Mobile information and communication tools in the hospital

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Abstract

Mobile information and communication systems in clinical routine have the potential to greatly improve communication, facilitate information access, eliminate double documentation, and increase quality of patient care in the long run. Projects to date have focused, for the most part, on highly specialized applications of the mobile computer. In our research project, ‘Cooperative Problem Solving in Health Care’, we have, among other things, designed a multifunctional mobile information and communication assistant. A prototype version of this system was implemented. This article outlines the close-to-reality evaluation of our prototype in a 1-week simulation study in a Heidelberg University hospital. We describe methods, aims, design and results of the simulation study, as well as discuss our methodology and the results we have obtained. We argue that the diverse requirements of different professional groups cannot be fulfilled by a single multifunctional device and propose, therefore, a ‘multi-device mobile computer architecture’. Finally, we present consequences for the future computing infrastructure. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

Physicians and nurses are highly mobile in their daily hospital routine, moving frequently between wards, outpatient clinics, diagnostic and therapeutic departments, conference rooms and operating theatres. Their manifold information and communication needs at any number of locations and at all times of day and night are difficult to satisfy. Costly clinical workstations, which require additional allotment of valuable space, though often used, are not always accessible.

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Current patient record information for example is not always available during doctors' rounds. Current literature available in the library or at the clinical workstation can not be directly accessed at patient bedside. New orders or diagnoses noted during rounds must be transferred to the patient records or a clinical workstation at a later time.

It is not only because of their mobility, but also due to their distinct patient care responsibilities that communication is so important for physicians and nurses. We feel that both direct and indirect communication require support through information and communication tools. More often than not, physicians and nurses are very difficult to reach by telephone directly. Indirect communication devices such as pagers fail to provide detailed information on the reason for a call and its urgency. They are disruptive and, particularly when repeated contact attempts must be made, cause communication delay.

The use of the mobile computer in clinical hospital routine has great potential to solve at least a part of these problems and to fulfill information and communication needs in health care. The mobile computer can support both communication and information processing, where an appropriate infrastructure is available [1,2]. Yet its development and its use in clinical practice is still rare. Research projects to date have dealt predominantly with isolated application fields of mobile tools, such as mobile access to medical knowledge [3–5], mobile documentation [6–8], mobile access to patient information [9–11] and mobile communication [12,13].

The aim of our research project, 'Cooperative Problem Solving in Health Care', has been the development of a general mobile information and communication tool architecture in health care. At the beginning of 1997 (see Ref. [14]), we conducted a preliminary study which examined application fields for mobile computers in the hospital. Based on its results, we then conceptualized and prototypically realized a mobile multifunctional digital assistant for information processing and communication. In order to test this concept and the available technology in as realistic a setting as possible, we carried out a simulation study at the end of 1997. Physicians and nurses from the university hospitals of Heidelberg, general practitioners and nurses — 31 professionals in total — took part.

2. Study aims

During the simulation study in Heidelberg, an interdisciplinary research team tested the prototypical mobile information and communication assistant in a close-to-reality study with genuine users, but employing simulated patients. We studied a variety of research questions, whereby the following criteria were of particular interest: security, legality, reachability management, application scenarios, ergonomics and user acceptance. For a detailed description of all research questions, see Ref. [15].

In this paper, we focus on application scenarios and user acceptance. We present results mainly for the physicians from the university hospital of Heidelberg, as they presented the largest sub-population of users during the study. We aimed to answer the following questions:

- Suitability for routine use: is the mobile prototype suitable for clinical routine in its functionality and operability? Is mobile technology sufficiently powerful and robust?
- Mobile communication: is there demand for mobile communication and reachability management?
Mobile information access: which information needs of physicians could be met through mobile technology? Which situations benefit from mobile information access?

Mobile documentation: what kinds of documentation activities can be supported by the mobile computer?

Integration into hospital information systems: how can the mobile computer best be integrated into hospital information systems? Can mobile computers replace clinical workstations or will they be a complement to them?

3. The Heidelberg hospital information system

The Heidelberg university hospital has 14 clinics and 62 medical departments with 117 wards and a total of 1732 beds, 70 outpatient units and 31 operating theatres and an additional outpatient theatre.

In approximate figures, 50,000 inpatients and 250,000 outpatients are treated at the hospital yearly, 20,000 operation reports are written, 250,000 physicians’ reports drawn up and more than 1 million findings established (laboratory, radiology findings, etc.). Some 6.3 million pages are generated yearly, requiring about 1700 m of paper storage.

