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A Review of Decision Support Systems in Telecare

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This paper presents an overview of the state-of-the-art on decision support systems (DSS) in telecare. The main aspect examined is the use of smaller subsystems—components in an integrated DSS, with emphasis on two application areas: medical home unit monitoring and real-time prioritisation of the alerts generated by them, and drug interaction checking. The paper suggests the development of an integrated hybrid telecare DSS synthesizing most of the technologies reviewed. Implementation issues are also examined, with an emphasis on the international trend towards the development of platform-independent, component-based, distributed software.

KEY WORDS: telecare; decision support systems; alert prioritisation.

INTRODUCTION

Telecare is a rather broad field, recently developed as a collection of various procedures offering remote healthcare. Teleconferencing, for example, was the first aspect of telecare where the technology was applied for communication between a doctor or other medical professional and a patient at a remote site. The objective of this study is to briefly overview what is currently available in terms of technology in telecare. Looking at various case studies and commercial services in telecare, it is evident that although there are many successful applications in telehelp, attempts towards a complete telecare model are rather limited. A more integrated approach is suggested in this paper.

The medical field has been one of the most interesting application areas for artificial intelligence. As a result, many applications of artificial intelligence in medicine have emerged and some of them are indeed particularly successful. The paper presents these applications in some detail and tries to synthesize them into an integrated model. Introduction of intelligent systems in a complete telecare model is therefore another motivation for further work.

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Ethical issues regarding the privacy of the patient's data when transmitted over a telecommunications network, the risks involved when the patient is treated remotely, and the patient's readiness to accept telecare devices in the home are very important. A number of studies have been devoted on these issues exclusively.[1–3] Any attempt, therefore, to introduce home devices and intelligent systems in telecare must seriously consider these issues.

The rest of this paper is organized as follows: Section two presents a short overview on decision support system (DSS) in telecare, section three goes through various expert systems in some detail, and section four discusses medical databases and knowledge-bases. Section five makes an effort to classify these systems and gives a critical view on their synthesis and integration into a more complete DSS for telecare. Section six closes the study with some concluding remarks.

DEVELOPMENT OF DECISION SUPPORT SYSTEMS (DSS) IN TELECARE

The DSS, in the context of this study, is viewed as an "intelligent" system that can help medical personnel (doctors, pharmacists, nurses, care providers, etc.) in their routine tasks. It is composed of a number of smaller intelligent subsystems, mostly rule-based expert systems, as well as an efficient database storing electronic patient records (EPR), drug-related data, and other medical data.

An extensive overview on the methodology to be employed when integrating DSS in healthcare is given by Leao *et al.*[4] They emphasize the methodologies used for the construction of such systems, and the integration of DSS with other IT systems in healthcare. Their report proposes a strategy for accomplishing this through the definition of CORBA-based software components, which they applied in building an alert system. The conclusion out of this study is that object-oriented methodologies will soon lead to a vast number of software components, which could be used in the development of effective intelligent healthcare applications.

The system requirements for an integrated telecare system are also presented in a study by Williams et al.,[5] by using a modification of the Controlled Requirements Expression (CORE) methodology. CORE ensures a user-centred approach to the development of technology. Their resulting system model uses viewpoint analysis to establish the needs and requirements of the client and the care providers within a complete system context and discusses the implications for a user-centred, technology-based solution. The implementation of their solution is considered in terms of the enabling technologies required and identifies the monitoring, networking requirements, and system intelligence necessary for the provision of comprehensive telecare. A case study based on patient aftercare following discharge from the hospital was presented. Their results provided a foundation for the development of systems implemented in a modular fashion.

It is obvious therefore that a DSS for telecare cannot be developed without taking seriously into consideration the users involved in a formal methodology. The methodology to be followed has to take into account the trend towards distributed computing and component-based software development.

EXPERT SYSTEMS

In its simplest form, an expert system includes at least a knowledge base and some form of computer intelligence to process how the knowledge-base material applies to a specific situation. Having in mind that most expert systems are designed to do one thing well, the foundation of a successful expert system is a good knowledge base. For clinical knowledge-bases, like potential drug interactions, solid clinical content can be obtained in two ways: either to be developed in-house or licensed from a third party.

Many knowledge-based or expert systems have been employed in recent studies on telecare and related areas. A study by Wallace *et al.*(6) used a knowledge-based system as a control server to provide multimedia information to remote carers for the elderly and disabled. Carer knowledge and expertise were collected by carers themselves, stored in a specially designed database, and accessed dynamically through a WWW browser interface.

The expert system application areas of interest in this study are mainly the prioritisation of medical alerts received by remote devices and their handling, and drug checking for possible interactions. Both application areas are presented in the following subsections.

