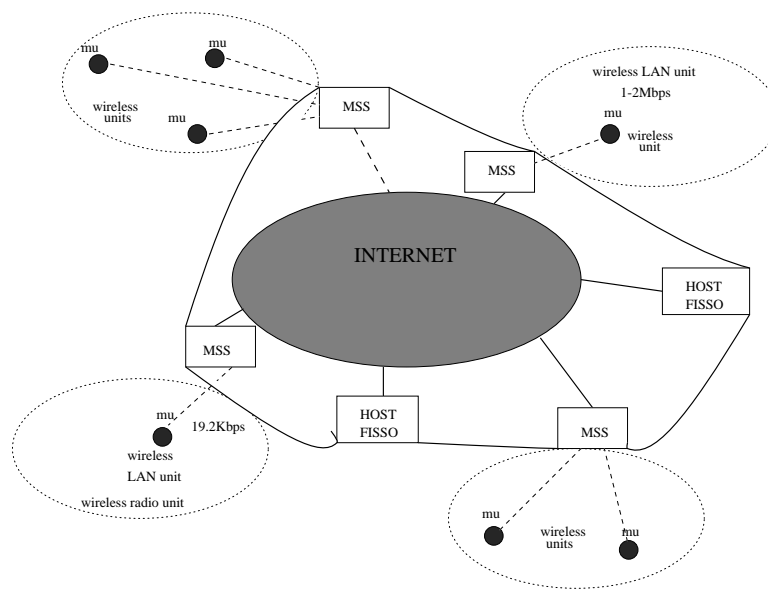


Figure 1: A wireless network

situations (business as well as home). In other words, whenever keyboard is sufficient for inputs, no pen based device is going to replace it. Ten years from now, voice input shall be the primary substitute for keyboards; thus mid-term forecasts for pen-based computers look at their future in the communication field: as long as interactions among individuals need handwritten sketches and notes, and cannot rely exclusively on voice (telephone).

Outdoor applications like ours are one of those niches where pen-based input is better than trackball-mouse interaction: in the outdoor environment, input to the portable computer has to be given in uncomfortable positions, either standing or sitting with the device on the knees. Besides, as we shall see in the next Section, the use of drawings and sketches is customary in field archaeology daily activities, and the amount of text to be typed in is quite limited.

The second technology advance which is exploitable in outdoor applications is wireless networking: mobile computers may connect to a network only without cables, and conversely, it is hardly possible to establish wired connections outdoor.

A typical mobile network is sketched in Figure 1. Three different entities can be identified: mobile computers (labeled *mu*), mobile support stations (labeled *MSS*) and fixed hosts. *MSS* units are workstations with wireless communication interface towards mobile computers, and possibly another interface (wireless or cable) towards a WAN such as Internet. The connection to a wireless LAN and the use of a mobile device introduces the concept of AirAwareness[11], i.e. the capability of being always on-line and having the access to information anytime and anywhere.

Wireless data communication and mobile computing technology is now seen as the next paradigm shift in the integration and use of information technologies in the day to day operations and business.

Using mobile computing is not as simple as adding a wireless network and portable computers to the network. Conventional application design does not apply to portable environments. The limited screen size and the absence of a keyboard has a great impact on the user interface. Also the priority of operations to be performed in a non-comfortable environment deeply affect

program design. Many mobile applications are task oriented, and use a mobile computer as an information tool to help a specific job[11].

Wireless connection and pen-based interfaces, as combined together in a palmtop, nowadays make it possible to design innovative applications for the outdoor environment. As an example consider those combining mobile computing and use of GPS inside what has been called "context-aware" or "location-aware" computing [3]. The possibility of interconnecting palmtop computing in the field is now being exploited in prototypal applications in urban archaeology (Sevilla), and for localization of ancient rural settings on the mountains of Corse. In such applications, the possibility of contextualizing a find, for example by use of historical maps, improves a critical interpretation of the territory. However there are other applicative scenarios in earth sciences, including archaeology, where GPS supported localization is scarcely significant, for example when no previously localized information is available, or when the scale of interest is different, such as localizing an object in the map of a room or inside a building. The application we are going to describe falls in the latter category.