Its information system consists of more than 30 autonomous application systems, each having communication interfaces with a communication server. Heidelberg University Hospital employs the patient management system, SAP IS-H. More than 800 health professional workstations provide health professionals with information when and where it’s needed. These workstations allow access to medical reports, laboratory and radiology findings, and support fundamental documentation, entry of current demands for pharmaceuticals as well as materials and food, medical knowledge retrieval, and several other information procedures [16]. The hospital utilizes a commercial application system for document and archiving management, and digital-optical archiving of medical records.

For details of the Heidelberg Hospital information system, see Ref. [17].

4. Mobile prototype technology and functionality

The mobile digital assistant is based on an Apple Newton 2000, measuring 20 × 12 cm² and weighing 660 g, and an attached GSM¹ — mobile telephone. Speech and data communication is realized by D1-Netz². Fig. 1 shows the hardware used.

Prior to the study, the department of medical equipment carried out extensive testing, which revealed that mobile telephones do not interfere with medical equipment when a safety margin of 2 m is guarded³. In order to

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¹ Global system for mobile communication.
² A German mobile telephone network.
³ As a result of these tests, the use of mobile phones in the university hospitals of Heidelberg is officially permitted on normal wards, in the corridors and in waiting areas, since 25 November, 1998.
Fig. 2. Electronic form for request of a psychosomatic examination.

To avoid any risk of interference, all users had been informed of this fact at the outset of the study. Disturbances of medical equipment by the GSM mobile phones were not observed.

In the study, we made the following package of functions available based on self-developed software and commercially available application systems for Newton:

- Electronic forms for examination requests: these could be completed and transmitted directly (i.e. radiology or laboratory requests). Existing information was automatically reused — thus, for example, previously made diagnoses were transferred automatically to the electronic form, and selection lists were available behind many fields to facilitate the completion of forms (Fig. 2).
- Personal organization: the prototype provided administration tools for appointments, tasks, addresses and notes.
- Communication of speech and text: both direct calls (over the mobile telephone) and indirect text messages (only to other test users).
- Management of personal reachability: call screening for protection from unwanted calls and disruption (for example from certain callers, in certain situations; for details, see Refs. [18,19]).

5. Study design

5.1. Method

To answer the questions outlined in Section 2, we designed a simulation study, in which test users are observed while working with prototypical technology in a close-to-reality environment. The simulation study is not an experiment. It does not allow a complete evaluation of technical systems, but rather aims to obtain design proposals for a new technology from experts in the field and from future users. For details, see Refs. [20,21].

Rather than simply conduct laboratory studies, we asked test users to actually work with our prototype on fictitious, but close-to-reality patient cases, parallel to their daily routine and in their usual environment. We
felt that the expert test persons could so better assess and evaluate the pros and cons of our technology. Real life events in the process of patient management and information processing could be captured and linked to the mobile technology.

At the same time, unlike in field studies, particular consideration can be given to predetermined problem areas (questions of data security, for example) through direct intervention in the simulation environment (i.e. by deliberately disturbing communication pathways). The simulation study also enables testing of prototypical technology in a (simulated) routine without posing risk to genuine patients, should technical failures occur.

The simulation study, as a test method, combines elements of the laboratory test and the field study. It has the advantages of both methods when applied with prototypical technologies: that is, in a still relatively protected and safe simulation environment, it allows for a test situation which resembles reality and yet enables the influencing of test case content and processing.

5.2. Participants

In November 1997, the simulation study was carried out at the university hospitals of Heidelberg in close cooperation with various research projects linked to Daimler Benz Kolleg Ladenburg [22].

Seventeen physicians and eight nurses from the university hospitals of Heidelberg, one administrative official, two general practitioners, one doctor’s assistant and two outpatient care nurses—31 expert test persons in total—participated.

Fig. 3 shows the distribution of professions. Most of the hospital personnel are employees of the departments of neurosurgery and internal medicine.

5.3. Course of the study

Before conducting the study, we interviewed the test users, eliciting their expectations and conceptions with regard to mobile communication and information processing. The 31 test persons were equipped with and trained on the usage of the mobile prototype. The simulation study took place between the 10th and 14th of November, 1997.

During this time, the test persons processed cases, which were prepared in advance. These test cases contained the name, age and sex of fictitious patients (played by students) and their symptoms. Findings were prepared to be available should a physician request a particular test. The study reflected typical daily hospital routine: patients were examined, necessary measures (X-rays, for example) were initiated through the mobile prototype, other physicians were consulted by mobile phone or e-mail, examination orders were written and transmitted, examination reports were transmitted and read, medical knowledge was accessed—all with mobile prototype support.
The database prepared for the simulation study contained the data of 21 fictitious patient cases, including administrative data, diagnoses, examination findings and documents of earlier hospital stays (discharge summaries, etc.). During the simulation week, the central patient database was accessed approximately 200 times (for loading new documents and examination findings, for example). 70 examination requests were written and answered by 42 examination reports. Diagnoses were documented for 20 patients. Altogether the test users exchanged about 1000 text messages and made about 2000 telephone calls.

