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Designing man–machine interactions for mobile clinical systems: MET triage support using Palm handhelds

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Abstract

The Mobile Emergency Triage (MET) system is a clinical triage support system that aids physicians in making triage decisions as to whether a child presenting in the Emergency Department of a hospital with a specific pain complaint should be discharged to a family physician, needs to be admitted for further investigation/observation, or requires an urgent specialist consult. The system's mobile component is designed to work on handheld computers. This paper presents our experience and discusses our original solutions with regard to designing man–machine interactions for mobile clinical support systems. The specific interactions adopted in the MET design that are discussed in the paper were created in consultation with potential end-users and tested at the Children's Hospital of Eastern Ontario in Ottawa.

Keywords: Decision support systems; Mobile devices; Clinical decision making; Emergency triage support; Human–machine interaction

1. Introduction

The Mobile Emergency Triage (MET) system is a computer-based clinical support system that aids emergency personnel in making a triage decision as to whether a given patient:

(1) should be discharged to a family physician,
(2) needs to be admitted for further observation, or
(3) requires an urgent specialist consult.

The MET system is developed in a modular way, with each module designed to evaluate a specific acute pain condition. Thus, the system's functionality can be easily modified by replacing existing modules or by adding new ones.

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The MET mobile component is implemented on a handheld computer, and at present we support devices running Palm OS. MET users, namely medical residents and Emergency Department (ED) physicians, enter data into a handheld computer about a patient's history, his/her physical examination, and/or the results of tests. The system has a triage function that allows a user to consult a rule-based decision model in order to get a triage recommendation. The decision rules constituting the model have been generated from historical data (transcribed from verified patient charts during a retrospective study) using data discovery techniques based on rough set theory (Michalowski et al., 2004). The triage function can be invoked at any time in the triage process, irrespective of the amount of information about the patient's condition that is currently available. The system consults rules that are most appropriate from the point of view of available data. It infers from partially matched rules if not enough data about the patient's condition is available, or there are no rules that can be matched against available information, and it infers from fully matched rules if enough data is available and appropriate rules exist. Matching of the rules is translated into triage strength factors calculated for each triage recommendation. The strength of the recommendation depends on the amount of available data about a patient, and the generality of matched rules; the more data is available and the more general rules are matched—the higher the strengths of the recommendations (Stefanowski, 1993). The triage recommendation that acquired the highest strength factor is then labelled the "suggested triage", but all possible recommendations are presented to a user.

It is worthwhile to notice that the system not only helps in making triage decisions, but also contributes to improved management by allowing physicians and residents to collect data in a structured way, which by itself would lead to improved clinical performance (Guerlain et al., 2001; Glas et al., 2002).

MET is designed to work in an ED environment. Due to the significant space limitations of most EDs, use of a desktop computer in such an environment is not a feasible option, and hence a handheld, that is a compact and mobile device, was selected. Mobility of the computing device is a significant advantage in terms of the system's accessibility, but adds to the complexity of the design. Drawbacks such as small screen, limited display capabilities, and restrictive data entry format place new requirements on the design specifications and the quality of man–machine interactions. Some design guidelines, especially those related to domain-specific and user-centered interactions were applied while designing MET (Gulliksen, 1996; Gulliksen and Sandblad, 1995; Weinger, 2000). However, lack of well established and tested design principles, combined with the scarcity of research on standards for mobile devices, made our work both novel and challenging.

The paper is organized as follows. In the next section we discuss the basics of man–machine interactions in the medical domain. It is followed by a presentation of the solutions that were implemented in the MET system, and we give the rationale behind them. The paper ends with a discussion.

2. Man–machine interactions in the medical domain

Well-designed interactions are essential in computer systems developed for the medical domain because the cost of potential flaws can be enormous. Notwithstanding such a requirement, many interfaces in medical/clinical systems "are poorly designed, fail to adequately support the clinical tasks for which they are intended, and frequently contribute to medical error" (Weinger, 2000). Possible reasons for this situation include:

- lack of the ability to field test the interaction framework outside the application context (namely the operating room, the ED, the ambulance),
- discontinuity between the development effort and end-user requirements.

Due to the nature of the application domain (clinical environment) and work pressure on end-users, it is very difficult to develop a controlled clinical trial to evaluate the interaction framework. This is especially true for the ED, where the nature of the work and constant time pressure on the healthcare providers do not create the testing opportunities that are available for business applications. Such a situation leads to a phenomenon that is well documented in the Information Systems literature, namely a lack of congruence between design specifications and end-user expectations, further amplified by the fact that the analysis stage of the system design is for practical considerations curtailed because of the reasons outlined earlier. In order to address these problems Wiklund (1998) proposed to adhere to specific principles while designing man–machine interactions for medical devices. These principles come mainly from software engineering research; thus a design framework proposed by him aims to improve typical interactions by eliminating information and control overload, eliminating the liberal use of colors in a manner that is inconsistent with medical conventions, and by allowing easy navigation within the system's components.

