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Telemedical systems for home monitoring of patients with chronic conditions in rural environment

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Abstract

This paper describes the requirements and possible implementations of a telemedical system. The idea of remote patient monitoring is a point of interest for researchers in Poland, and is also in high demand in fields such as diabetology, cardiology, and geriatrics, among others. Aging society, medical care costs and many other factors make remote patient care a promising idea for the future. For each and every condition, a specialized type of sensor must be used to allow specific measurements to be performed. Moreover, a local data storage and communication device must be provided for the sensor to be able to relay data to the station. A smart phone can be used perform such tasks. By implementing such remote diagnostic systems it is possible to collect, process, store and present vital medical data that can be used immediately to perform diagnosis, or later as reference for expert systems. The 'Borboleta' and 'SaguiSaúde' systems already implemented can serve as a base for system analysis. The systems provide necessary functions and can be used as reference. Many factors contribute to the success of the telemedical system, such as ease of access, scalability, safety, platform independence, and many others. For easier implementation and clarity, the system should be divided into independent layers, which will also make it easier to modify and integrate into other medical systems. Making the system easy to use for patients, medical staff, administrators and data managers makes the task of system design especially challenging. One must decide which information is necessary for each type of user and provide them clearly and in an orderly fashion.

Keywords

Telemedicine, monitoring, diagnostics, data analysis, system design, database

INTRODUCTION

Remote services are a solution for many current post-industrial society problems. The trend of increasing life expectancy is accompanied by increased need for the simplest medical care. More and more people require or would benefit from constant contact with specialized staff or from remote at-home health monitoring. Conditions like diabetes, circulatory system problems, neurological or psychosomatic cases require mostly observation, and monitoring, with staff intervention limited to the most acute cases [1]. The solution to this problem lies in telemedicine. Taken from Latin (*tele* – far, *medicina* – medical art), it is a science devoted to remote patient observation and communication by means of specialized equipment, which allows for medical data to be transmitted and analyzed and further used for diagnostic purposes. By gathering patient information using mobile devices and mobile sensor data it is easy to construct complete a medical history and case study, which is easier to manage than standard medical documentation [2]. It is possible to supervise medical procedures undertaken by a doctor. On the other hand, the patient experiences less discomfort. Also, the corresponding cost decreases and staff procedures monitoring is also a benefit.

Telemedical applications are directly tied to the development of information society and modern telemetric science [3]. Solutions have been available since the 70s, when the first 'knowledge stashes' on university computers were introduced. Those platforms were used to gather, sort and systematize the knowledge taken from medical expert system databases. Along with the introduction of the personal computer and its popularity increase, telemedicine was brought directly to the patients. Rapid growth of Internet availability in the 90s provided means of remote communication between doctor and patient using videoconferences or expert systems available as web services. Apart from these function, modern telemedicine can use mobile devices, which significantly increase freedom of patients and provide them with means of consultation and remote life functions measurements relay [2, 4]. Thanks to new technologies in multimedia, video communication and networking, the rapid development of telemedicine geographical barriers have been broken down. Teams of specialists can now provide accurate remote diagnosis and medical care rather by travel of information than by travel of people. It is especially crucial in countries where the medical care points are hard to reach within a limited time [5].

Building telemedical information systems poses many challenges. Popularity and availability of mobile devices can

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open this industry for new solutions and services, allowing measurement simplification by introducing an intermediate layer, responsible for data preprocessing before acquisition [6, 7]. The aim of the presented study was to present the main problems concerning telemedical systems design, as well as possible solutions, some of which have already been implemented and tested in numerous systems.

Teleinformatic systems for remote patient supervision. Information technology for telemedicine can be divided into a number of types. However, the most valid division can be based on the object that the system deals with – whether if it supports a particular facility, such as a hospital or clinic, specific personnel, or the supervision of a patient's health. Several examples of concepts of the use of telemedicine technology are presented below. Above all, the division and focus on the monitoring of the patient, especially in rural areas, are taken into consideration.