### 3 An outdoor application: field archaeology

Location-awareness is present in field archaeology at various scales of resolution. The largest topographical unit to be considered is the site, an area of interest which has variable dimensions, usually very large ones as well. A site cannot be excavated at the same time in all of its surface; a selected portion of it where excavation activities are operational is called test. If possible, an interpretation directs a selection so that an unitary portion of the site is treated at the same time, such as a single building. It can be further subdivided into smaller units called sectors, whose size and shape may encompass further interpretation, e.g. a room inside a building, or may just be convenient portions of an interesting area. Inside a sector there may be several stratigraphic units, each of them being a convenient unit of archeological information and the basis for cataloging. A stratigraphic unit may have a volume by itself (e.g. a wall), or just be a profile or section (e.g. plain ground where several bones were found lying). As interpretation of finds proceeds, stratigraphic units may be aggregated to form a structure called archaeological context, an example of which could be a small building, composed by the four walls delimiting it. Other relationships among stratigraphic units can be spatial (above, below, inside,...) sequentialization (referred to excavation time sequence: a wall has been excavated during 1996 campaign, another in 1997), and stratigraphical (referred to dating of finds: previous, subsequent, contemporary,...)

Let us examine field work in more details for better understanding how mobile pen-based computers may support it. Archaeologists usually bring their paper and pencil diary in the field, where they collect daily notes. These notes are the most important, and often the only, means to record and eventually later reconstruct archaeological evidence, which is being excavated day by day. Off the field, diaries are used to extract the official archaeological reports, that is, a selected portion of their contents is copied to standard forms in order to document excavation results to the archaeological scientific community. This copying operation is tiresome and subject to possible errors: one cause is the temporal delay between excavation and reporting. In fact, if the site is not connected to computer centers, post-elaboration of daily notes takes place only when the archaeologist is back in the lab: it could be months later. The pen-based shockproof and waterproof device is intended to replace pen and paper with a digital substitute for archaeologist's diary.

The test in an excavation site is usually marked by a regular, square grid (approx. 2-3 meters each edge) identifying areas to be excavated. Each square in the grid is separately considered and in turn it is subdivided into smaller sections (approx. 30 cm. each edge), by means of strings. This subdivision allows easy identification of the exact position of finds at

the current level. The current level is inspected, removed earth is sieved, and finally the fine grid is remapped at the next lower level. When current level is lowered, track is kept of the previous one by marking its orthogonal projection to vertical sides of the excavation: thus, we end up with a vertical grid too, in order to be able to identify finds proximity in 3D space.

Finds at each level are cataloged and then separately stored in boxes (one per square and level in the large grid). Information to be kept for each find are:

- spatial information: its position in the tridimensional grid and its size;
- additional visual details (if needed): the shape, by means of a sketch or snapshot;
- classification: possible material, colour traces, status and so on;
- additional data (to be determined later): possible origin and period.

We then have to collect in our "digital diary" textual, visual and spatial information. The next Subsection shall detail how.

The lack of communication facilities is cause of potential troubles as well: in case a database or a colleague has to be consulted, someone has to physically travel to or from the site. Even cooperation between archaeologists at the same site, but not on the same test, is tiresome and slow, requiring to walk from the respective working areas to a meeting place, or else be delayed until the evening. The delay could be most significant if no decision can be taken on the field, and the answer resulting from such interaction is needed before proceeding. Such problems need some kind of real-time networking in order to be solved: this is where mobile, wireless connectivity is needed.

Our wireless network consists on one or more workstations, and two or more mobile computers connected to a wireless LAN by radio devices. The workstations are installed in some building close to the excavation site, and they are connected to Internet by telephone cables or satellite. To give some figures taken from specifications of existing systems, a mobile computer may connect directly to the fixed host within one mile distance; for longer distances, or to overcome obstacles like hills, repeaters (i.e. antennas) should be installed.

Mobile systems provide pen-based input, and support local computations (data acquisition and preliminary analysis) as well as remote computations, which result as transactions on the workstation. Remote computations include data base queries, comparisons with previously entered data, contacts between mobile computers and scientists in the nearby or remote areas and anything else which could be done by means of Internet. The next Subsections deal with further details on this subject.

### **3.1 Data Entry: Drawings and Text**

Mobile computers perform on site data entry of textual, visual and spatial information. Textual information is locally collected on the palmtop computer by means of selectable menus, or by using special input software like the T9[12] software system, or handwriting recognizers. Menu-based classification is thus strongly recommendable. If a whole text has to be entered, we developed a special software called WordTree [13] that speeds up input of text on pen-based devices.

