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A Mobile System for Recording Examination Data of the Analysis of Functional Disorders of the Masticatory System

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Abstract

Simplifying and streamlining data access and recording tasks in medical settings is an important and successful application area for mobile computing technology. An interesting research topic in this area are user-interface design concepts that allow for an optimal integration of system operation into working situations where the user is tightly involved in interactions with his physical surroundings.

We describe an ongoing project that aims at developing a mobile information system which uses pen-computers for recording data of the analysis of functional disorders of the masticatory system during examination. Long-term goal of this project is the design of an interaction concept that allows for an optimal integration of the system operation into the established examination procedures.

A comprehensive questionnaire for the analysis of functional disorders of the masticatory system has been developed. This questionnaire then has been structured with respect to established examination procedures and coded into a pen-computer.

Experiences with a first system prototype within the scope of a limited field trial show that our approach is viable and simplifies the recording task. Future work will concentrate on a further streamlining of the user interface by providing additional task-specific graphics interaction techniques and by a detailed study of usage patterns.

Keywords

Medical Informatics; Mobile Information Systems; Mobile Computing; Data Recording; Dentistry.

Motivation and objectives

The foundation of clinical diagnosis and therapy planning is the comprehensive recording of a patient's medical history and examination findings. Even in the age of digital data processing, paper-based media, such as forms, the patient's file card, etc. are used for the initial on-site recording of this information. In order to allow for the computer-based processing of the data, a secondary recording step is required, in which the data is manually transferred from paper-based to electronic media. Such a two-step approach has inherent disadvantages: it requires more manpower, increases the probability of errors, and delays data availability.

In order to address these problems, PCs are increasingly used as a means for primary data recording in medical routine. Parallel to an examination, findings are directly entered into the computer, either by the examinator herself or by assisting personnel (*e.g.*, [1]). However, a prerequisite for using a computerized solution based on conventional hardware is the availability of sufficient „desktop real-estate" and networking facilities in order to allow an installation of a PC in the examination rooms and the immediate transfer of examination data to a centralized processing facility. The fundamental disadvantage of a PC-based solution is the lacking mobility of the data entry stations. This means, a substantial number of entry stations has to be installed throughout the various locations of a clinic to allow for an easy and timely access from any place where data arises, resulting in comparatively high system costs.

The goal of this paper is to describe an ongoing project aiming at developing a system for the recording of examination data that avoids these problems by using low-cost, lightweight, highly mobile pen-computers („Personal Digital Assistants", PDAs) for data recording.

It is worth noting that the use of mobile computers in medical scenarios is already a quite well established concept. Numerous systems already exist for a variety of data recording and access tasks (*cf.* e.g. [2,3,4,5]). However, current applications for mobile systems in medical settings concentrate on usage scenarios that can abstract from ongoing social interactions between user (doctor, nurse, examinator) and patient. This means, the user's attention can be wholly directed to operating the application.

When building an application that is meant to be operated *in parallel* to social interaction, e.g., during a face-to-face consultation or examination, this implicit assumption of undivided attention is wrong. The user needs to direct most of his attention towards the patient resp. the examination routines and an application should distract the user as little as possible from critical manipulations and social interaction. Also, the patient usually expects the user to focus on him, rather than on a technical device.

The design of user interfaces for data recording systems that are meant to be operated during a face-to-face consultation or examination thus has to face substantial challenges. Specifically, it must be carefully adapted to the possible sequences of an examination process in order to allow for a minimal additional overhead in system operation.

Our project [6,7] investigates these topics within the scope of a system that uses mobile computing devices for recording the examination data of the analysis of functional disorders of the masticatory system.

The project has the following objectives:

- Study the use of mobile computing devices for interdisciplinary medical research and care.
- Develop concepts for designing user-interfaces of mobile information systems for non-intrusive use in everyday clinic routine.

The further structure of this paper is as follows: in the next section, we outline the application area and the system requirements for the data acquisition tool. We then describe the system design and the results of our first trial phase. Concluding, we outline work planned for the near future.

Application area and system requirements

In dentistry, the analysis of disorders of the masticatory system (short: ADMS) is an integral part of the medical routine examination of a patient prior to beginning a therapy.

It is specifically important for assessing the health state of the oro-facial system with respect to occlusal situation, disorders of the masticatory muscles, and pathological conditions of the temporo-mandibular joints (TMJ).

In order to allow for a timely identification and treatment of pathological processes, the ADMS is required before and after orthodontical treatment, in prosthodontics and in restorative dentistry before treatment.