To uncover the effects of and user experiences and problems with the new technology, we conducted group discussions every evening of the test week.

Each test user was observed for at least one full day. At the end of the study, the users were asked to fill out a questionnaire (return rate: 84%), in which they were asked to assess the different functions (for the questionnaire and the results, see Ref. [23]), and they were again intensively interviewed. Thus, we were able to elicit from the medical professionals not only their experiences with our prototype, but also extract design suggestions for future development of mobile computer technology.

6. Results

Our results are presented according to the questions listed in Section 2. Evaluations and information taken from the 16 physicians who completed the questionnaire and took part in the interviews (from 17 participants) are presented first. We then present the compiled results for participants from outpatient care4.

4 Note: ‘n = x + y’ after the results indicates that x users regarded this function as ‘very useful’, and y as ‘partly useful’. ‘n = x’ it indicates that x users agreed with the given statement.

For a global presentation of all results, see Refs. [24,15].

6.1. Suitability for routine use

Most of the medical test users felt that the mobile prototype was too large (n = 14) and heavy (n = 12), but were satisfied with the size of the Newton display (13 × 9 cm2) (n = 12). Some physicians complained of poor representation quality (brightness, contrast) of the display. Apparently, it was difficult for several persons to view the screen at the same time (i.e. during discussion).

Most of the physicians rated the built-in English handwriting recognition (no German recognition was available at the time of the study) as average (n = 4) or poor (n = 10). The use of a ‘virtual keyboard’ as back-up was found useful but only for shorter texts. A few users asked that for text entry a small keyboard be attached. Overall, the available input devices were not yet considered fit for practical use.

At the beginning of the study, frequent use of our Hotline indicated that many users had difficulties handling the new and complex hardware and software. Nevertheless, by the end of the study, participants felt that they had either partly or fully mastered the technique.

The processing speed of the prototype itself, as well as the available data transmission rate of the GSM network (9600 bit/s), was considered too slow.

The physicians complained of problems caused by the GSM technology. At some locations, no GSM connection could be established. Network breakdowns sometimes caused data loss and data inconsistencies.

6.2. Mobile communication

A majority of the participants felt that mobile communication has a place in assisting them in their daily hospital routine (Fig. 4)
necessary. The person receiving messages could then process the accumulated communications at leisure.

The reachability manager was considered useful by the majority \((n = 11)\), who saw advantage in the fact that both communication partners could identify each other by name (rather than number) \((n = 12)\), and that calls could be screened when necessary (i.e. during discussion, OP, or rounds) for caller identity \((n = 14 + 1)\), urgency \((n = 10 + 2)\) or subject matter \((n = 6 + 6)\), thus allowing for selective prevention of disturbance. Four users did not see any advantage in the use of the prototype — these were mainly stationary doctors (laboratory researchers, for example) or senior doctors with private secretaries.

Physicians would welcome a simplified version of the complex rule based reachability manager, arguing that only a few situations would suffice (fully reachable — reachable only in case of emergency — not reachable). Switching from one situation to another should be easily possible (i.e. with situation buttons) — to allow for a quick switch of reachability according to a change in situation.

### 6.3. Mobile information access

Participants expressed diverse opinions on the usefulness of computer-aided mobile information processing (i.e. access to patient data). These depended, among other things, on the activity and on the general attitude of a physician toward this technology. The majority of users found mobile information processing either very important \((n = 6)\) or somewhat important \((n = 5)\) (Fig. 5).

Representation possibilities of the mobile computer were viewed with skepticism (‘The screen is too small to display radiographs or mammographs’). Users posed questions concerning patient data security on mobile computers and called for strict security measures.
to prevent data misuse in the case of theft or loss of a mobile computer.

Where participants felt that the clinical workstation is indispensable, offering more comfortable input and output devices (such as display, keyboard, printer), they did see place for the use of the mobile computer within selected areas — as long as it is stable, fast and user friendly (‘When a clinical workstation is not available, I look up the information in the mobile computer’). Fig. 6 shows the results from the questionnaires in detail.

