Mobile computing in a hospital: the WARD-IN-HAND project

M.Ancona, G.Dodero, V. Gianuzzi
DISI, Università
Via Dodecaneso, 35
Genova

F.Minuto
DISEM, Università
Viale Benedetto XV
Genova

M.Guida
TXT
Via Socrate
Milano

Abstract

We present the guidelines of a new project whose main task is to exploit mobile computers, connected via a Wireless Networks, in Personal Health systems, computerizing the patient clinical records with sophisticated solutions for taking clinical information *at the point of care*.

The challenging technology of the project is to marry pen-based and voice interaction within a user friendly and safe human computer interface.

1 Introduction

Most European hospitals already have wired LANs and WANs supporting the traditional interconnection of the whole health care system (administration, personnel management, patients' record management, reservations of tests, inventory systems and so on). Quite often, the health care system is partitioned into several components, and the "bedside" medical treatments are out of it. That is, checking the various treatments, prescription and delivery of chemicals, notes taken by doctors and the like still do not receive networked computing support, unless handwritten notes are later on copied to electronic supports.

As a result, it is impossible to get the information in real-time and have it available at the patient's bedside, thus improving the quality, and perhaps the very nature, of patient care.

Many systems allowing electronic filing and management of clinical records do exist, including a few commercially available products and an enormous amount of custom software developed by hospitals and university clinics for their own internal use. Unfortunately, such systems are located in fixed positions within an hospital unit, therefore forcing people to move there for data entry and data retrieval; also, information is first written on paper, and later typed into computers, therefore leading to errors, omissions, duplication of information and adding huge overheads to doctors' and nurses' work. It can be estimated that up to 50% of the time of doctors and nurses is currently spent in filing and retrieving information and in co-ordinating and synchronising among themselves. The impact of such inefficient practices on the quality of the services provided by hospitals is dramatic, and their cost for the community is enormous.

Let us consider what may happen to a patient inside an hospital. When entering an hospital unit, a patient first receives a visit, aiming to perform a diagnosis and to define the likely duration of its hospitalisation and the key milestones (exams, surgery, treatments, etc.). A clinical record for that patient (either on paper or electronic, or both) is then created.

During his/her stay in an hospital, a patient receives periodic visits by doctors, which check the status of the patient and eventually prescribe additional analysis, specialists' visits, further checks, treatments, etc. During such visits, doctors need to have access to the complete clinical records of the patient, which may include, for instance, results of analysis or other scheduled treatments. The search for such information often requires time, and therefore a close and timely monitoring of patients progresses turns out to be difficult, and the prescription of treatments may have to be differed, requiring the doctors to visit the patient again.

During visits, doctors may annotate information on boards attached to patients' bed, and instructions are typically given verbally to the head nurses, which may take notes on his/her diary. Afterwards, the head nurses assigns tasks to individual nurses, which, in turn, annotate instructions on their own diaries. Co-ordination is vital for patients' safety: all necessary actions have to be performed, they must be performed only once and they must be performed exactly when and as needed.

In case some analysis, specialist visit or dedicated treatment is needed, the request has to be forwarded to the interested laboratories and treatment rooms and, once scheduled, nurses have to take care of bringing patients in the right place and at the right time. When treatments are given by nurses, they have to record the event in the patients' clinical records.

Some co-ordination with the hospital administration department (which has to account all the costs linked to each patient) and with the logistic department (which is responsible for replenishing the stocks of medicines, materials and consumables) is also needed.

In summary, the entire process is centred around the patients' clinical records and involves activities such as: retrieving information about the patients, including results of analysis, monitoring progress, prescribing treatments, scheduling, executing and monitoring them, etc. It also comprises activities such as: exchanging information among doctors, among nurses and between doctors and nurses; co-ordinating and synchronising activities; ensuring that the necessary drugs, or consumables, are available when needed; etc.

Currently, the above activities are heavily paper-based, they are characterised by duplications of information, possible errors, omissions and delays; in some cases, co-ordination takes place only through informal communications.