The ADMS is specifically significant in consultation hours that address patients suffering from cranio-mandibular disorders (CMD). Especially in this case, a complete and thorough examination is an indispensable prerequisite for an exact diagnosis. Here, an assessment of the occlusal situation, painfulness of the masticatory muscular system and TMJ, as well as functional findings are of highest importance.

ADMS therefore is an important part of medical routine. At the same time, a valid set of pre- and post-therapy ADMS-findings plays an important role in assessing the effectiveness of therapeutic measures. This of course requires the availability of ADMS-data for computerized processing.

However, ADMS is rather complex in comparison to, e.g., assessing the patient's dental state. So, in order to encourage the use of this important analytical instrument in everyday routine, it is crucial to provide tools that optimize the examination as much as possible.

At the Dental School of the Rostock University Hospital, we have therefore begun a project that aims at developing tools which help to provide this efficiency. As recording of substantial data volumes in machine-readable form is a significant part in ADMS, we concentrate on the methodological aspects of this recording process.

Specifically, we were looking for a data recording mechanism that would simplify this task by using suitable computer technology. In detail, the following objectives were the primary goals the desired recording system should be able to meet:

Reasonable cost. The system should allow for low unit costs, allowing the deployment of a large number of devices with a limited budget.

Non-intrusive deployment. The system concept should be usable without requiring changes in established routine and without requiring the installation or modification of fixtures in the clinic rooms.

Usability under semi-sterile conditions. The device should allow the quick use of standard germicidal substances on all accessible surfaces. (Which rules out, for example, the use of keyboards.)

Non-intrusive usability. The system should not distract the examinator's attention from the patient by providing a simple, straightforward application usage, instant access to the application even in case the device has been turned off, and an easy physical handling of the device.

Social acceptance. The system and its use should be unobtrusive for the patient, supporting a personal, cooperative examination situation.

Location independence, ubiquitous availability. The system should be usable at unforeseeable places in- and outside the clinic buildings.

Specifically, the system should provide at least a day's worth of battery power to enable field examinations.

Time savings. The system should save time by rendering the manual transcription of paper forms onto digital media obsolete. Also, it should save expensive data conditioning efforts through providing a higher initial data quality.

Functional equivalence and superiority. The electronic form should provide at least the flexibility of the paper-based version. This specifically includes data entry capabilities such as free-hand drawings of jaw movement graphs, free text notes, etc.

Furthermore, the system should exploit new functionality, such as:

- on-line plausibility checks.
- guided input (*e.g.*, popup-menus)
- use of textual notions instead of numerical codes.

We found that using pen-based PDA with suitable data acquisition software would be an optimal system choice with respect to meeting these requirements.

System design

The first step in designing our mobile data acquisition system has been the definition of the data items that should be recordable.

For this purpose, a comprehensive ADMS questionnaire has been developed at the Rostock University. It is based on a questionnaire provided by the German Equilibration Society (AG Funktionsdiagnostik) of the German Dental Association (Deutsche Gesellschaft für Zahn-, Mund- und Kieferheilkunde).

The raw set of data items then has been structured into thematic groups, resembling the different main areas of an ADMS examination. These resulting areas are:

- The patient's personal data record.
- Clinical anamnesis.
- Clinical examination.
- Occlusion analysis.
- Diagnosis.
- Therapeutical measures.
- Treatment progress.

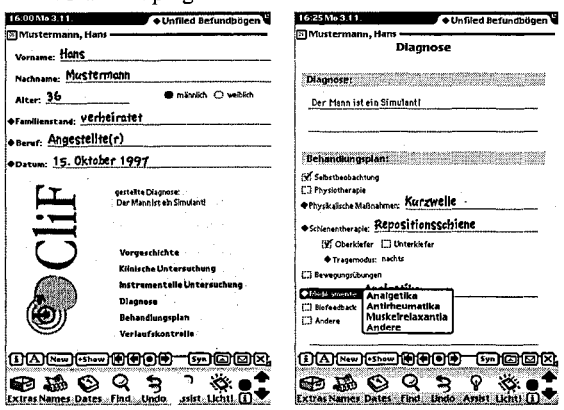

Figure 1 - Example form pages

Within each area, we have ordered the items roughly into the sequence of examination steps, yielding between one and eight „pages" of items for the thematic areas.

So, although the electronic version of the ADMS may look like a simple straightforward translation of a paper questionnaire, there has been some effort in optimizing the interactions required for completing the electronic questionnaire w.r.t. the typical course of the examination process.

It should be noted in this context that an important factor for achieving a good match between user requirements and system functionality has been the direct involvement of responsible clinic personnel in the user-interface design.