Physicians gave mobile computer use for information access a positive rating in three principal areas:
- Medical knowledge access (pharmaceutical inventories, medical literature): for example during discussion with a patient (‘Mobile computers can serve as information center’).
- Patient data access (electronic patient record): examination and laboratory findings and diagnoses during the current hospital stay, documents from earlier hospital stays, etc. (‘If I require the latest laboratory findings, they can be looked up immediately — before, I had to go search for the paper-based patient record’).
- General information access: telephone books, physician address books, encoding catalogues and other often needed information (‘I would be glad to always have the complete ICD code with me’).

Besides functionality evaluations, we asked the users to give us situations in which they felt the mobile computer could best be applied. Fig. 7 shows their answers in detail. On-call services ($n = 10 + 3$), night duty ($n = 10 + 3$) and emergencies ($n = 7 + 4$) topped the list — all situations in which the usual information sources (patient records and clinical workstations) are not always accessible.

Interestingly, mobile prototype use during doctors’ daily rounds, which at the beginning of the simulation study was thought to be an obvious instance for mobile computer implementation for speedy current information ac-

![Fig. 6. Responses of physicians to the question: ‘how useful is the mobile access to...’ ($n = 16$).](image-url)
Fig. 7. Responses of physicians to the question: ‘in which situation do you consider the mobile information access useful?’ (n = 16).

cess, was found to be ineffective (with n = 3 + 5). A number of physicians saw a potential risk to healthy doctor patient communication and declined to use the computers during talks with patients (‘The use of the mobile computers at patient bedside does not correspond to my understanding of medicine. We deliberately leave patient records behind during rounds, we want to speak with, not about the patient. We should do the same with computers.’). Some physicians, however, did not agree: ‘I believe that patient discussion develops quite normally, despite the computer.’

6.4. Mobile documentation

Test users evaluated mobile documentation of diagnoses (n = 7 + 5) and mobile examination requests (n = 7 + 3) positively, particularly when facilitated by selection fields. Additionally, they much welcomed (n = 10 + 2) automatic data entry of existing data (i.e. patient administrative data).

Some saw potential use for mobile documentation during rounds — eliminating request book entry and subsequent tiresome transcription to paperbased forms. In this case, a physician could simply fill out the digital form directly, sign it and dispatch it electronically. Some users, however, expressed concern at taking over work otherwise done by nurses.

A suggested alternative was that nurses could fill out the digital form on behalf of the physician. The physician could then sign it and dispatch it immediately. Thus, doctor/patient communication would remain undisrupted. The usual time delay for examination requests could be reduced with mobile documentation.

Used in conjunction with the clinical workstation, electronic forms have therefore an advantage over conventional paper forms. Pen-based documentation of longer reports (medical record writing, etc.) received less positive ratings. Some users indicated difficulties in using a pen-based computer while standing or walking. Nevertheless, use-
fulness of the mobile computer was to a large extent affirmed, due to the shortened time delay between doctor’s orders and the transfer of the request, as was also the case in the documentation of diagnostic and therapeutic procedures (‘If you don’t document them directly, it often just does not get done.’).

6.5. Nurses’ and general practitioners’ assessment

This section outlines the findings involving the eight clinical and two outpatient nurses, and the two general practitioners who participated in the simulation study. These results aim at demonstrating the variation in opinions on and requirements of professional groups in regards to the mobile computer.

6.5.1. Clinical nurses

In an assessment similar to that of the physicians, the seven clinical nurses, who completed the questionnaire, saw advantage in the use of electronic forms (meal requests, materials, pharmaceuticals, examination requests) and considered the mobile computer a useful information source (patient information, telephone book, literature, data bases).

In the question of documentation, however, opinions differed. Nurses regarded even extensive documentation using the mobile computer (nursing documentation, for example) as possible and practical. Time reduction and the avoidance of double documentation were regarded paramount.

One-half of the nurses (n = 4) could see no place for mobile communication in nursing, as wards are already equipped with ample possibilities for communication (telephone, etc.). Nurses considered the personal mobile computer for nurses unnecessary, but rather felt that one or two mobile computers for the whole ward to be used for nursing documentation in the patient rooms or during ward rounds would be of benefit, in addition to a clinical workstation.

6.5.2. General practitioners and outpatient care nurses

Both general practitioners (n = 2) and outpatient nurses (n = 2) saw great advantage in the use of the mobile computer during home visits. Patient information, which is available in their offices, can be more difficult to access outside the workplace — in particular, if the home visits must be made at short notice. Users rated the mobile computer positively in providing all relevant patient and medical information, no matter the location.