Current state. Since 2009, Poland has been participating in the project 'e-Health Poland', which is aimed at implementing information technologies to the medical services. The plan prepared by the Centre for Health Information Systems (CSIOZ) 'e-Health Poland' for the period 2009–2015 includes the following areas [3]:
- improvement in the field of information on health care access for citizens;
- improvement of the healthcare system efficiency within the electronic documents circulation. Creation of the procedures, guidelines, collection and provision of good practices, which would facilitate the healthcare institution management, an aiming to improve the capability of teleinformatic system management;
- modernisation of the medical information technology in order to analyse the demand of performed healthcare services;
- practical implementation of healthcare IT solutions in accordance with the guidelines of the European Commission, which allows the inclusion of the Polish Republic in the interoperable electronic medical document (EHR).

The information system prepared by the CSIOZ has the following tasks to accomplish [8]:
- facilitation of access to the information on healthcare benefits in favour of the patient to: patients, doctors and authorised persons to the access such information;
- control of the public spending earmarked for healthcare, and improvement of the efficiency of its use through 'sealing' the system;
- improvement of the quality of medical services by increasing their availability and introduction new methods ex. telemedicine;
- provision of the consolidated tools, allowing monitoring and analyzes in the field of the whole healthcare system, thereby providing data for more precise planning and strategic decision-making in this area;
- enabling realization of health safety standards in the national and European Union structures, and the exchange of information and services within the EU;
- obtaining control of the whole healthcare and optimisation of its operation.

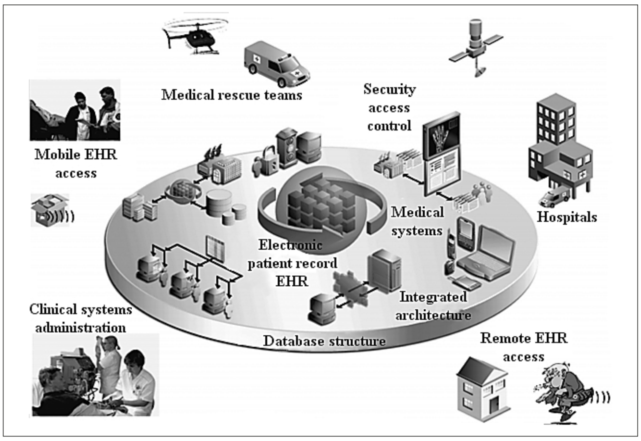

Figure 1. General view of healthcare bodies and applied information technologies [9]

In view of these objectives and actions, CSIOZ considers the following e-services as the most important to be developed [3]:
a) telemedicine systems (teleconsultation, telemonitoring, patients registration 'on-line' via the Internet);
b) electronic prescriptions (e- Prescriptions);
c) electronic health card (EHR) that can be combined with a new identity card 'pl.ID', which after 2010 was to become the basis for any electronic identification of the citizen/patient.

In the next part of the current study, systems already implemented will be discussed and a new model for solving these assumptions will be presented.

Demand for telemonitoring services in the province of Lublin. As one reads in the 'Strategy for the Development of Telemedicine in the Lublin region in 2008–2012', one of the projects to be implemented is called 'home-monitoring' [5]. Below is a description of the project from the above strategy:

> The main objective of this project is to provide the remote medical monitoring of patients residing outside the healthcare units by monitoring relevant vital signs, e.g. heart rate, glucose level. Because of the necessity to adapt methods of the supervision to the specific features of disease, the subprojects of this group will be first concentrated on a narrow groups of diseases. These projects should use similar methods (procedures) of work and common telecommunication infrastructure.

Home-monitoring transfers part of the responsibility for the treatment or prophylaxis on the patient.

Assumptions. This project can be divided into separate parts for different medical specializations:
- cardiology (ECG monitoring in cardiac rehabilitation);
- diabetology (monitoring of blood glucose levels);
- obstetrics (monitoring the foetus through CTG records);
- geriatrics (monitoring the basics of life and social activity of the elderly);
- psychiatry (contact with the patient in order to capture the early exacerbation of psychotic symptoms), and others, including solutions for communications in emergency situations.