A typical page interaction items such as:

- Binary fields (check boxes).
- n-ary fields (popup-menus).
- Text input fields with recognition functionality tuned towards dates, numbers, or arbitrary text, depending on the expected data value.

(see Fig. 1 for some examples).

For most values that had to be entered as numerical codes in the paper questionnaire, we have provided pop-up-menus indicating the available choices (and displaying the selected choice) in full text (*cf.* Fig. 2). This reduces errors and simplifies recording by giving better visual cues for different options.

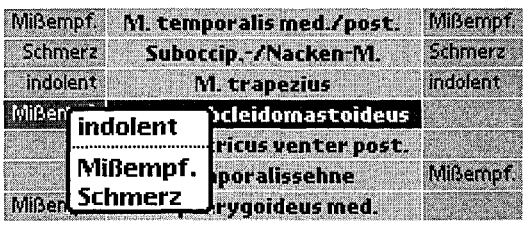

Figure 2 - Popup-menu usage

In addition, we have created a specialized interaction component simplifying the recording of tooth contacts in eccentric movements of the jaw. Here, a tooth state is presented, where the occlusal prematurities (habitual, centric, protrusive, laterotrusive left and right) of each tooth is visualized using a five-element icon (see Fig. 3). Prematurities are recorded by clicking on the individual teeth and by selecting the respective values from the popup menu.

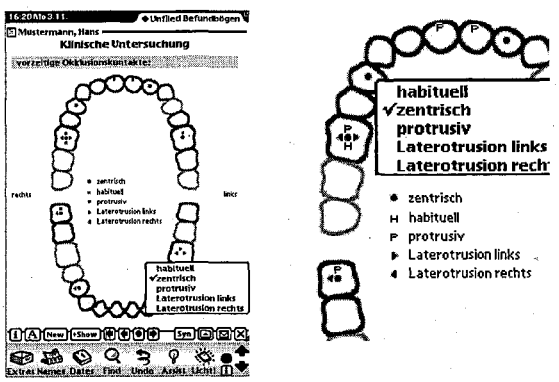

Figure 3 - Tooth state recording tool (detail at right)

Additional features streamlining data recording are:

- Simplification of diagnosis through the automatic generation of a questionnaire summary that provides a concise textual description of all pathological findings.
- An interaction mechanism allowing the simple graphical recording of lower jaw movement by using a pen drawing (Fig. 4, lower part). Here, we also provide an automatic classification of the jaw mobility graph, giving a direct diagnosis of pathological deviations.
- Graphical recording of incisal distance using sliders (Fig. 4, upper part).

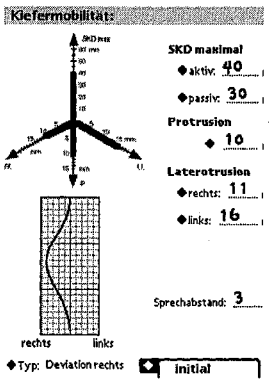

Figure 4 - Jaw movement

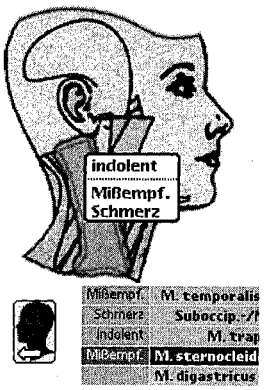

Figure 5 - Palpation record

- An alternative graphical interaction mechanism simplifying the recording of the painfulness of the masticatory muscles (see Fig. 5).

Besides the data entry itself, the system provides the following additional facilities:

- Questionnaires may be organized into collections using „folders".
- It is possible to search for questionnaires based of recording date and/or textual content.
- Questionnaires may be printed from the PDA.
- Questionnaires may be sent via Fax or Email.
- Between different PDAs, questionnaires can be transmitted using wireless infrared communication.

Furthermore, the system provides a data exchange facility that allows to transfer questionnaires between a PDA and a stationary database using ODBC (Open Data-Base Connectivity).

The complete mobile ADMS data recording system consists of a number of PDAs[1] used by the examinators for recording examination results and a stationary PC running a database such as MS-Access. In regular intervals (*e.g.*, every evening), the PDAs are docked onto the PC and the new recordings are downloaded into the centralized database.

Initial evaluation and first findings

For an initial evaluation of the first system version, we concentrated on the following aspects:

- Ease-of-use for the examinator.
- (Improvement of) data validity.
- Data handling ability.
- Data-base connectivity.
- Social acceptance.