General practitioners and outpatient care nurses, all of whom make use of mobile communication tools (mobile telephones), see a need for mobile communication. Where a reachability management feature was poorly rated in outpatient care, it was felt that the possibility of leaving messages could bring about considerable improvement in communication between outpatient and inpatient health care.

7. Discussion

7.1. The results

As the results show, the test persons found need, for the most part, for mobile computer implementation in clinical routine. In this chapter, we summarize the three main fields of application — mobile communication, mobile information access, and mobile documentation.

Mobile communication in clinical routine provides two possibilities: direct and indirect communication (through message leaving). Information exchange in an interdisciplinary working team can thus be substantially facilitated, and reachability much improved. To
balance the interests of caller and called, application of a reachability manager can allow for a specified reduction of disturbances.

Availability of relevant information at any location is the general advantage of mobile information access, for which a need can be seen not only in access to general information sources (diagnosis catalogues, pharmaceutical inventories, etc.), but also to medical knowledge (current medical literature, medical databases, etc.), and to mobile electronic patient records (to current findings and documents, access to earlier discharge summaries, etc.).

While the use of conventional patient records and paper-based knowledge resources carries with it the disadvantage of being available only at one place and can therefore be accessed by only one person at a time, mobile computers are not restricted to any one particular location, and can be consulted by several users at the same time. There is, however, an obvious contradiction between the request for a small and transportable device on one hand, and for a large display on the other.

Mobile documentation allows for data acquisition at patient bedside, at the same time solving the problem of double documentation—a task neither stationary personal computers nor conventional forms can perform. Mobile computers can replace any paper-based form, cutting down time taken for form search and eliminating the risk of errors in transcription. In order to contribute to the quality and completeness of electronic patient records, it is preferable to directly process the electronic forms. Nevertheless, it is also possible to print out the forms and to process them in the conventional way.

The standardization of forms is a precondition for the implementation of mobile documentation. Only then input aids such as selection lists and electronic analysis can be used. Reuse of data already entered (patient administrative data, diagnoses, etc.) is then possible. Extensive input of free text is not viable at the present state of mobile input technology.

Many test users feel that the mobile computer can complement the functionality of the clinical workstation in the above described areas. Mobile tools provide their greatest support particularly to physicians during night watches, on-call services and emergencies, when mobility is a necessity.

Others users, in contrary, saw no need for the mobile computer, as long as basic functions (information processing, and communication) can be performed at the clinical workstation. It must be pointed out here that the multifunctional clinical workstation is widespread at the university hospital of Heidelberg. Workstations can be found in nearly every ward, operating theatre and doctor’s office, thus there exists no obvious need for the mobile computer. In contrast to the more enthusiastic mobile personnel, such as ward physicians, the more skeptical users were less mobile in their work, spending more time in the laboratory or office. Their information and communication needs are fulfilled by the latter group with the telephone and clinical workstation.

We conclude that not only stationary, but also mobile tools play a meaningful role in fulfilling the information and communication needs of diverse users in their varying degrees of mobility.

7.2. Methodology

The simulation study seems the most appropriate method to obtain both a close to reality and a safe assessment of prototype technology. Most test persons welcomed the possibility of participating in the design and
evaluation of a new technology before its introduction into routine. Some test persons suggested that work with genuine rather than fictitious patient data would have been more meaningful (‘missing practice reference’).

We felt that in order to conduct a field test with genuine patient data, a different set of basic conditions would have to be present; that is, in particular, a more stable technology as well as stable integration into the existing hospital information system. To avoid misunderstanding concerning the usability of our prototype, it was important that we explained in detail to our test persons the methodology and aims of a simulation study before the beginning of the study. In this simulation study, it was advantageous that the communication functions and access to medical knowledge was not fictitious, but rather real in their application, thus aiding in the motivation of test persons to also use simulated functions.

The additional work load caused by the study due to working with the technology and simulated patient cases, was often higher than expected (‘The study has taken up much more time than I had expected’). We were aware of this issue when recruiting test users and we thoroughly informed our test users during the preparation phase, explaining the likelihood of the additional workload. Nevertheless, our test users were highly motivated and active in testing our prototype system.

All of the 31 clinical test users selected for the study participated on a voluntary basis. It was our aim to involve a variety of users from different professional backgrounds as well as clinics, with differing attitudes, ranging from the skeptical to enthusiastic, toward the use of the mobile computer in the hospital. With, in particular, the integration of the more skeptical user, we hope that our results reflect a balanced and realistic picture.