Individual subprojects can be performed in parallel, destination recipient of the services, the patient, should be given the ability to use many services within a single technical and organization infrastructure.

It is necessary to mention 3 operation levels of the functioning of the home-monitoring group projects:
- 'green' – the state of the tested parameters are correct-action – prevention: health education, support groups;
- 'yellow' – deviation from the norm, with no life-threatening action: medical consultation, treatment correction, changes in behaviours;
- 'red' – serious threat of monitored activities – action: immediate contact with the patient, arrival of rescue team, transportation to hospital "[5].

The above-quotation indicates a high demand for telemonitoring systems, especially in the Lublin Province. The presented study focuses on the 'red' system.

Models of the systems. In this subsection, examples of operating telemedical systems are presented which are monitoring patients' health surveillance.

Home tele-care system in 'Maisons Vill'Age'. This system was introduced in Loria, France, by the MEDETIC group which builds 'smart houses' to monitor the elderly [10]. In different parts of the home environment, such as beds and chairs, automatic sensors are installed in order to monitor patient activities. The records are analysed by the applications based on the artificial intelligence algorithms and fuzzy logic. This is supported by a mobile sensor system for monitoring the health of patients, and checking that the patient has not sustained a fall.

Application of open source AeXist to supervise diabetics. AeXist is a Dutch application which supervises the blood sugar levels and other indicators important for diabetes [1]. It allows communication with the leading doctor or nurse.

The medical personnel, however, have access to the patient's medical history, recent tests and recommendations, or patient's glucose trends. This has been created based on an open medicine technologies, such as Health Level 7 version 3 (HL7V3), Reference Information model (RIM) and Systematized Nomenclature of Medicine – Clinical Terms (SNOMED CT).

Medical data management systems in the customer-server 'Borboleta' and 'SaguiSaúde' structures. The 'Borboleta' project is an initiative of Sao Pauolo University in Brazil which is aimed to create a platform with an open code to manage the data and services provided in health centres [11]. This application implements mobile devices which collect the data about the surgeries and the patient's disease history in the field, and sending them further to the centre with 'SaguiSaúde' software. The second project is focused on creating the service in the form of database application, which will allow comprehensible management of the contents collected by medical staff from the mobile devices. The objective of these systems is to improve the service of medical information provision by permanent access via the Internet and via mobile application. For a large country like Brazil, with plenty of decentralized areas, permanent access to medical data without the necessity of using the physical transport of the documents is a great counterbalance and facilitation for both the medical personnel and patients.

Technologies of telemedical system construction. In order to meet the functional requirements of telemedical systems, a proper hardware and technological infrastructure is essential. However, it should be realized that these are necessary but insufficient conditions. Construction of modern telemedical systems also requires using relevant programming environments and architecture.

There are many types of possible uses of telemedicine, which is why it is very difficult to define only one programming architecture. Nevertheless, it can be assumed that if the majority of such systems require communication between their elements and remote data access, it will be advantageous to use dispersed architecture. It is also important that in the architecture a layered and modular structure should be used, which increases system transparency and the possibility of its further development and implementation. Furthermore, the architecture should be scaled and opened to new ways of access. Considering the problem of the system architecture, one should be aware that the safety of medical data and providing access only for authorized persons is vital [12].

Modern systems in general are used from the level of so-called 'light customer access', which constraints the system functionality to presentation requests. Logic of application processing is transferred to the other system layers. Thanks to that, it becomes achievable for wide range of customers and fulfils a need for the general availability of telemedical services. Apart from the customer layer, one or more layers could be added, depending on level of the system complexity. To a large extent, the way of functionality division on layers depends on demands that are supposed to be met by the application [13].

Therefore, the characterisation of multilayer architectures will be discussed in the context of two types of systems: web-centric systems and multimedia communication systems.