Real-Time Alert Prioritisation and Response

Particularly for telecare systems, assuming that many patients are monitored by a single DSS, issues on real-time response and control arise. In case many alerts are received simultaneously by the system, the DSS should help in their correct ranking in terms of priority as well as in their handling, depending on the severity of the alert, which is a combination of many factors, mostly depending on the patient's record.

Timing is not critical to a millisecond level in telecare projects, since the human factor is always involved. There is no need, for example, to complicate the prioritisation algorithm to save some CPU time of the order of milliseconds, when the human response time is of the order of minutes, or seconds in the best case. Therefore, algorithms developed for real-time telemonitoring in systems like nuclear plants and missile control are not directly applicable. Instead, technology developed for safety critical systems would be more applicable.

A study by Sixsmith(7) described an intelligent monitoring system with sensors installed at the house to identify emergencies. The study involved 22 elderly people, with ages from 60 to over 85, for 3 months. The system received about one alert per client per month, initiated by the sensors. The control centre was responsible for responding to the alert and initiating appropriate action, which could include informing a carer platform to provide on-site help. It included, therefore, the necessary intelligence for identifying alerts and generating appropriate responses.

Another example of such a system would be the telemonitoring for drug compliance at the house, through pill-dispensing home units. In case the home unit identifies a noncompliance, it transmits a signal to a central server, which is monitored by a human operator. The alert prioritisation to take place in a telecare system based on home units needs to be dynamic, depending on the current patient condition as appearing in the EPR, and the drug for which a noncompliance alert is given. Upon receiving an alert message from a specific home unit to indicate a noncompliance occurrence, the DSS should act accordingly. Possible actions could include, for example: responding to the home unit with an order to present a visual alarm, an audible alarm, place a phone call to the user's house, inform the service platform so that medical personnel visits the house, etc. In addition, in instances of noncompliance, appropriate adjustments must be made to the patient's drug regimen. All necessary information towards this decision should be available on the underlying database.

A system along these lines was developed by the Medical Informatics group at Washington University in St. Louis.[8] Through an alert delivery application, alerts are delivered to the appropriate recipient. The application examines the alert severity and other factors (destination, etc.) and determines the forwarding method, based on user-specified preferences as well (pager, fax, phone, e-mail, etc.). In case the alert is of a high priority, the system sends reminders and escalations to the recipient until the alert is acknowledged.

The human operator acting in response of the prioritised alerts, must be presented with the minimum amount of information required. Information reduction is therefore another issue the DSS must handle. The operator should only be given the necessary information in order to be able to respond as quickly as possible to an alert that requires his/her intervention. Any extra information that may be needed, for example, when the operator is talking over the phone with a doctor, should be within easy reach but not flooding the operator at the time of the alert.

Another aspect that could be examined towards the automatic alert prioritisation is the use of neural network technology, in order to provide an adaptable system that can learn as experience is accumulated. In particular, reinforcement learning can be applied to improve the performance of the prioritisation as time passes and experience builds up, and support vector machines could be employed in the classification of the importance of the alerts. Both of these technologies could work in parallel with the standard expert systems in a hybrid environment, improving thus the performance and the reliability of the DSS. Hybrid systems employing both symbolic and subsymbolic subsystems have been studied in detail in the last decade and it is demonstrated that they can work significantly better in synergy,[9] combining the advantages of each paradigm.

Finally, considering the future expansion of telecare systems to include complete telemonitoring of patients, the use of multimodal sensing and wearable computing devices should be examined. All vital signs of the patient should be periodically sent to the control centre, where they can be analysed by the intelligent system and provide alerts if necessary. To record though all such signals, while at the same time allowing the patient complete freedom of movement at least in the house, a wearable computer should be used with multimodal sensing to record indications like heartbeat rate, blood pressure, temperature, sugar levels, etc. Most current wearable devices include wireless networking and advanced power management with significant miniaturization efforts. The user of a typical wearable device is well aware of the device but the opposite does not hold. The device is not aware of its user since it has limited sensing capabilities. For the application under discussion though, multimodal sensing is the central notion since the device should be fully aware of its user; this is exactly its purpose. Therefore, wearable devices and multimodal sensing should be combined with the concept of ambient intelligence for telecare applications.[10,11]

Drug Interaction Checking

An area with significant importance and direct application of expert systems is the check for possible adverse effects with the drugs that are described for a patient. These could either be drug-to-drug interactions, drug-to-medical condition, drug-to-food, or drug-to-allergies interactions. Such a system must ensure that no medication is prescribed that could cause adverse reactions or is contraindicated based on the patient's record and their current medication regimen. A number of such expert systems have been developed, both as the outcome of basic research activities (see, for example, the PharmADE product developed by Washington University's Medical Informatics group,[12]) as well as commercial products. Some representative examples are examined in the following paragraphs.