Due to the prototypical architecture and the complexity of the technology, problems such as network breakdowns and slow response times occurred during the study. These problems dominated the group discussions in the evening, and they were also stressed in the interviews. The cause for these problems, among other things, can be found in prototype programs not optimized for speed, in partial unstable prototype technology, as well as in slow data transmission rates of GSM networks. Nevertheless, both the questionnaires and the interviews showed that the users were able to differentiate between these technical problems and general potential of the mobile computer. The rather error-tolerant users did not seem to be influenced by technical problems, which were therefore not directly decisive to the general assessment of the mobile technology.

Despite the mentioned restrictions, we were able to achieve our aim of obtaining a concrete evaluation of the mobile technology, as well as suggestions for future mobile technology. Through working with the technology in their daily routine, the users were motivated to seriously consider the new technology with an eye to possible future implementation. Thus, we were able to extract from the interview ideas and suggestions, which would not have been available otherwise. The answers to the questionnaires showed clear tendencies in many areas. Frequent use was made of the possibility to enter free text on the questionnaires. These valuable statements and suggestions would surely not have been uncovered through a laboratory study.

Can the study results be applied to other areas and other institutions? Since a large number of physicians from different departments and levels of hierarchy participated, we feel that, at least in the field of hospitals, this is indeed possible. This, however, is the case only where similar conditions concerning the
8. Consequences for the future computing infrastructure

Based on the results of the simulation studies, consequences for the future computing infrastructure can be drawn, taking into account mobile computers.

8.1. Multiple functionality

The results of the simulation study supported the principal idea of offering multiple mobile functions for the user. Like the clinical workstation, a mobile tool should be useful in many ways. It should support medical professionals in most situations, eliminating the need for several tools and therefore leading to cost reduction. Its very convenience motivates the users to carry the tool. The primary fields in which mobile tools can best be implemented as found in the simulation study are: information access, documentation, knowledge access, communication and personal organization.

8.2. Design of mobile software

Application software for mobile tools must fulfill a number of special requirements. On the one hand, software should be designed according to basic common design requirements for software (i.e. ISO 13407, ISO 9241), on the other, mobile tools place additional application-specific demands on the software (e.g. the pen as an input device).

We feel that the design of mobile tools should be such that they can be used in the most simple and intuitive ways possible. Applications should be reduced to their main functions. These should be quickly and easily accessible. Sophisticated menu structures, for example, are unsuitable. The mobile tool should support, not distract its user.

Mobile software should also respond very quickly to user input. Any user, who wants to gain advantage through time reduction in mobile information access and documentation, would resent long waits in mobile software response, causing work disruption.

Because of the tool’s restricted screen size, mobile information access should be limited to only relevant data. The clinical workstation, with its large screen, is better suited to the presentation of complex information.

Generally, despite the constraints discussed, mobile software should have a similar look and feel to the software used at the clinical workstation. Training time can be substantially reduced, and in only a short time users are able to support their work with the tool. The user interface requires adaptation for mobile use (see for example Ref. [14]), even when the same application systems are used.

8.3. Design of mobile hardware

The simulation study showed that the mobile tool should be small and lightweight, yet combined with the largest screen possible. We propose a folded screen, for example, or that data be beamed on a flat wall — thus, allowing more than one person to view the screen at a time. All necessary technology should be integrated into the one device to avoid the necessity of carrying additional equipment for data transmission, etc.

Users of mobile tools should be able to rely on at least 24 h of working time, using battery recharging stations for storing any unused mobile tools.

Keyboarding from a standing position is impractical, whereas pen-based input devices
(with their analogy to paper and pencil) have proven their worth. Reliable handwriting recognition is therefore essential. Keyboard hookup, however, should be possible, or the temporary use of a clinical workstation as a docking station.

In the field of mobile information processing, various mobile computers with varied functionality and application fields are already available. The personal digital assistant (PDA), a small computer used primarily for personal information organization (diary, telephone numbers, appointments, notes), offers display and text input devices (mostly pen-based), and often operates on special systems, such as Newton OS or Windows CE.

Also available on the market are larger mobile computers (pen-based computers, notebooks, laptops, virtual terminals etc.) which usually operate on the same systems as personal computers (Windows, Mac Operating System, for example). Both the PC and the mobile computer, then, can make use of the same software.

The mobile technology available on today's market, therefore, already offers a variety of tools for mobile information processing and communication. Users should select a particular technology according to their information and communication needs.

The rapidly advancing wireless LAN technology will, in the foreseeable future, make possible a stable and powerful integration of the mobile computer into the hospital information system.

8.4. Integration of mobile tools into hospital information systems

Unlike the clinical workstation, mobile devices cannot be permanently integrated into hospital networks by a network cable. A temporary integration, however, is necessary, for example for access to new laboratory findings or immediate transmission of new diagnoses. In general, synchronous or asynchronous integration of mobile tools is possible.

