An RFID and Multi-agent Based System for Improving Efficiency in Patient Identification and Monitoring

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Abstract: Hospital today are under increasing pressure to increase the quality and efficiency of patient identification and monitoring procedures. Most patient health records are stored in separate systems and there are still huge paper trails of records that health-care providers must keep to comply with different regulations. This paper proposes an RFID-based system (named SIMOPAC) that integrates RFID and multi-agent technologies in health care in order to make patient emergency care as efficient and risk-free as possible, by providing doctors with as much information about a patient as quickly as possible. Every hospital could use SIMOPAC with their existing system in order to promote patient safety and optimize hospital workflow. In this paper we will concentrate on the RFID technology and how it could be used in emergency care in order to identify patients and to achieve real time information concerning the patients' biometric data, which might be used in different points of the health system (laboratory, family physician, etc.). We describe a general purpose architecture and data model that is designed for collecting ambulatory data from various existing devices and systems, as well as for storing and presenting clinically significant information to the emergency care physician.

Keywords: e-health, electronic medical records, RFID, emergency care, embedded system.

1 Introduction

Electronic medical records (EMRs) may easily alleviate the distress of most doctors and nurses working in today's care system. Besides improving the degree of data availability among physicians and patients, they certainly increase the traceability of numerous medical details so deeply buried in traditional records. Although doctors have been slow to adopt electronic health records, their potential benefits cannot be disregarded.

Most hospitals have improved patient care by reducing wait times in the emergency ward when they decided to replace their paper-based process for emergency ward admission with a solution based on informatics systems. With these solutions in place, hospitals save minutes each time they admit a patient because doctors and nurses no longer fill out forms manually and improve healthcare outcomes. Thus, it has been estimated that 15 to 18 per cent of US physicians already use electronic health records [1].

"Instant access to patient information is key to lifesaving care, especially in the emergency room and intensive-care unit, where delays may mean the difference between life and death", Dr. Mark Smith said [2]. Currently, Emergency Medical Service (EMS) providers rely completely on personal and medical history information provided by patients or family members. It is common knowledge that stress, physical and mental discomfort prevent most patients and family members to impart vital medical information. Problems may also arise if there are no family members around or if the patient is unconscious, incoherent or unable to talk or communicate (e.g. language difficulties).

The next step beyond the EMR is to connect and provide medical information to primary care physicians, medicine and surgery specialists, anesthesiologists, nurse practitioners, assisted-living staff, patients themselves, patient's family and so on.

However, each hospital may use a different system, store data in many ways and even decide upon its own data format. Furthermore, file system access and data retrieval are often governed by inconsistent parameters seriously affecting the availability of medical information. Hence the inefficient communication among physicians.

Microsoft's Feied, a pioneer in medical training computer programs and medical intelligence software, said physician collaboration is the critical element for improving health care. He offered an impassioned testimonial. An emergency room physician who estimates he treated 80,000 patients "with my own hands", Feied said the thing that stuck out as he looked back on his career was how many times he was put in a position of "guessing over and over", "flying solo" in an information vacuum. In situations where people "die right in front of you", he said he often felt he was "one data element away" from stopping a patient from dying [1].

The market for bringing healthcare data from disparate sources into one view is growing by leaps, according to a new study from KLAS, a healthcare research firm based in Orem, Utah [3].

For example, through Microsoft HealthVault and Google Health, Microsoft and Google have a common goal of managing vast quantities of personal health information to benefit end users. Thus, these systems encourage and support healthcare patients/consumers to control and account for their own and family health records.

According to [4], data integration – the automated aggregation and consolidation information from a variety of disparate systems and sources – across sites of care (inpatient, ambulatory, home), across domains (clinical, business, operational), and across technologies (text, video, images) – is the Holy Grail of healthcare information technology.

But, it's necessary to find a way to get the vital medical data into the hands of those who can use it to save lives in emergency medical services, even when there is no connection to the Internet or the server is down.

The level of applying informatics within the healthcare system is relatively reduced for the time being in Romania, where information about patients has not been shared at the level of medical entities, where the medical records of patients are not unitary and complete, and cannot be accessed online by the medical staff, when in need. In this context our research team proposed an integrated system for identification and monitoring of patients – SIMOPAC [5]. This system was designed to integrate within the distributed medical information system, and privately, to solve the problems related to patient identification and monitoring. The SIMOPAC system will assure the information exchange with electronic health record (EHR/EMR) [6][7] systems set up to healthcare units. This information exchange will be in accordance with the HL7 [8] standards specifications. Within the SIMOPAC system, the access to medical services is suggested to be carried out by means of information stored within a *Personal Health Information Card* (CIP, in Romanian) [5]. This card will be implemented by using the RFID technologies [9], where information carrier is represented by a transponder (tag) – an electronic memory-based chip.