Web-centric systems. While constructing the web-centric systems the four-layer model should be used. The functionality of the system is divided between the data storage layer, data processing, presentation and customer layer (Fig. 1).

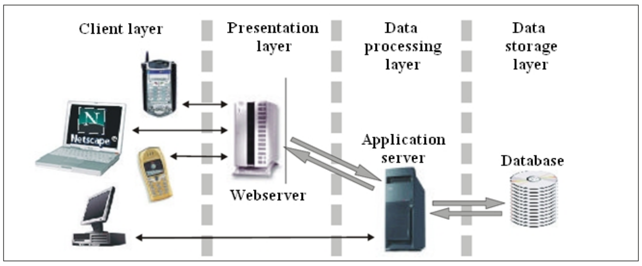

Figure 2. Web-centric systems

Data storage layer. This layer is responsible for data storing and sharing. In order to reach that goal, most often one uses relational databases. While constructing information systems, the problem of independence from the specific implementation and the specific supplier should be considered. That is why one should use databases with functionality access possible via JDBC. JDBC (Java DataBase Connectivity) is a standard element of the Java language defining the collection of interfaces and functions that allow the application to execute SQL database queries.

Data processing and access layer. The data processing layer focuses on the logic of the system operation. It has to embrace services such as loading balance, ensuring access continuity and safety. Because of the fact that it is the most complex layer, in the case of more compound systems, it might be divided into sublayers which changes the system from four-layer to multi-layer. One of the most advanced solutions used in that layer is multi-layer application construction platform, in Java language called J2EE (Java 2 Platform, Enterprise Edition).

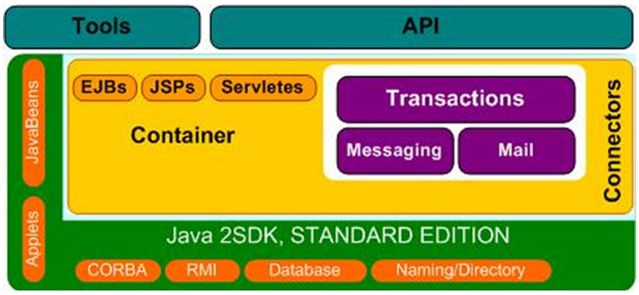

Figure 3. J2EE platform

The fundamental element of this platform is the applications' server based on Enterprise JavaBeans (EJB) technology. This defines the component model and the collection of programmistic interfaces for the applications' servers in Java [14].

Presentation layer. EJB components make available their functionality in the customer layer by Java RMI calls. This way of communication is acceptable for independent customer applications.

To be able to use the WWW browser, one must first prepare the interface on the webserver [15].

Customer layer. The customer layer task is to use the functionality of the presentation layer, which usually constraints it to interaction with the user by presenting data to the user and reacting to user's commands. As a way of communication with the user, dynamic websites are most often chosen. The advantage of this solution is that the majority of operation systems have built-in web browsers; it is therefore not necessary to install additional software on final devices. Moreover, these solutions optimise system management, because software modification does not require installation work on customer devices [16]. However, it is not a solution that can be used in every case, because of constraints imposed by HTML.

User interface. Interface stands between the system and the user and decides about so-called 'first impression', as well as about 'dialogue with machine'". Even the best designed and programmed system has little usability if it cannot communicate with the user in a comfortable way. Interfaces evolved from a simple text form giving commands in command line to a developed graphic form (GUI- Graphic User Interface). There are so many tools and possibilities available (development of vector and 3-dimensional graphics) that the requirements of the potential user can be very high.

In order to ensure efficient and explicit communication, interface should have a clear form, enabling easy and flawless information access. The success depends on:

- Aesthetic – the graphic project and final visual effect;
- Ergonomics – planning of particular interface components (grouping, spacing, creating unchangeable fields, etc.);
- Functionality – specification of available options, creating relations and the structure of displayed pages.