A synchronous integration allows the mobile computer to access data in the information system online-possible only in those hospitals where wireless LAN (such as infrared or radio) is available. This is made easier if the mobile computer and the stationary computer work with the same operation system, and the same application systems are used. If this is not the case, it's necessary that communication interfaces between the application systems on the mobile tool and on the clinical workstation be developed.

Synchronous integration has the advantage that new data can immediately be transmitted in both directions. Data storage on the mobile tool, with all the problems of data redundancy and data synchronization is unnecessary. Access to knowledge, which remains unchanging for the most part (medical databases, for example), could be realized by memory cards.

Asynchronous integration of mobile tools is an option, where synchronous integration is not possible (i.e. funding may not be available for purchase of a wireless network). An asynchronous integration allows for data exchange only when the mobile computer is connected to a workstation or directly to the network. In all other cases they operate autonomously and unconnected. For example, before taking meal requests from patients, the nurse connects to a clinical workstation to download relevant patient data to the mobile computer. Once the meal requests have been taken, the mobile computer is reconnected and all meal requests are forwarded to the kitchen system. Because no wireless LAN is necessary and normal serial or network connections can be used, this integration mode is the more cost effective
(for a comparison of wireless and wired solutions, see Ref. [10]). The mobile computer works independently of a network and is therefore more stable.

The necessary data synchronization of the mobile and the stationary computer is, however, difficult and laborious, especially when two or more users have to work with the same data (for details on the problems of mobile databases, see Ref. [25]). Asynchronous integration is only an option if the same data are used by a few persons at the same time, and if it is not time-critical. Locally stored data, even if only temporary, poses a risk to data security (what if the mobile computer is stolen?). Today, the asynchronous integration of mobile computers is already being put to use in the areas of ordering and stock-taking.

To prevent that users need to be concerned with communication tasks, data transmission in any form should take place automatically. The mobile tool should then inform the user of incoming data — for example, by highlighting the patient for whom new laboratory results are available. Naturally there must be sufficient data speed — longer waiting times to transmit or receive data causes loss of any time saved by using the mobile computer.

9. A multi-device architecture for the integration of mobile computers

The simulation study shows clearly that requirements for mobile computers and for application fields can be very different. For example, a mobile computer to be used for mobile communication should be small, easy to use, and have a long lasting battery; a mobile computer, however, which will be used for information processing, requires adequate display size and convenient data input tools (‘The display is too small and the mobile computer too big — this is a dilemma. It’s one or the other.’). The demands made on the mobile information processor and the mobile communication tool for both software and hardware design vary greatly, as do the needs of different professional groups. Physicians frequently ask for personal digital assistants, whereas nurses prefer the function-oriented computer, which can be used by all nurses in a ward (i.e. for meal orders and nursing documentation).

Needs are also a matter of personal preference — they depend on professional duties, workload, and mobility. In particular, personal preferences, as well as the technical equipment already used, influence the evaluation of the mobile computer.

There is not any one universal mobile computer which can possibly fulfill all requirements in all areas (this is as impossible as there being only one kind of car or one kind of personal computer). Thus, we realize that the concept of a single integrated mobile personal assistant, as it was seen at the beginning of the research project, is in practice not feasible.

We therefore propose a ‘multi-device architecture’ for electronic information processing and communication in clinical routine. This architecture fulfills two requirements: it is flexible enough to provide a framework for the use of mobile computers in any environment, and it gives decision makers and users a guide for the selection of adequate technology.

The multi-device architecture consists of three main kinds of computers.

9.1. The small personal mobile computer

These mobile computers support each employee mainly in his communication tasks. This includes, for example, mobile telephoning, reachability management, answering ma-
chine use, telephone book organization or exchange of short text messages. In this field, mobile telephones with display and PDAs are commercially available, in hospitals increasingly replacing the pager. They can be used by professionals who do not require a mobile tool for information processing.

9.2. The larger mobile computer

The larger mobile computer allows for mobile information processing with central functions such as patient data and patient document access, medical information and general information access, use of electronic forms, order entry and e-mail. The selection of functions available depends upon user needs. Technology for these tools comprises different kinds of larger mobile computers (for example laptops, and notebooks). We can divide the technology into two classes:

- Function-oriented mobile computers: used for special tasks (i.e. meal orders, examination requests, nursing documentation) in a certain area (i.e. the ward, the operating theatre).
- Personal mobile computers: used by mobile and/or technology friendly doctors. Functions offered are, for example, information access and personal organization.