2 RFID Technology

RFID technology is classified as a wireless Automatic Identification and Data Capture (AIDC) technology that can be applied for the identification and tracking of entities [10]. An RFID device called RFID tag or transponder can be used as a means of identification. This tag contains an integrated circuit for storing information (including serial number and desired data), modulating and demodulating a (RF) signal, and other specialized facilities. The RFID tag transmits data in response to an interrogation received from a read-write device called RFID reader or interrogator. The tags and readers are designed with a specific operating frequency. Given the wireless communication between the RFID chip and the RFID reader, all data may be read from a distance. Tags fall into three categories: active (battery-powered), passive (the reader signal is used for activation) or semi-passive (battery-assisted, activated by a signal from the reader). Generally speaking, tag memory size can vary from 1 bit to 32 kbits and more. In certain tag types, the information on the tag is reprogrammable.

The general architecture of an RFID-based system is presented in Fig. 1.

The RFID-based systems are generally composed of three components:

- an RFID reader;
- an RFID tag;
- a computer or any other data processing system.

The RFID technology has been used for inventory tracking [11], animal and person identification, supply chain management, toll collection and electronic payments, intelligent manufacturing process [12], vehicle identification for gate entry etc. For example, one important RFID based application is the e-passport. Although the photo page (including photo and physical characteristics of the person) was kept there are new additional features like the possibility to keep track of a person's travel history.

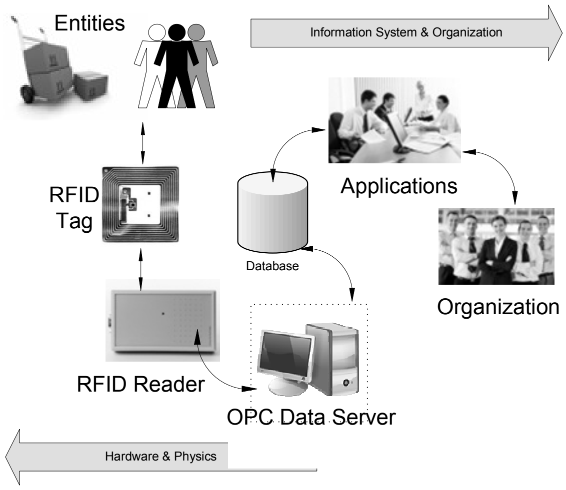

Fig 1. The general RFID-based system architecture.

In today's healthcare applications, RFID technology is usually employed to:

- improve patient monitoring and safety;
- reduce the possibility of mother-baby mix-ups;
- increase asset utilization with real-time tracking;
- reduce medical errors by tracking medical devices [13];
- enhance the efficiency of supply-chain.

For example the pharmaceutical industry has adopted this technology, particularly for the management of returns, contraindications, and product diversion and counterfeiting. For example, the US Food and Drug Administration (FDA) has launched a program to fight drug counterfeiting based on the use of RFID technology in packaging.

3 Multi-agent Technology

Agent technology is an emerging and promising research area, which increasingly contributes to the development of value-added information systems for different applications. An agent is a small, autonomous or semi-autonomous software program that performs a set of specialized functions to meet a specific set of goals, and then provides its results to a customer (e.g., human end-user, another program) in a format readily acceptable by that customer [14]. For example, agent technology has been applied in the area of extracting information from heterogenous data sources in the World Wide Web. The performance evaluation of the agent-based system versus traditional systems (client-server and relational database based systems) was undertaken by some researchers [15][16]. The tests reveal that the agent approach provides better response times as well quicker notification processing.

Healthcare systems are characterized by wide variety of applications that work in separated and isolated environments. The use of agent technology in healthcare system has been on the increase in the last decade. Multi-agent systems do have an increasingly important role to play in health care domains, because they significantly enhance our ability to model, design and build complex, distributed health care software systems [17].

4 SIMOPAC Presentation

We propose to develop a comprehensive clinical information system called SIMOPAC, based on RFID and multi-agent technologies, for the rapid integration, organization, display and mining of data in real time from different EMR systems across regions. Thus, our proposed system could help link the different elements into a powerful system interconnecting hospitals, patients, public health officials and other health-related bodies.