This situation may be dramatically improved by use of bedside mobile computers [1, 4], connected to the centralized databases (that is, with the patients', administration and logistics databases) by means of a wireless connection. These systems would allow doctors and nurses to have real-time access to existing clinical records and to all those information (including digitised images) which may be relevant.

Doctors and nurses would be equipped with personal handheld PCs linked via wireless networks with a server. The server will collect in a repository all clinical records and all relevant information about patients, including traditional clinical records, results of tests and clinical analyses, etc. The server will also be connected via either wired or wireless LAN with existing hospital systems, such as systems running in the analysis labs, treatment rooms or the logistic department (see Figure 1).

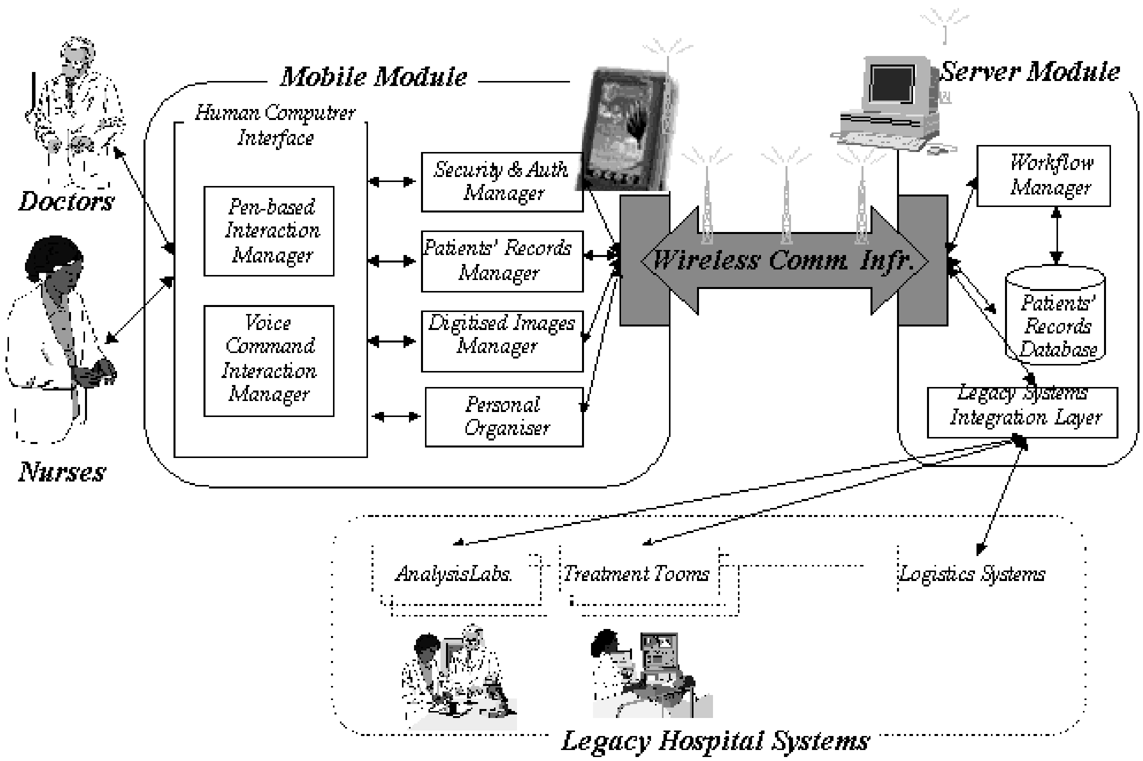

Figure 1: Mobile Computing at bedside

The server, on the basis of collected information, could trigger related actions (e.g. drugs stock update) and, via wireless networks, update the information on the palmtop computers of doctors and nurses, automatically assigning and scheduling tasks for them, so that alarms could be raised whenever critical tasks are being delayed.