In the systems dedicated for doctors, the way of presentation should enable easy data management concerning different types of data (from personally identifiable information and description of condition, through ECG results, to multimedia data-video/audio recording from consultation).

Generally, it should be assumed that a system will have several types of users. For the telemedical systems this will be: patients, leading doctor, researchers/consultants, medical personnel, archive manager. etc., and, of course, the system administrator.

Because of the remarkable data differences in each group of users, it is necessary to individualise the interface content and appearance of each of them. Furthermore, each of the interfaces should be designed taking work comfort of every group into account, especially that of the patient (trust and feeling of safety while using the interface).

Recently, the number, quality and standard of available final devices has increased dramatically. In the modern system, access should be possible not only by personal computer, but also, for example, by mobile phone – even if it does not have Bluetooth or GPS, there is a high possibility that it is able to connect with the WAP service, and it can certainly use access to data via SMS. The other access devices currently worth mentioning are: notebooks, PDA (Personal Digital Assistant) and digital television.

Telemedical monitoring system in rural conditions. This section deals with the system of the model to supervise the patient using the mobile DVR.

Functional analysis of the system. The first criterion concerns analysis of the system functionality. From the point of view of telemedicine, the most important is the doctor who is regarded as the main end-user of the system (although not central to the database itself. So-called 'usable values' are examined with regard to the doctor [9]:

a) relevancy of information;
b) completeness of information;
c) timeliness of information;
d) reliability of information;
e) clarity of information.

The database system is supposed to meet the requirements. In this case, it should contain the information that is comprehensive, current and relevant to the monitored patient's condition for the clinical unit. These features must be determined by regular measurements of vital functions through the use of appropriate classes of medical diagnostic devices. A proposed solution to this problem is to use mobile measuring devices [4]. Their objective is to monitor the patient's health condition and send the data at specified time intervals to a centre – the Patient Monitoring Station. Reliability and readability are provided by consultations with the medical personnel and their recommendations about the usable values above, and proposed functionality (Fig. 4).

The second criterion in the analysis is the structural approach – this deals with the construction of the database itself. Apart from the classic features of databases, such as consistency and correct reflexion of the real world dependencies, scalability is essential for the telemedical projects. The scalability is understood as either quantitative records or the easy way to extend the system with new types of diseases to be supervised. The system is supposed to offer the ability to easily attach both new measuring devices and new data in the case of serious changes in the knowledge of existing or just discovered conditions. It can be achieved by creating an appropriate database management class to operate the disease units and measuring devices.

Thanks to this solution, different diseases will be able to have default time intervals to measure the patient's vital functions and individual threshold indicators, which will allow detection of changes in the patient's status as the measurements error or changes in health.

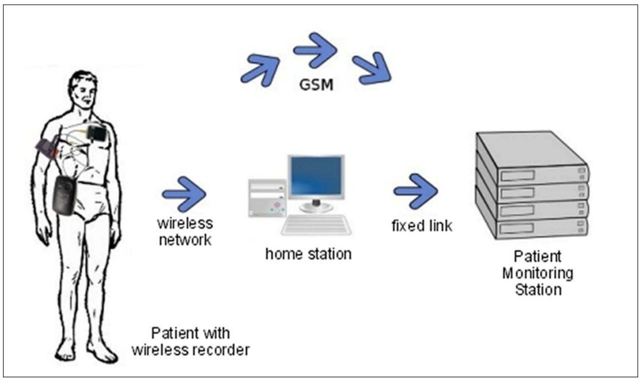

Figure 4. Conceptual system model of mobile patient [2]

The last criterion of the system analysis is the equipment approach. The databases should include suitable equipment for this purpose. A significant feature is the system dispersion with a single central server. The use of mobile devices as a way of measuring and transferring data can greatly reduce the costs and increase the availability of this solution (Fig. 4).

Contextual model of the system. The first step in modeling the system and its scope is to define the basic data flow (Figure 5). The Patient Monitoring Stations assume the role of the data flow centre in the system, in which successive actors (Consultant, Doctor, Patient) and data storage (customer's applications) exchange information.