Visual and spatial information may consist on sketch creation and retrieval, find positioning in the 3D grid, spatial relationships to other finds such as on-top-of, and association of sketch to related textual information. We designed special purpose software on top of a drawing system. Each find can be sketched on the screen of the palmtop by means of the magnetic pen; it can then be measured and related to the grid, measuring its distance from grid edges. The sketch can also be automatically adapted to measures once they have been taken (e.g. zoomed, rotated, stretched,...) for more realistic appearance. Attachment of a snapshot taken by a digital camera may be useful for the most significant finds.

The use of a graphic-based object oriented tool [8], allows to separately manipulate each object (find), which encapsulates all relevant attributes as defined by the archaeologist. Each object may also be spatially and thematically related to other objects, by linking them with distances and same attributes, in order to be able to recall them on the screen. In a side window, textual information can be attached to objects as annotations.

All acquired data can be downloaded to the central workstation and automatically inserted into the site object store (and made available, via Internet, to remote scientists). example thematic finds, as soon as they

Figure 2 shows..... **Insert Figure 2**

### 3.2 Communication scenarios

The above subsection discusses advantages given by a palmtop computer in a site; the present and the next subsections examine in more details what facilities are given by a mobile unit, that is by communication to the central workstation and through it to other networked computers.

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The major infrastructures available for data communication are Analog Cellular systems and Packet Radio systems. Both have been discarded, however, due to some their features. These include limited system capacity and low data services (about 20 Kbps from a stationary user). Moreover, since different protocols have been adopted by different states, it could be difficult to provide a software and a target system widely usable in every excavation site, without considering the possibility of having no connection service provided at all.

For these reasons we prefer to consider Radio Frequency systems, in particular the Frequency Hopped Spread Spectrum Radio technology, which offers high speed (about 2Mbps) along with reasonably secure communication data links, low power consumption and a coverage radius of about 1-2 km. without repeaters. Moreover, no licence is required, and its use is accepted also in military areas, so the equipment can be easily transferred in every excavation site.

**fine.**

In our application, mobility is restricted to a single excavation site, thus, in almost all cases a single support station is sufficient to support all MUs of a site. It follows that we do not have the problem of locating the user unless in a very large site, which would require just a few fixed support units. Even in such a case, since archaeologists move by walking, MUs execute transactions while being relatively still. However, we may have a problem of elective disconnection[5], when the archaeologist is working in an unaccessible area (e.g., underground).

To this purpose, each MU has a large caching capability: it can support long periods of work without connection, thus a caching model is more suitable than a remote access model[7]. Remote access is relatively rare and only on specific user requests, where a peak of communication from the MU to the support station is needed. Typically, peak situations arise during remote data acquisition, that is in case a data acquisition device has been connected to the MU. Examples of such devices are GPS, a digital camera, or a metal detector (assuming the site includes metallic tools, coins etc. among possible finds).

For all devices, acquisition of erroneous data due to calibration errors would result in time waste for repeated measurements: this should be avoided by performing thorough calibration checks. Thus, start-up of data acquisition may need some computationally intensive data calibration checks that can be performed in real-time only by the support station.

Another example of communication peak happens when significance of a find can only be assessed by contextual information (other finds from the same site), which may influence future excavation in the site. For example, various pavements of the same kind in different areas of the site may suggest the existence of a road connecting them, so that it may be

important to look at intermediate grid positions where the road may still be hidden. In this case, immediate communication (messages and sketches exchanged among MUs through fixed units) among people in different areas of the site may allow real time changes of excavation plans.

Assessment of relevance of an object which cannot be related to other finds in the local site database may on the other hand require the opinion of an experienced person, whether at the fixed station or remotely accessible at some Museum. A digital snapshot (taken with a digital camera) may thus be sent with the message/query, or just the pen-drawn sketch. Searching non-local databases may also be needed: this latter feature is however limited by the availability of digitized data and compatibility in the internal organization of different archaeological databases.

These features result in support for cooperative work: a remote scientist may thus actively participate to the excavations, almost like he were personally on the site e.g by suggesting where to concentrate the activity or by joining discussions to interpret the acquired information.