The importance attached to well-designed and non-ambiguous man–machine interactions in the medical domain intensifies the need for their domain-specific and user-centered design (Gulliksen and Sandblad, 1995; Gulliksen et al., 1993). This implies, on the one hand, an understanding of human behavior in terms of task execution, reasoning, problem solving and interpreting, and on the other hand, development of a "clean" interaction framework. Such a framework should allow an end-user to focus his/her attention on the tasks to be supported through enhancement of his/her cognitive abilities. This should be accomplished by the use of domain-specific metaphors, and eliminating end-user's need to be concerned with the operation of the computing device. While there are some general frameworks enforcing such an approach, they were not developed with a handheld computer in mind. In the following section, we will describe how through research and extensive experimentation we were able to develop specific interaction solutions for a mobile triage support system.

3. MET man–machine interactions

3.1. General design

The MET system design (presented in Fig. 1) follows the general principles of a client—server architecture, with the server being responsible for management of the databases (*database subsystem*), synchronization of the clients (*sync subsystem*), and decision model calibration (*model subsystem*). The mobile MET client, implemented on a handheld computer, is used for entering information about a patient's condition, and for invoking a rule-based clinical algorithm for recommending the triage. The Web-based MET client that could be executed on a desktop computer connected to the Internet or Intranet, has the same functions as a mobile one, with the additional capability of managing the patients' data that is collected on a mobile client.

The MET mobile client was developed according to object oriented principles, and its design blueprint is illustrated in Fig. 2. When designing the system we separated out a generic solver (*triage subsystem*) that could be used for various problems from knowledge bases (*modules*) associated with specific presentations of acute pain. Such a design not only improves the reusability of the system's components (there is no need to customize the *triage subsystem* for specific *modules*), but follows directly from research in medical informatics, where generic solvers reflect fundamental algorithms for processing data, and knowledge bases represent specific health-related application areas (Musen, 1999).

For the purpose of this discussion, only the *dialog* and *interface subsystems* are of interest. The role of the *dialog subsystem* is to manage man–machine interactions according to the embedded principles that specify the sequence of displaying appropriate screens associated with individual symptoms and signs, and prescribe the system's behavior in response to the end-user's actions (e.g., tapping a button). The *interface subsystem* is a repository of interface elements (building blocks) that are used by the *dialog subsystem* to interact with an end-user. These blocks include: screens common to all clinical *modules* (e.g., login

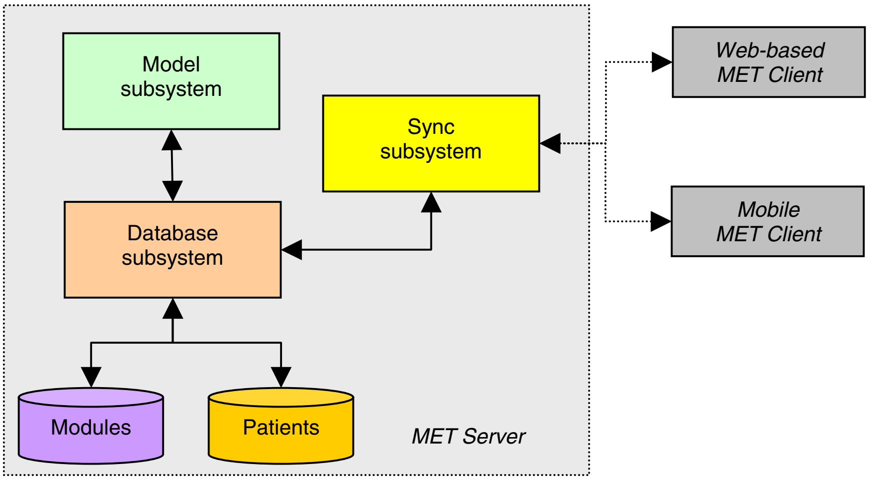

Fig. 1. MET architecture.