Our system will use a passive RFID tag, named *Personal health Information Card* (CIP), to store the vital health information, such as medications, allergies and sensitivities. CIP will store the vital health information, such as medications, allergies and sensitivities. We consider the health information that is crucial in helping determine the way emergency physician should treat the patient. The system will allow physicians to retrieve valuable medical information just in time for a quick and accurate diagnosis.

Furthermore this CIP will also store some data that will serve as a reference to patient electronic health care record from an informatics healthcare system, located elsewhere on the Internet, like URI (Uniform Resource Identifier) of EMR server and patient identification information. The information that will be stored on the tag will allow the retrieval of medical information from the corresponding database; this information is collected from many individual sources and to be effectively analyzed it must be characterized by consistency. Also, in order to protect the rights of both patients and providers, security and privacy mechanisms will be implemented.

The proposed RFID-based system could be used to ensure the positive patient identification (PPI) in a hospital. Our intention is to extend the procedure of patient identification beyond hospital and country boundaries. Thus, our RFID-based software system will be an open-loop RFID application functioning across global hospital boundaries. It will require the adoption of common standards (e.g. HL7) or new standards to support an international health information communication, especially for emergency healthcare.

The system will be developed for a greater interoperability of electronic medical records. It is an inspired technical solution offered to healthcare professionals in order to preserve and transfer complex healthcare and patient information that requires no replacement or change of the informatics system employed. The SIMOPAC complexity is further amplified by the fact that most individual electronic health record systems are packaged products supplied by a variety of independent software vendors and run on different platforms.

4.1 SIMOPAC Architecture

The SIMOPAC architecture is shown in Fig. 2. Since the system architecture will allow users to capture, integrate and display an enormous amount of patient-related data from a variety of sources, medical decisions and outcomes will be considerably improved. The CIP will allow the identification of patients, and this RFID card will provide access to an ambulatory EMR, namely a data repository devised as a subset of a longitudinal health record.