2 Existing systems

Some hospitals around the world are already taking advantage of the mobility, flexibility and speed of wireless LAN-based mobile computing technologies to improve the quality and reduce the cost of patient care. Prototype systems have been already in use, mostly developed in collaboration with Computer manufacturer Industries. Among others, consider the following examples.

- Apple Computer and the US Department of Defense are sponsoring a collaborative project (ProMED) to explore the usefulness and feasibility of employing Personal Digital Assistant (PDA) technology in the context of military medical practice. The project's mission has evolved to now embrace other PDA devices, to explore the use of wireless networking in medical settings (both within Medical Treatment Facilities and in the field).

- The Liverpool Women's Hospital wireless network relies on Netwave Technologies. This solution has allowed the hospital to implement a paperless care planning system, operating at the patient's bedside and throughout the different wards of the hospital.

- Other prototypes have been experienced at the Good Samaritan Hospital (Fairlawn, OH) in cooperation with Aironet, and at the North Carolina Hospital, using Symbol's wireless network. All of them use handheld computers which are wirelessly connected to the network via radio. The systems support the IEEE 802.11 wireless LAN standard and operates in the 2.4 GHz band using Frequency Hopping Spread Spectrum (FHSS) modulation.

Results of these experiences show some remarkable improvements over computer processing of paper-based clinical records; the most important is that of safety. The staff has gained confidence in the networking system due to the elimination of double data entry and errors in transcription and, most importantly, an increase in the level of care provided to patients. Moreover, the networking system provides reliable high data throughput and excellent immunity to interference, thanks to the FHSS technology. This means that wireless LANs not only extend the reach of the network, but preserves the value of that investment.

3 Ward-in-hand: project objectives

The authors are at present cooperating within a research project, which involves three hospitals, companies and Universities, aiming at the exploitation of a wireless network of mobile computers within different hospital departments.

Wireless terminals are the ideal way to bring caregiver, patient and application access together. The network is a wireless LAN of sophisticated pen-based industrial terminals (e.g, Telxon PTCs or Symbol PPTs) based on FSSH Radio Frequency communication at 2.4GHz, with a communication bandwith up to 2Mbs. They will be connected to the already existing wired LANs. They have the capability to bring all kinds of information (including images) to the point of care and represent the most advanced application in clinical records processing.

The key features of Ward-in-hand are:

1. achieving the maximum from "hands-free" fault tolerance and safety.
   - Doctors and nurses need freedom and mobility to provide effective patient care. Some of the above applications use mobile laptops: we believe that this is not sufficiently comfortable because of the weight and size of the keyboard. For this reason, we rely on pen based tools and, heavily, on voice recognition.
   - Good connectivity is mandatory for reasons of safety: the network should be engineered for an extra bit of redundancy rather than skimping in coverage: for instance, it should be able to survive a failure or two on each floor and still have coverage. An additional advantage of redundancy is extra throughput, so access points will not become overpopulated. And should further extensions require higher bandwidth in the future, more bandwidth is already available.
2. use of widely available and secure hardware and software, in order to reduce costs and be compatible with existing systems. All the above prototypes have been developed as stand-alone systems, without concerns for possible integration and compatibility to other systems or networks in the hospital. This is not surprising in early prototypes, where the key issue is to demonstrate the feasibility of wireless networks. The present project, on the other hand, takes into account both legacy systems, and emerging standardization efforts. The project will be implemented as an open system, in order to be compatible with existing european de-facto standards, such as for example patients'record management in XML and the DICOM medical imaging standard.
3. An additional issue is that of security. Only those who have the right to access information can read and update patients' files.

The next two sections give more details about the first and third features.

4 Human Interface

The handheld PC must offer an extremely user-friendly human computer interface, to allow an easy access to the integrated applications. To this purpose, the problem of data entry is the most crucial one: users are normally standing, a fact that discourages the use of a keyboard, even with a reduced number of keys. To ensure the highest possible usability in any circumstance, the system could support two modes of interaction: Voice-based and pen-based.