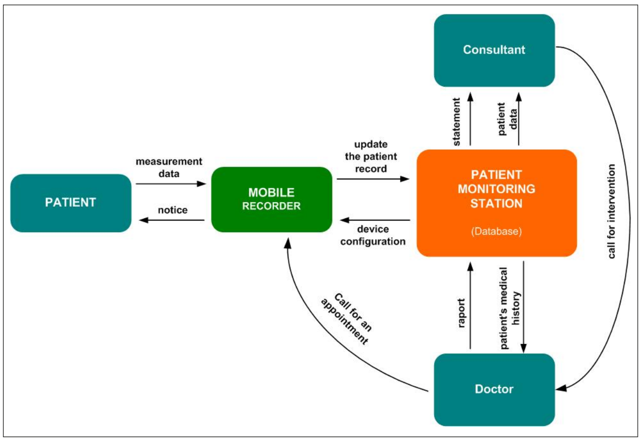

Figure 5. Context diagram of the proposed system

The sequence of data exchange begins with the measurement of patient's vital functions by the measuring device at certain time intervals, which performs an acquisition using the customer's application on the mobile device. The application then processes the data and sends it in the form of a specific structure to the Monitoring Station to update the records in the database. This structure can additionally contain the information about the state or configuration of the device [17].

This system gathers the data in the base, and in the case of discovered errors, it sends a statement to one of the supervisors. In this case, an employee of the Monitoring Station can download the patient's data for further analysis, and if the worker notices any alarming situation or the system discovers it at once, he may contact the patient's leading doctor. If it is a condition that requires a diagnosis, the doctor can see the patient's complete medical history and, if necessary, call the patient for the visit [18].

If an emergency for the patient is initially diagnosed by the system, the consultant can send an intervention call to the team, which consist of the data such as last patient's location and the results of the measurements from measuring device sensors. After this, the doctor leading the intervention sends a report to the Monitoring Station centre. The doctor leading the intervention can send the report stored in the Monitoring Station base [6].

Methodology of system design. Designing the system should start with a review of the works concerning the subject matter, and comparison with the modeled idea. The first of the works is the ***New Type of Sensor for Heart Rhythm Monitoring*** by Dr. Wojciech Surtel, MSc Marcin Maciejewski and Dr. Teresa Małecka-Massalska [19].

In this work, the authors present the project of the measuring device, based on an idea which corresponds to the system presented in this study. They assume that their small-sized portable recorder is constantly active and retrieves data transmitted at specified intervals to an external data storage site. It can be assumed that the user of the device – or one similar to it – will be a patient in the proposed system, especially when comparing functionality of a mobile recorder and an alternative solution in the form of a mobile device application.

In the case of such systems, according to Rogger Pressman's advice concerning web projects engineering, one should focus on the process, methods and the production technology. Methodology deals with first two problems based on the agile software development. The methodology of the agile software development is emphasised on frequent code iterability, with less accent on precise modelling, but bigger accent on revising the project with customers and final users. In this case, consultations with the medical personnel using the system and their opinion and observations about the functionality and project future development are essential. Analysis of the web-based application should be based on three fundamental questions [7]:

1. What sort of information and content is supposed to be presented and manipulated in the application?
2. Which functionalities should be available for the final users?
3. What types of user actions should the application predict?

The answer to the first question is defining what precisely is supposed to be the object of content exchange. As underlined before, it is worth referring to the new heart sensor designed by Surtel, Maciejewski and Małecka-Massalska. However, data processing and supervision of the patient is only a part of the possibilities that provides the suggested database system. The patient measurements possessed and data that is used for monitoring might be further processed, as undertaken by the teams working with the 'Barboleta' and 'SaguiSaúde' systems. One should remember the possibilities for 24-hour patient supervision, as provided by the 'Maisons Vill'Age' provides – the higher safety of the patients and constant inflow of data that can be used for analysis by the medical team. In connection with the conceptions mentioned above, one can see the picture of the database system collecting measurements data from the sensor attached to the patient. The system analyses the data, and in the case of critical situations, can cause and alarm. Additionally, it will be possible to supervise the work of the medical personnel, and in the further development of the project, to collect the statistical data to improve the measurement methods and treatment techniques. From this point of view, the system will deal with the operations on the medical data and their basic statistical processing. It will be also able to collect and present personally identifiable information in the case of emergency intervention or analysis of treatment costs.