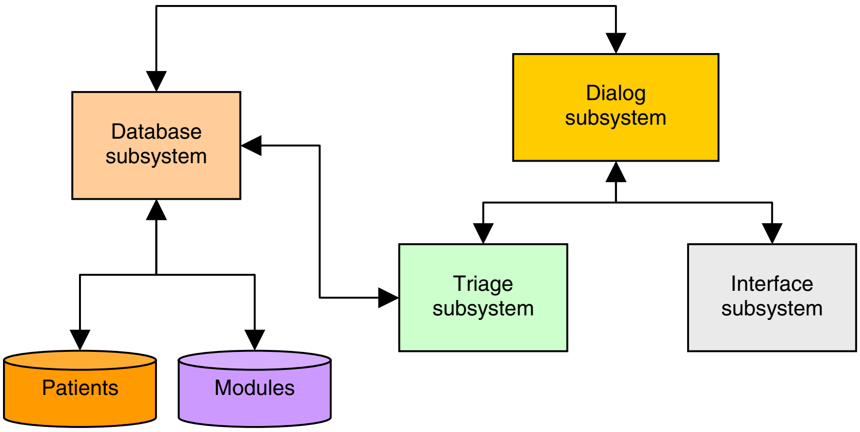

Fig. 2. Mobile MET client architecture.

screen, list of patients, etc.), general screens customized for the particular *module* during the runtime (e.g., history or report screen), and editors, i.e., tools used for editing the values of clinical attributes (pictograms, check boxes, lists).

In developing the framework for man–machine interactions in the MET mobile component, the following domain and user-specific principles were followed:

- keeping the overall interactions transparent, simple, and clean,
- making efficient use of the display,
- eliminating data entry using a handwriting recognition system (graffiti),
- contributing to the accomplishment of the task at hand by using cognitive clues.

It is clear that the cognitive needs associated with a specific application domain should play a paramount role when designing interactions aimed at a particular work environment (Gulliksen et al., 1993). The MET system is designated to be used in the ED, and any obstruction of the task at hand caused by the system would simply make it unusable. ED medical personnel will be consulting the

MET system while performing tasks under pressure, when the need to use a computer is often perceived as a hindrance. Thus, one of primary objectives was to develop a system that does not deter medical residents and physicians from routine patient management. Consideration of the intended user group, the way in which its members perform tasks and what type of systems they are accustomed to were very important factors when deciding about specific solutions. The users of the MET system were more familiar with clinical activities, filling out patients' paper charts and administrating tests, than with scrolling and navigating through screens, tapping buttons, and using graffiti. In order to facilitate their interactions with the MET mobile client, symbols that are familiar to the end-users, such as check boxes, body pictograms, icons with well-known cues (e.g., microscopes or thermometers) and labels used within the hospital, were incorporated as the main design features. They were combined with intuitive navigation between the different system elements and the elimination of the use of graffiti and textual data entry.

3.2. Navigation

The main concept behind managing the navigation between the different MET functional elements was to focus on four main activities associated with triage: taking a patient's history, conducting a physical examination, evaluating the test results, and triaging a patient. Correspondingly, MET has four main screens—one for each activity. Selecting an icon associated with a given activity invokes the MET element responsible for data gathering for that activity (see Fig. 3). The icons are subsequently repeated (in smaller format) on every MET screen, thus enforcing a cognitive image of each of the activities, and allowing an end-user to move easily throughout the system functions (see Fig. 4).

There are good reasons behind the use of icons in MET, the first being that icons require less screen space then the usual navigational buttons, such as 'next', 'back' and so forth. Also, the use of graphical symbols enhances man–machine interactions, as suggested by Wiklund (1998).

Fig. 3. Main triage activities.

Fig. 4. Navigation between activities.

Deriving the specific graphical icons used in the MET system was an interactive process characterized by numerous consultations with the ED physicians at the Children's Hospital of Eastern Ontario. As a result of these consultations it was decided to use the graphical presentation of a label standing for the appropriate activity. These labels (*Hx* for History, *PE* for Physical Examination, *Ix* for Tests, and *TR* for Triage recommendation) are typical short forms used by physicians in describing the routine activities on a patient's chart.

The use of color should be consistent and not overabundant in order to enforce the end-user focus on the task to be accomplished. The MET interface relies on a few colors that are limited to icons and pictograms only. The colors enhanced with text labels on the icons are used as visual cues to reinforce the distinction between the four main triage activities.

3.3. Inputting data

Data entry on a handheld device generally involves using a handwriting recognition system (graffiti), or the virtual pop-up keyboard. It is difficult to master these data entry modalities, so we decided to significantly simplify the input mode in the MET system, and use fast shortcuts whenever possible. In the case of attributes with a limited number of possible values (i.e., those taking yes/no, present/absent, etc. values) it was achieved by presenting check boxes (see Fig. 5). Check boxes are familiar constructs to all who have ever filled out a form, and therefore, they were selected over pull down lists or other similar solutions. A special case was made for those attributes that refer to a site on the human body (i.e., a site of pain, site of tenderness, etc.)—then, the check boxes were augmented with pictograms representing appropriate body parts (i.e., abdomen) so possible ambiguities associated with the interpretation of presented choices are diminished. A user can identify a specific location by tapping the appropriate area on a pictogram or by checking a check box (see Fig. 6). The utilization of graphical controls (photographs, pictograms) for selected data entries enhances the cognitive association between the task and the MET function by presenting an end-user with an image that is very closely associated with the clinical activity he/she is familiar with.