4.1 Voice-based interaction

Voice is at present the main mode of interaction between doctors and nurses, hence it is natural to use the same mode also for computer interaction. The safety of such a system is then mandatory under two aspects: a correct recognition of spoken words, and discrimination of those said by the authorized personnel only.

The voice-based interaction will be the key success factor of the entire project: it will allow to entirely replace the current paper-based practices with minimal changes in the current working behaviour and without adding any overhead to users. The challenge is to make voice-based interaction, whose underlying technology has today demonstrated a good level of reliability, robust enough to be effectively used in a real-life, noise-intensive and safety-critical environment such as an hospital unit.

The voice-based interaction will first of all allow the user to use the other applications included in the Mobile Module: voice will be therefore transformed into commands to activate options and specific functionalities of such applications. It will allow, for instance, to interact with the Patients' Records Manager to retrieve a specific patient's record from the database; or with the Personal Organiser to declare that a certain scheduled action has been performed.

But the main and most innovative use of the voice-based interaction will consist in allowing doctors and nurses to, e.g., prescribe treatments, checks, analysis; to express diagnostic opinions; to post requests for actions; to send messages; to declare execution of actions and their outcome, etc.; and more generally to generate all the information needed for the workflow in the hospital unit to take place in the smoothest possible way. Thus, the voice recognition software must have the capability of selectively recognising in a sentence the presence of words from a pre-defined lexicon (which may include several thousands words).

One of the world-wide leader producer in voice technology is Lernout & Hauspie, which sells their products in the forms of engines and libraries of components which can be incorporated into end-users applications. The technology underlying the product does not require special individual training by each end-user, but only an overall environmental training (composition of the end-users population, male, female or both; presence of environment noise; etc.), therefore offering the necessary degree of flexibility and adaptability to a dynamic environment such as an hospital unit.

In our application, of course, major work and developments are needed around the basic Lernout & Hauspie's products, mainly in the following areas:

- Creation of the lexicon: it will include both a general-purpose lexicon (typical of any hospital unit) and a specialised lexicon (which will likely be different from a hospital unit to another one).

- Development of high-resolution voice selection mechanisms. Depending upon the specific context of use, mechanisms to exclude voice which may be in the environment (e.g. patients' voice; nurses' voice while doctors are prescribing treatments, etc.) have to be devised and developed.

- Development of a probabilistic self-assessment engine. The system will have self-diagnostic capability, thanks to a probability-based engine which will issue a warning whenever the degree of reliability of the command recognition will be lower than an acceptance threshold.

4.2 Pen-based interaction

Aa a secondary mode of interaction, users may interact with the system using a pen and the touch-screen. It will also serve as a back-up mode of interaction in those cases, when the main voice-based interaction will possibly fail, i.e. whenever the voice-based mechanisms will recognise a command with degree of certainty lower than a given threshold and there is a risk of mistake [5].

The more common approaches used for writing texts on a handheld computer are:

- Using *sidebar* lists and *pop-up* selection menus.
- Using *hand-writing recognition* software.
- Using a *virtual keyboard*[1] drawn on the palmtop screen.

An extensive use of menus and lists is envisaged whenever possibile, taking into account that this approach is feasible only for short lists of words, and become unusable with a large dictionary.

We think that selective methods, based on the selection of keys or entire words, will outperform hand-writing recognizing system for a long time. In fact, in the latter case the user is required to hand-write (i.e., to draw) all the letters forming a word with adequate precision, that is a time consuming task. Moreover, handwriting recognition has today still a severe limitation in its real exploitability, due to the need of training on individuals' writing style.

On the other hand, a virtual, possibly reduced keyboard, lets a user to select the letters composing a word quickly through simple key pressing actions, instead of a complete drawing of the corresponding letter shape.

However, use of a full-size keyboard is space wasting, and the user has to click on all characters composing a word, while it is possible to select frequently used words, by clicking a lower number of keys sufficient to extract them from the dictionary.