Using the concepts of the network engineering projects by Pressman, the priority for the designed system is to examine the processes which will be performed by the users. An essential issue also is to picture the system in terms of its functionalities (Fig. 6).

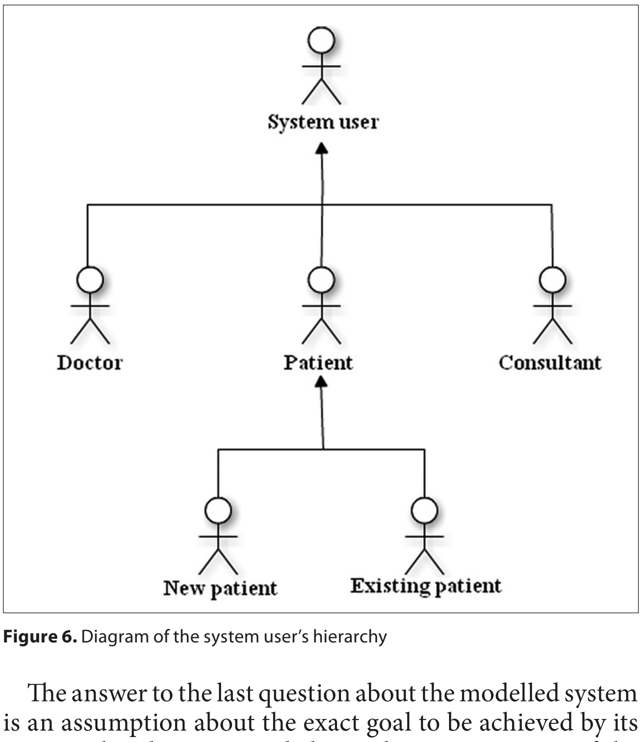

Figure 6. Diagram of the system user's hierarchy

The answer to the last question about the modelled system is an assumption about the exact goal to be achieved by its use. As already mentioned above, the main purpose of the database application is the supervision of a patient's health. Therefore, the system has to deal not only with the data collection, but also allow for medical intervention in life-threatening situations. Thus, the application should be able to alert the medical personnel when the life of a patient is threatened. As a data storage site, it must also have the option not only to edit the input information, but also to ensure their safety, especially when dealing with sensitive data [2]. Finally, the database system should give the possibility to display the basic analysis of the collected data easily and clearly [20]. In the following subchapters are presented models of the described system using the analysis above.

CONCLUSIONS

Telemedical systems require advanced technologies to transfer, store, process, and visualize data. Nowadays, their design also has to implement Internet technologies which guarantee accessibility. Modern environments for the creation of distributed applications can be used to create scalable and modular systems which are well-suited for further upgrading. This in turn makes possible the adaptation of the application to growing and changing requirements. It is worth mentioning that most of the currently used medical systems utilize technologies that provide either limited or no possibilities to adapt the modern telemedical systems.

New technologies can be used to provide remote patient care, reduce cost, introduce improvements in the field of condition management, and increase the quality of life. Telemedical systems mentioned in the presented paper deal with modern-day civilization conditions, such as arterial hypertension, diabetes, or neurological or psychiatric disorders, and offer the following functionality: on-line patient monitoring, data transfer to the patient monitoring centre, raw data processing, storage and presentation of results, as well as remote system management. Solutions based on mobile technologies, relation databases and web services provide means of easy interaction between the system and its users, including patients as well as doctors.

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