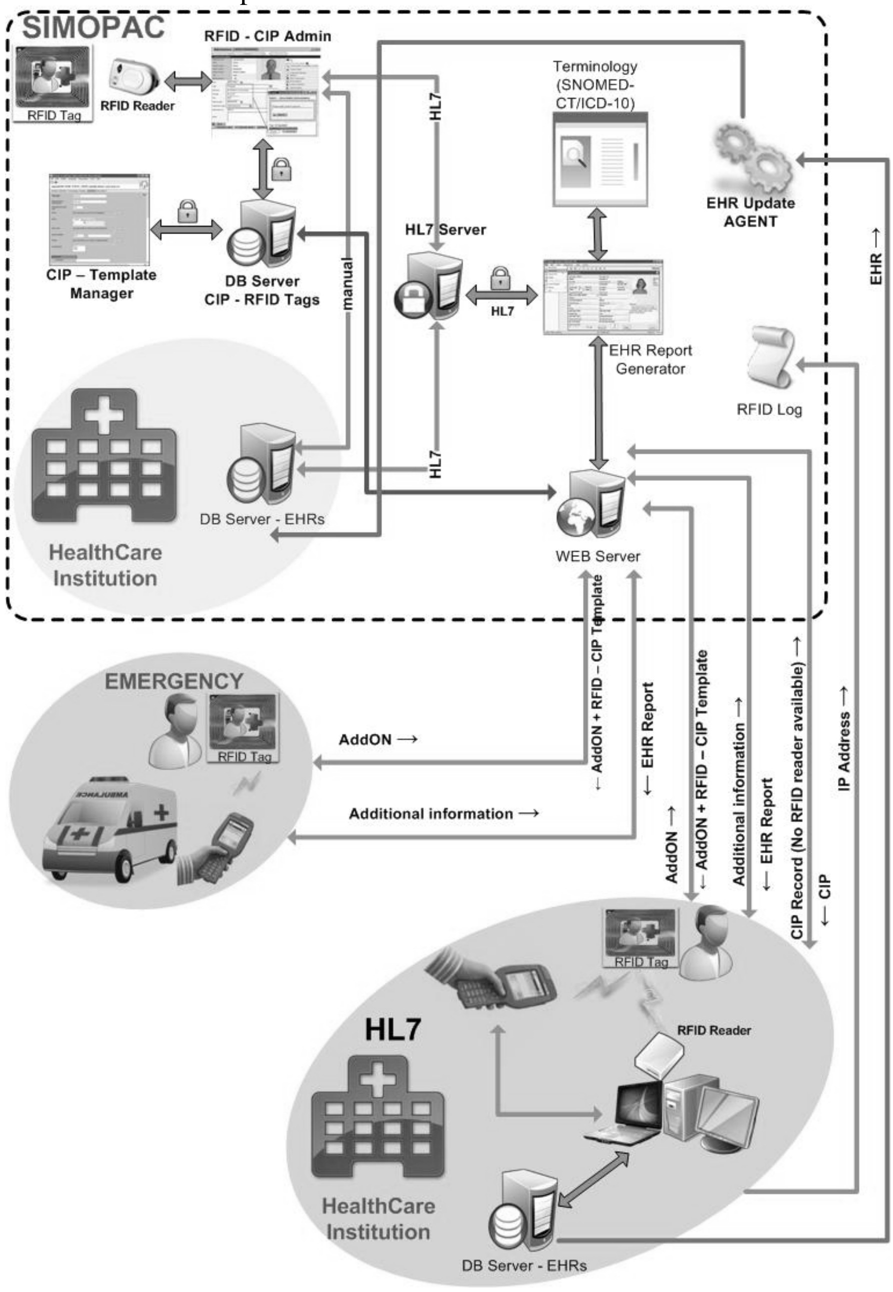

Fig. 2. The SIMOPAC architecture.

Furthermore, the CIP could be used to allow physicians to connect to the SIMOPAC server. To link patient identifiers to patient information the SN@URI approach has been proposed, where SN represents the CIP serial number.

Thus, in order to provide an up to date patient's healthcare history, SIMOPAC will tie together many unrelated EHR systems that are using a wide variety of data types.

The RFID medical record will be devised in such a way as to provide a synopsis of patient healthcare information and, more importantly, to store only those values corresponding to significant data defined by the template. It is meant to enable a rapid assessment of patients' overall health and recent visits to healthcare providers.

For every system that produces patient data, SIMOPAC will create an agent collecting data according with HL7 standard. This agent will be integrated in a multi-agent system that will be able to:

- gather healthcare information electronically across healthcare units;
- bring real-time data from a wide variety of clinics and hospital departments into a concise collection of information that can be shared.

In this way a physician may visualize the medical history of any listed patient. Nevertheless, the data from the original sources is not co-mingled. Thus, through SIMOPAC when a physician refers a patient to a hospital, he is also able to provide an electronic copy of some relevant part of his/her patient's medical record extracted from the electronic medical record (EMR). In addition, when the patient is discharged from a hospital, a discharge summary could be transferred from the facility's hospital information system (HIS)/EMR into the doctor's system through the CIP and the agent system. That would allow the electronic loop to be closed.

Furthermore, SIMOPAC will provide a translator, so no manner which places the physician is working he could understand the data presented. Thus, SIMOPAC will enable the querying of different sections of a single user's medical record or across multiple user records, even in different EHR systems across the globe.

Terminology module will provide service for validation, browsing and translation of HL7 specific codes. Also, this module will provide terminology services for external coding systems such as ICD-9, ICD-10, national drug code lists.

The URI on the CIP enables a rapid assessment of the patient recent visits to healthcare providers. Using the URI on the CIP SIMOPAC allows physician to obtain historical patient data instantly. It communicates with numerous different hospital computer systems and automatically pulls up comprehensive medical information about individual patients identified through the CIP.

In this new collaboration system of health information providers, information privacy and control will become an important issue. Thus, privacy and interoperability issues are potential deal breakers as the medical practice goes electronic. SIMOPAC access will be secure, password protected. Furthermore, there will be many checks and balances in the system to ensure that patient confidentiality is safeguarded and that only people eligible are granted system access. Our system will implement the highest standard of web security involving the use of digital certificates and end-to-end public key encryption.

SIMOPAC will be able to scale across a range of devices, including Pocket PCs, and to handle a large number of work stations and a large volume of medical data. Thus PDAs will be used by emergency physicians at the emergency scene to input data. An RFID reader device attached to a handheld will allow the emergency physician to identify a patient and read the stored vital information about the patient. In addition, the handheld device will be equipped with 802.11b wireless connectivity, to allow the medical staff mobility and network connectivity to the hospital's information systems.