The above problems can be avoided by combining the keyboard and the menu selection approaches. By drawing a small menu oriented keyboard that dynamically changes its shape to the user needs and displays, at each time, a reduced number of selections, we can permit the user to select the required key.

A software system becoming a standard text input on mobile computers and phones is the **T9 program** of Tegic Communication[6]. T9 enables efficient generation of any desired text using a reduced keyboard having only a small number of keys. Multiple letters are assigned to each key so that the specific letter is ambiguous: it is disambiguated by comparing a sequence of keystrokes to words in a database. The name T9

[1]With the term *virtual keyboard* we intend a software system and a connected user interface emulating the task of a keyboard device.

stands for *typing with 9 keys*. Applications include pocket organizers, "smart" cellular phones and wireless email devices.

Our solution of the above problem, called **WordTree** (WT hereafter) is a virtual keyboard structured into a sophisticated pull-up menu based on the selction of *complete words* through a successive selection of intervals of contigous words in the dictionary.

WT [3], as suggested by its name, is a smart keyboard allowing a user to select a word from a dictionary organized into a *trie* of words dynamically displayed on the screen. WT starts by displaying (in a compressed form) the roots of all tries, i.e. the first few subset of *level-0* in which we partitioned the dictionary. The user selects the first subset of words and WT opens the corresponding sub-trie by displaying the successive subsets, until the entire requested word appears on the screen, together with few other *neighbor* words (see Figure 2).

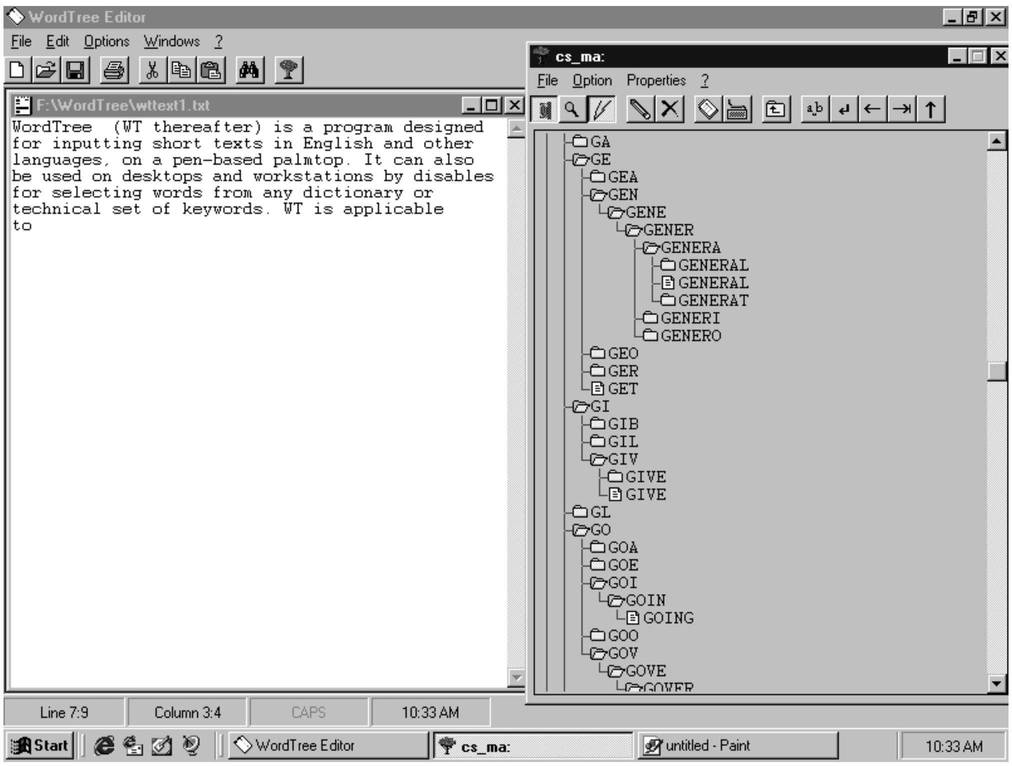

Figure 2: Five clicks to write `general`

In this way the user selects words from the database by clicking almost the *minimum* number of letters necessary to discriminate the desired word.