Numeric attributes (those having a virtually unlimited number of possible values), such as temperature, or duration of pain, require different data entry modalities. The appropriate data is entered, using a simplified keypad that mimics a phone keypad (see Fig. 7); thus, such data entry tool should not present problems for inexperienced users.

3.4. Writing comments

Physicians are accustomed to writing comments on charts, so it is important that the MET system

Fig. 5. Using check boxes.

Fig. 6. Using pictograms.

Fig. 7. Using a keypad.

also has such a facility. Following our earlier assumption about the cumbersome use of graffiti, we decided on an alternative comment entry format. After analyzing hundreds of patients' charts, we have developed dictionaries with frequently used terms and keywords for almost all clinical symptoms and signs used in the system. The physician simply needs to select an item from the dictionary to create a simplified comment (see Fig. 8).

Fig. 8. Writing comments.

Fig. 9. Presenting results.

3.5. Presenting results

As mentioned earlier, the system does not give one definite suggestion, but shows all possible recommendations that acquired positive strengths (see Fig. 9), and labels "suggested" the triage recommendation with the highest strength. Thus, the system's operation reflects the uncertainty that is inherent for clinical reasoning, further amplifying the fact that MET does not work as an oracle that replaces the physician, but as a helper (influencer or debiaser (Spreckelsen et al., 2000)) that tries to point out and eliminate possible biases when triaging a patient.

4. Discussion

As with any man–machine interaction framework, feedback from the intended end-users is extremely important for the practical acceptance of the system. Throughout the design stage, medical students, medical residents, ED physicians, and paediatric specialists were consulted about alternative design solutions. These consultations, combined with adhering to the principles of user-centered and domain-specific design, resulted in an interaction framework that is intuitive, easy to use and supports the tasks at hand. It allows the ED physicians to focus on the interactions that take place while conducting the patient interview or physical exam, and provides for a seamless transition between the tasks of gathering and entering data and triaging a patient. Thus, we have developed a man–machine interaction solution for a mobile device that is in line with the end-user cognitive expectations, and minimizes the cognitive burden associated with the change that would accompany use of a computerized support tool for ED triage decisions. Following the initial positive reception of the MET system by the physicians, we had proceeded to evaluate MET's operation during a regular clinical trial in the ED of a pediatric hospital. The trial lasted for 7 months and ended in the winter of 2004. During that period, the MET system was used by over 150 different members of the ED staff (physicians and residents). This group had diverse prior experience with handheld computers, ranging from complete novice to advanced users experienced with medical applications. Each of the ED staff members participated in a short orientation session after which he/she was able to operate the MET mobile client without any difficulties. Overall, the participants were satisfied with the clear and easy-to-use interface.

The overall triage accuracy of the MET system during the trial was slightly higher, though not statistically different, than the accuracy of ED physicians (72% for MET and 70% for the physicians). Though some may question the utility of a tool with 72% accuracy, we maintain that the performance of the MET system is satisfactory, given that it is similar to this of the physicians themselves, and that it is a support tool used at an early stage of the patient's assessment, when a small amount of information is available. Moreover, while calculating the MET triage accuracy, we considered the recommendation with the highest strength only and matched it against the gold standard. In everyday use, the physicians interacting with MET would receive the recommendations with associated strength, and analyzing the differences in strength between the recommendations should provide an additional piece of information to be used while making a triage decision.

One of the interesting discoveries following the clinical evaluation of the MET system was the observation that the individual's acceptance of a clinical DSS in the ED was significantly influenced by the person's comfort level with computing technology in general. Thus, residents trained in emergency medicine that were exposed to computers as early as primary school, perceived the handheld-based triage support as a helper in their work, as long as it fitted the workflow. The same cannot be said about older physicians whose comfort level with general computing technology was varied.

With the development of the MET system, we have demonstrated that the creative use of existing design frameworks, combined with a thorough understanding of the application domain, is essential for the successful development of the man–machine interactions appropriate for the medical domain. We have shown that even complex applications (much more sophisticated than standard address books or to-do lists available for handhelds) can be successfully implemented on mobile devices and introduced into practice if their design follows the principles of simplicity enhanced with domain-specific and user-centered guidelines.

Clean and intuitively designed interactions for a clinical application have the additional advantage of contributing to the structured collection of information about a patient's condition. Several studies (Glas et al., 2002; Guerlain et al., 2001) have shown that structured data collection and the use of standardized forms to collect data about the patient, improve the diagnostic performance of ER medical personnel in evaluating patients' conditions. This aspect should not be underestimated when deciding about the format of man–machine interactions in clinical support systems.

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