The PharmADE product was developed as a clinical DSS with the primary function of detecting potentially dangerous drug combinations. It does not only provide alerts at the time the prescription order is entered in the system, but also provides reminders and escalations. It is limited to the most severe drug interactions but can be updated with recently discovered interactions or interactions with newly marketed medications. When tested at a large teaching hospital with a capacity of around 1400 beds for a whole year, it detected 156 potentially lethal drug combinations. The alert reports provided by PharmADE included patient's data, drug dose, start date and end date of interacting medications, pertinent laboratory or drug data, a comment with a recommendation for alternative therapy, expected adverse events and treatment options, etc.

Similar tools are also available for public use on the Internet, such as the Drug Interaction Tool by PersonalMD.[13] This tool checks drug interactions of current medications using the medications listed in a personal medical record, as well as new medications against the current medications already listed in a personal medical record. It provides immediate results about potential interactions, explaining how and why the drugs listed interact with other drugs and food.

To help with this process, drkoop.com[14] has created a tool that can be used to check existing drug regimens for potential interactions between each other, interactions with certain foods and supplements, or interactions with a new medication when prescribed. The new medication may have interactions with other prescription drugs or over the counter (OTC) drugs that a patient already takes, or the medication may interact with food and supplements. drkoop.com is partnered in this venture with Multum Information Services, Inc., a company that delivers a comprehensive and up-to-date database of drug information.[15]

An important aspect of a DSS that deals with drug interactions is the explanation of the interaction to the doctor, pharmacist, or care provider personnel entering a new prescription in the system. In addition, suggestions for alternative drugs, if they exist, with the same effect but without interaction problems should also be given. The various tools described above are summarized in Table I.

Table I. A Comparison of the Features of Some Representative Free Drug Interaction Checking Tools

	Provide (Product)			
	Drkooop.com (DrugChecker)	PersonalMD (Drug interaction tool)	Washington University Medical Informatics (PharmADE)	Project inform (Drug interactions)
Internet based	√	√		
Drug/drug	√	√	√	√
Drug/food		√		
Drug/allergy		√		
Recommendation for alternatives			√	

Finally, another issue to be resolved prior to the design and implementation of a complete DSS, as the central part of a telecare system, is whether the necessary expert system on drug interactions should be developed internally or could be introduced as a ready-made component. The cost and the functionality of such a system towards the needs of the telecare system should be considered. The vast amount of data on all available drugs in all of their forms is already collected in electronic form by a number of vendors, charging usage fees on a yearly basis. Regular updates on these data are needed, since new drugs are continuously developed and new drug interactions are detected. The data suppliers also supply monthly or yearly updates on their databases.

Open Issues

User interface aspects are always important in expert system design. A major concern, for example, is how to combine alerts with expert systems without flooding the user with information and imploding the normal workflow. Alerts can quickly shift from important reminders to time-wasting irritants, so the expert system may need to be customised for the telecare application at hand to produce not more than enough alerts.

In the PharmADE product this issue was examined and it was developed so that it does not require direct physician interaction. Drug orders are screened at real time when entered into the pharmacy order entry system, and when an interaction is detected an alert is sent to the appropriate person. This could be a pharmacist who can access the validity of the alert before approaching the physician to change the prescription. Rather than requiring the physician, therefore, to assume the duty of entering all prescriptions in the system, prescription orders are screened in the background automatically.

Any DSS is just that: it can only support the decision-making activity of the human involved. Some issues arise as to where the responsibility line is drawn between the system and the human operator as far as the alert prioritisation is concerned, and between the system and the doctor or the pharmacists as far as the drug interaction checking is concerned. For example, should the system check upon the doctor's decision to prescribe two interacting medicines in the same prescription or should that be the responsibility of the doctor? Such issues need to be resolved between the parties involved in a complete telecare system. The expert system's role is to make sure that a safety net exists and it is activated whenever the human expert makes an error or an omission, usually due to work stress.

Another issue is the drug code to be used to associate a drug on a prescription with the relevant drug information stored in the system's database as explained in the next section. A number of studies (for example, Ref. (12)) have employed the National Drug Code (NDC), maintained by the U.S. Food and Drug Administration,[16] to associate drug orders with the expert system rule base. As soon as the problems of multiple codes for the same generic drug were encountered, the above study has switched to a more clinically relevant drug code that is generic and not vendor-specific.

An interrelated issue that the DSS should handle is the automatic issue or at least a reminder for issuance of repeat prescriptions and the parallel notification of the pharmacist/doctor and the nursing platform. In cases where noncompliance alerts have been received, this activity is not a simple one, so some intelligence is required on this aspect as well.