It should be noted that given the almost perfect tree structure of the dictionary representation on the screen few levels are sufficient to find any word in the dictionary (6 levels cover about $26^6 = 3.0815E8$ words).

5 Security

Several issues related to safety, security and confidentiality are considered in the present project. As for network coverage, we have already selected a redundant approach in order to increase availability; and we have already pointed out voice recognition possibilities and problems.

- *Identification.* To reduce the number of mobile computers, and hence the costs, in our project doctors and nurses in the same unit share the available mobile computers, so only a limited number of them needs to be bought. (The assignment of a mobile computer to each individual would certainly simplify safety and security problems, but it would be too expensive). Thus, every hand-held PC should be operative after an initial log-in phase, for example, by recognizing the voice or the hand-written legal signature (written on the touch screen with a magnetic pen) of a member of authorized personnel, or by individual smart card insertion. Once the user is logged-in, he/she will be identified as belonging to a pre-defined security level, and the allowable operation set will be correspondingly defined: doctors and nurses have different access rights (for instance, doctors may add/remove prescriptions, nurses may not).

- *Logging.* Once electronic notes have been transmitted to the central databases (connection takes place at fixed time intervals), they cannot be removed or modified, neither deliberately nor by incorrect subsequent operations. This feature is needed to provide documentation to insurance companies that there have been, for example, checks for drug interactions or verification that certain criteria were evaluated under high-risk medical conditions. In this way, the patient clinical record may be used to evidence both individual and hospital's responsibilities in the event of litigation.

- *Confidentiality.* Most of the medical related data, circulating in the hospital's network, both wired and wireless, are highly confidential, hence besides authentication at client side, data must be protected also when being transmitted, by encrypting and scrambling. The FSHH protocol is however one of the most difficult to be intercepted by itself, since data packets are randomly distributed across frequencies, in accordance with a code which differs for each transmitting unit. Thus, several mobile computers transmitting at the same time will not interfere among themselves.

- *Electromagnetic compatibility.* Last but not least, a further concern is that of possibile interference with hospital medical devices, which could be inadequately shielded with many radio frequency sources. This problem is not caused by the presence of a wireless network, since most electronic medical equipments are sources of radio frequencies, thus hospitals and suppliers of medical equipments already know how to to manage compatibility of potentially susceptible electronic devices. In fact, looking for example to statics reported by the US FDA, in a one-year period ending in September 1994, only .052 of 1 percent of problem reports were EMC (ElectroMagnetic Compatibility)-related. None of the prototype experiences in hospitals ever reported of such problems specifically due to a wireless network.

6 Conclusions

Improving the quality of medical care within hospitals is one of the most serious concerns in European countries, given the ever increasing amount of public and private funds being spent in health care. To this respect, information technology is still far from being optimally exploited.

Ward-in-hand is a new R&D project, whose aims have been described above. With respect to other medical applications with mobile computers, the strong innovative points consist in the integration of state-of-the-art technologies like voice recognition amd wireless networks, which in the past have already been experienced as stand-alone. The strong involvement of end-users (three different hospital units) from the very beginning is a guarantee for future product usability and diffusion.

The authors from DISI have already developed another application of mobile computers, within a research project to support field archaeology[2]. This prototype, [2] which has already been field tested in the excavations on the Greek island of Poliochni, had significantly different issues with respect to WARD-IN-HAND, especially from the point of view of safety and security. Archaeological data has very little concerns for safety and security; the number of involved mobile computers to be found in a site is significantly smaller, and the user interface requires input of complex drawings and digital snapshots, rather than voice commands. However the previous experience will be most valuable in the definition of network parameters and user interfaces for the present project.

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