9.3. Clinical workstations

The clinical workstation, as described, for example, in Ref. [16], continues to offer a base for electronic information processing and communication in clinical practice. It provides exhaustive functionality, such as access to medical records, to information and knowledge resources, to e-mail and electronic forms, for all clinical professions. Its use in wards and outpatient units is mostly function-oriented.

9.4. Multi-device architecture

Table 1 portrays the multi-device architecture in detail.

The given functions of the clinical workstation are only examples, for exhaustive lists, see Ref. [26]. A more elaborate list of the functions of the mobile computer can be found in Ref. [1].

We will not go into integration details of mobile application systems into other (stationary) application systems. This depends largely on the technical infrastructure and on the architecture and interfaces of the application systems involved. Mobile computer integration into information systems is simplified if both can directly access the same databases as used by the clinical workstation. For details of the integration of the mobile computer, see Ref. [27].

The multi-device architecture stresses the fact that mobile computers can only complement, not replace the clinical workstation. Mobile computers increase the availability of important functions in those places where a clinical workstation — due to limitation in funding or space (in patient rooms, meeting rooms, etc.) — is not present.

We feel that the greatest advantage both for staff and patients can be achieved when several information and communication technologies are combined and integrated, using as a framework the multi-device architecture.

The simulation study has shown that a number of distinct demands made on mobile computers must be considered before they are selected and established. The multi-device architecture presented here can at this point provide the support for the management of information systems.
<table>
<thead>
<tr>
<th>Kind of device</th>
<th>Mobile telephone with extended functionality (personal tool)</th>
<th>Mobile computer (personal tool or function-oriented tool)</th>
<th>Clinical workstation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>Telephoning; emergency calls; reachability manager; receiving messages; sending messages; answering machine</td>
<td>Patient record; electronic forms; electronic mail; diary; notes; address books; updating the patient’s chart; nursing documentation</td>
<td>Patient registration; patient record; diagnosis documentation; medical report writing; access to medical knowledge; electronic mail; Internet access; material ordering; meal ordering; duty roster planning; nursing care planning</td>
</tr>
<tr>
<td>Interface</td>
<td>Via radio telegraphy, for example DECT, GSM; important: a 100% accessibility inside the hospital</td>
<td>Asynchronous: via serial cable attached to a clinical workstation; via network cable attached to the computer network Synchronous: low data volume — DECT, GSM; high data volume — wireless LAN, infrared</td>
<td>Via network cable attached to the computer network</td>
</tr>
<tr>
<td>Example</td>
<td>GSM-phones respectively DECT-devices from Alcatel, Bosch, Ericsson, Grundig, Hagenuk, Motorola, Philips, Siemens, Sony etc.</td>
<td>Apple Newton 2100; Pilot III, Psion; Nokia Communicator 9000; Windows-CE-Palm-/Handheld-PCs</td>
<td>Personal computer; UNIX-workstation; network computer</td>
</tr>
</tbody>
</table>
10. Conclusion

As the single term ‘information and communication technology’ suggests, communication and information processing are becoming one. This development is leading to new opportunities in cooperation, to change of workflow, and to new organization structures in hospitals.

The results of the simulation study show that the majority of the participants sees a place for mobile information and communication tools in the workplace. Medical personnel would welcome speedier access to information, the possibility of recording data at patient bedside, and the opportunity to communicate everywhere when the need arises, thus allowing healthcare professionals to better work together and leading to an improved quality of patient care.

During the simulation study, we tested application scenarios for mobile tools. Future long-term field studies would be able to confirm our results, whereby available mobile techniques, computer-user interface, data security and aspects of integration in hospital information would require particular attention. Additionally, the influence of mobile techniques on workflow, communication and the patient–doctor relationship would need careful consideration.

During the simulation study, we were unable to confirm cost reduction. This requires research in further field studies. We expect considerable savings could be made, for example, as the need for expensive specialized paper-based forms is reduced.

In the near future, we will start introducing extended mobile telephones at Heidelberg University Hospital. First, we will create the necessary communication infrastructure. We will then introduce mobile information tools in selected environments, using the mobile communication infrastructure for data transmission.

We are convinced that mobile tools will play a fundamental role in health care information processing in the future. The architecture and infrastructure of information systems, as well as technical equipment and legislation, will be influenced by this development. Just how large the portion of mobile information processing will be, can not be assessed at this point in time. Tasks, which can only be fulfilled by the clinical workstation, will always exist. Last, but not least, the use of the mobile computer will never be seen as a substitute for direct contact with patients and colleagues.

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