MEDICAL DATA AND ELECTRONIC PATIENT RECORDS

In a telecare system as the one discussed in this paper, a rather involved database must be developed to hold the necessary data on patients (Electronic Patient Records, EPR) as well as the different drugs, their substances and the possible interactions among those substances. In addition it should hold data on the hone units, prescriptions, and possible noncompliance statistics. The EPR field is getting rather mature, with relevant standards already published in Europe.[17]

As far as drug information and drug interaction data are concerned, various organizations publish such information, either for a specific area of medicine (HIV/AIDS, for example, Ref. (18)) or for a much broader range but in less detail. Multum Information Services, Inc., is a company that delivers a comprehensive and up-to-date database of drug information. Other organisations provide more complete databases for a fee, like MicroMedex.[19] Finally, a rich set of patient data, drug data, and drug compliance data is developed and continuously collected in such systems. Further statistical and other analyses of such data could provide insight information on the issues examined by the DSS.

Given that all necessary data for updating the drug database are available on the World Wide Web, but in an unstructured dynamic format, techniques of web intelligence gathering should be considered. Fuzzy logic and hybrid neuro/fuzzy approaches have been gaining increasing importance due to their undisputed advantages in handling information that is vague and imprecise.[20]

Ethical issues arising from home telecare and the storing and accessing of clinical data by multiple providers are reviewed in the European context by Stanberry.[2,3] Implementation of home telecare services requires the informed and voluntary consent of the individuals, who are entitled to solid assurance that personal information will not be subject to unauthorised access, and will be used only for the purposes it has been collected for. This requires procedures and processes to ensure that personal data can only be accessed by those authorised to do so.

Automatic encryption of data should be mandatory for any transmission of identified patient data. Web-based security is now dependent on two standards, Secure Sockets Layer (SSL) and Secure Electronic Transaction (SET), which must be implemented if patient data are to be transmitted via the Web. These security systems depend on the exchanging or sharing of keys, which must be protected from access by others.

A CRITICAL SYNTHESIS

Although the various technologies required in a complete telecare system are currently available, with some of them even considered mainstream, their integration presents a significant challenge. A successful integration of these individual technologies, though, can lead to a successful telecare system.

A drawback encountered in some of the systems examined, which may lead to the failure of the adoption of such a system, is its user friendliness. Systems asking an experienced (i.e. rather old) doctor to work with a terminal emulation software on a character-based workstation is definitely less than ideal. Even if such a system could be of great benefit (for example the one proposed by Tountas *et al.*[(21)] on the prescription of antibiotics for infectious diseases), it cannot succeed in practice.

The integration of the Internet in telecare systems is also a must nowadays. Certain aspects of current healthcare are particularly affected by the penetration of the Internet and the relevant advances in Internet technology.[(22)] Until very recently, most telecare and telemedicine systems have relied on proprietary technologies over the analogue telephone network. Only very recent work has embodied the Internet in telecare, simply due to the maturity of the technology.

Risk management is another major issue in telemedicine and telecare. A number of studies have examined this issue. In particular, the review study by Williams *et al.*,[(23)] addresses the implications of any failure of the technology in providing reliable telecare, looking into distributed intelligence, built-in self testing, and redundancy.

Security is already identified as an issue, but has not been extensively studied in the usually small-scale telecare systems developed so far. The use of standard security protocols and the development of related procedures and processes is therefore an important aspect of any future work on telecare.

Implementation of such systems has been carried out with a number of different technologies so far. Following the international trend towards the development of platform-independent software, Java could be considered as the technology of choice for the development of the various software components of the system, both at the server side as well as the client side, which includes thin clients with standard web browsers or even mobile phones or personal digital assistant.

Finally, integration issues should be considered. Assuming the creation of an intelligent environment both in the house and the control centre monitoring the houses, the notion of ambient intelligence becomes very important. A user, either a patient at home or a control centre operator, should be able to operate as much as possible without even noticing the existence of the intelligent systems behind the scenes. The use of traditional computer interfaces should therefore be minimized, and a shift towards normal life as the starting point for access to services offered by technology should be considered. This can only take place after studying normal life habits and then exploring acceptable ways of using technology to enhance the user's experience.

CONCLUDING REMARKS

It is clear that significant breakthroughs have been achieved in the field of artificial intelligence, and DSS in particular, as applied in telecare. An integration of systems developed so far can lead to improved performance of a DSS developed specifically for telecare. Further work should concentrate on developing such integrated systems, employing and customising the technologies developed for this application field.

As identified in this study, an aspect that could be examined towards automatic alert prioritisation is the use of neural-network technology, in order to provide an adaptable system that can learn as experience is accumulated. In particular, reinforcement learning can be applied to improve the performance of the prioritisation as experience builds up. Support vector machines could also be employed in the classification of the importance of the alerts. Both of these technologies could work in parallel with the standard symbolic expert systems in a hybrid environment, improving thus the performance and the reliability of the DSS.

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