The purpose of this evaluation has been to give a first qualitative assessment of the system w.r.t. the above points, without requiring an expensive quantitative formal analysis. We wanted to have a clear indication, whether the system would at least in principle be able to meet our demands, before investing a substantial effort into a thorough usability analysis. We therefore chose a simple ad-hoc approach with subjective ratings and a comparatively small number of users and patients.

In this first field trial, our system has been used in the consultation hour for CMD patients in the department for prosthodontics and material sciences at the Rostock University Hospital. During the trial, the data of 50 patients have been recorded with the mobile system and transferred to the stationary data base.

Ease-of-use. We found that, after a short training time, the data recording process was experienced as simple as on paper.

The use of handwriting recognition raised some problems. Even a trained examinator was sometimes unable to successfully record free text input, as required for basic patient data (name, occupation) and individual anamnesis notes. Recognition errors specifically affected terms taken from medical jargon, indicating the important role of a domain specific vocabulary.

Data validity. By using a guided approach to data entry, the data validity seems to be improved with respect to missing values (*i.e.*, overlooked fields). Also, the possibility of wrong (*i.e.*, meaningless) values has been eliminated.

Data handling ability. One important goal of our first project phase has been to prove the basic feasibility with respect to answer times and data volume. Earlier experiments in creating an electronic version of the questionnaire using a general-purpose forms construction tool have failed to provide satisfying results. The software was unable to handle the number of data items per questionnaire. Also, answer times became unacceptable when trying to handle more than a trivial number of questionnaires.

The current system proves that, by using adequately tailored software, our mobile platform is able to handle substantial volumes of questionnaires with virtually arbitrary size and graphical complexity at a reasonable performance.

Data base connectivity. We have tested the transfer of data to two database systems on different operating systems (Windows and MacOS) and found the software to operate sufficiently fast and reliable. (Fig. 6 shows a screenshot of the MacOS database)

Social acceptance. Lastly, we found that patients accepted the PDA as recording tool quite well during a consultation. The PDA is usually not experienced as technical barrier between examinator and patient. Only 12% of the examined patients raised questions about the purpose of the device.

Conclusions

In this paper, we have outlined the goals and current results of an ongoing project that employs mobile devices for optimizing data recording tasks in clinical examinations.

1. We use Newton MessagePad systems.

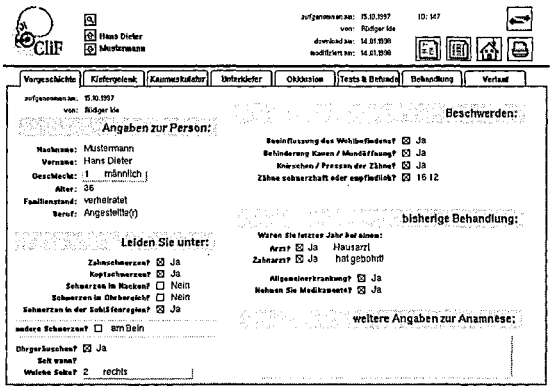

Figure 6 - Stationary database (MacOS version)

In the current project phase, we have built an initial version of this system and have used it successfully in a trial phase. Besides proving the fundamental feasibility of our approach, this system can already be employed in everyday-routine as data recording means. At the same time, the system allows to gather important user feedback on design flaws and missing functionality, which will be used for guiding the software improvement process.

Based on results from the first trial phase, we have already planned the following enhancements for the next system version:

- Improvement of handwriting recognition by providing a custom built dictionary containing the medical terminology required for recording patient data and individual anamnesis.
- Customization means that allow the user to further adapt the system's dialogue structure and recording facilities to his indivdual examination procedures (this seems to be a very important feature)

Also, we think about integrating additional diagnosis functionality, such as (limited) expert system support, potentially using exploiting wireless on-line connection to powerful stationary deductive systems.

Finally, the reader should note that the system so far is not overly complex and contains little challenge from the technical side. (The overall development time for the application itself amounts to only a few man-days.) The *interesting* technical aspect of the system, which, to our opinion, sets it apart from other mobile information systems for clinical use, is the emphasis on a seamless integration into the normal examination routine[1]. Here, substantial user-interface challenges, such as supporting split attention, fast context switches and fast function selection with minimal cognitive overhead have to be met [8]. The use of graphic-based interaction techniques, such as the ones outlined above, is one of the important strategies for achieving this goal, as they simplify orientation in the application by providing distinct visual cues for different contexts. Our institutions are partners in a basic research project on mobile visualization [9,10], where basic solutions to these problems are investigated. The goal of the next project phase is to exploit these results for our data recording system.

1. And we must admit that these considerations have played only a limited role during the first project phase.

Acknowledgments

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