### 3.3 Cooperative work on the wireless WAN

We have already remarked that field data is collected within a data base, which takes the form of an object store, as a result of collecting finds from mobile units in the various tests. Storage/retrieval and analysis of archaeological data should not be thought of as a simple man-machine interaction, rather as a distributed system where different data is kept on different machines, for varying purposes. To this respect, the role of the site object store is close to that of corporate document stores. In fact, various objects with different attributes (textual, graphical, location, other relationships based on possible interpretations) should be kept as aggregates into larger units (stratigraphic units and contexts) as excavation work proceeds; they should also be "viewed" at different levels of details by various people in the organization. There usually is no concern for security among scientists, the reason is rather that of filtering irrelevant details once an interpretation has been given to the finds.

Data in such an object store is considered as experimental evidence, and its aggregations are subject to updates as excavations proceed. Thus, tentative interpretations can be made and later discarded if further data becomes available which contradicts initial hypotheses. This flexibility and the possibility of keeping several such versions at the same time, until a final choice is taken, are implicit in computer supported tools for cooperative work.

Once data is settled, the same tool should also be used to derive reports, to be given to sponsoring organizations.

Track may be kept also of emails to colleagues, with non-textual information as attachments. Again, workflow manipulation tools already support such an organization as their usual specifications; data downloading to commercial databases is also supported.

The choice of what tool for workflow support should be used [9] falls to Lotus Notes for the following reasons:

- It is designed for cooperative work so it is possible to interface it immediately with several mobile systems at the same time.
- Web services and email support are integrated and available at no additional cost (actually, it has been originally designed for such purpose)
- It is a multi-platform tool, which could be run on different workstations; it should also be loaded on the mobile computer if sufficiently configured with disks and RAM space
- It has provisions for supporting synchronized update of local copies of the object store, which may result from elective or accidental disconnections.

Thus, our system provides novel features with respect to other archaeological information systems, due to different attitudes towards data manipulation as in group activities. Notes allows to keep multiple copies (replicas), even incomplete ones, of each object repository, to be stored on different client computers. Consistency of multiple independent replicas, even when simultaneously updating the same object, is kept by Notes itself: in fact, it contains proprietary synchronization software to such purpose. Any user, either mobile or stationary, and even connected via Internet from the University labs, may independently retrieve, update off-line and then send back to the server a selected data subset: for example, a replica may collect objects belonging to a specific test in the whole site, or to a certain period of time over all the site, or to stratigraphic units at the same level in several tests.

## 4 Conclusions

This paper has presented how mobile computers, integrating suitable communication technology, as nowadays available inside a palmtop computer, may be used to develop field archaeology support tools. Application scenarios in field archaeology have been examined comparing present with future situations. Innovations in this project include:

- substituting handwritten notes, sketches etc. in the field and eliminating computer data entry and post-elaboration by means of a single integrated system;
- real-time communication by means of a fixed workstation located close to the site: communication to/from the workstation, among mobile computers in the site, and possibly over a WAN;
- use of object-oriented technologies for finds storage and retrieval, on the mobile computer as well as on the fixed workstation.

Wireless mobile networks like ours make collaborative work feasible, in real-time, also with outdoor (and remote) activities. In our opinion, this latter aspect shall open the way to new outdoor applications not covered before by traditional computing.

The most innovative aspect for field archaeology derived by our communication scenario is the possibility, for a scientist, to achieve true collaboration with colleagues, like he were on the site, thus reducing mobility costs of an excavation campaign. Similar considerations hold for several outdoor activities, where presence of experienced but elderly scientists can be shortened or even made impossible by uncomfortable life conditions, like in tropical forests or deserts, where only young (and inexperienced) people may operate in difficult climate conditions.

The devices we are presently using are:

- a palmtop computer Telxon PTC 1134 as mobile device; it runs Windows 3.x for Pen and the drawing tool has been developed using 16bit C++ and graphical libraries. The choice of such a development environment is motivated by the need to optimize tools performance on small configurations like the 16-bit one we presently have, while preserving upward compatibility for future expansions on 32-bit machines. The system is fully operational, mobile unites communicate on the network by using asynchronous message exchange (email messages) and emulated shared memory (shared directories and files).
- Pentium based PCs, and DEC Alpha stations, running Windows NT and Lotus Notes operate as objects repositories (Lotus servers).

The project results from a cooperation among archaeologists and computer scientists at our University. In Summer 1998, a prototype has already been field tested in the island of Lemnos, Greece, at the prehistoric site of Poliochni by the archaeological team.

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