The system will provide an easy-to-use interface through which medical users can see any patient's medical history with just a few clicks.

We will use Java and mySQL database software to create a Web-accessible interface so that physicians may see their patients' medical records via an Internet connection from anywhere in the world. Thus SIMOPAC will gather data from all sources of information and merge them together.

4.2 Hardware Components

The SIMOPAC system includes an intelligent embedded subsystem, in order to achieve real time information concerning the patients' biometric data, which might be used in different points of the healthcare system (laboratory, family physician, etc.)

This device will read the patient's CIP and will carry out its interpretation. The contents of the patient CIP can be seen by means of a display, which is endowed to the mobile device. A mini Web server can be installed on the embedded device and the interpreted content of the patient CIP could be accessed through the local Ethernet network. If supplementary information is asked, the device will be connected to the Internet and the application of the server indicated by URI (Uniform Resource

Identifier) on CIP will be started. The device will transmit to the SIMOPAC system its IP and the serial number of the CIP, for which the information was asked. This device can also read information from different medical devices (for instance, the blood pressure monitor), corresponding to a patient, being able to transmit it towards the SIMOPAC system of the healthcare unit level. The advantage proved by this device is represented by its mobility. The development of a low cost device is aimed to be achieved. The production costs for such device have to be below 600 Euro (the cost of a PDA with RFID reader and wireless network). In this paper, two possible solutions are presented, one allowing the accomplishment of complex operations and one being able to carry out just the file inspection of the CIP content.

Before defining the potential solutions, the functional and non-functional requirements of the hardware subsystem have to be defined. The functional and non-functional requirements of the hardware subsystem are defined. Thus, it has to carry out the following functions:

- to allow the connection of an RFID reader, by using a USB port or a serial port (RS232 or RS485);
- to allow the data sending/quering towards the central database;
- to allow the visualisation of patients' data (the CIP content);
- to allow reading the information from the medical devices;
- to send alarms;
- to allow the communication with the SIMOPAC system, in order to achieve supplementary information about a patient identified by CIP;
- to modify the CIP content;
- to assure a high-level of security.

Our first solution refers to the embedded computer eBox2300SX [18], which connect RFID readers, medical devices and various sensors which can detect the patients' vital signs, such as electrocardiogram (ECG), and body temperature. The development kit eBox2300SX, presented in Fig. 3, might be used to implement the proposed hardware system. This development kit is a low cost computing embedded system, based upon the x86 processor, that includes enough specific features towards a desktop PC.

The Vortex86 processor provide a SoC (System on Chip) solution, fully X86 compatible. The power consumption is reduced (about 15W towards those 700W for the desktop PC), but the computing ability is less than that of a PC. It has 128MB DRAM, an AMI type PC BIOS, and an internal flash memory of 256MB. Within this configuration, operating systems as Linux embedded and Windows CE can operate. Operating systems as Windows XP and Windows Vista can be set up also, where the system might be able to operate as desktop type system, but having limited resources.

Fig. 3. The eBox 2300SX kit.

The advantages of the solution:

- high storing capacity – an HDD can be set upon;
- execution of real time tasks by using Windows CE operating system;
- capability to operate as “mini web server”, which can be used in order to remotely visualise the patients' records;
- using of agents to transmit towards the physician the analysis results and alarms information;
- local visualisation of recordings corresponding to a patient – the embedded device can be used with a monitor connected to the VGA output;
- capability of connection with RFID readers at 3 USB ports and 2 serial ports;
- low price.

The disadvantage of the solution:

- it is not possible to use a display; only a monitor can be attached.

The use case diagram for the application that will be carried out on eBox 2300 is presented in Fig. 4. On this system, Windows CE 6 operating system will be set up.

The application will read the information from the patient CIP through an RFID reader. Upon basis of readed information, immediate medical data can be achieved (blood group, RH, allergic substances, HIV/AIDS, or other chronic or transmittable diseases, etc.).

In order to achieve supplementary information, the application will be connected through the Internet to the server indicated by URI on CIP. The user will indicate the preferred language, of certain potential on that server. The SIMOPAC server processes only the authorised request for accessing an electronic medical record of a patient and returns the answer. Within this application, the content of CIP can be modified, but any modification can be accomplished only for authorised user. This application allows reading information from the medical devices that have a Bluetooth communication interface (by using an USB – Bluetooth interface). This information can be saved on the CIP and/or send to the SIMOPAC system. Due the dual functioning mode of the eBOX 2300 system, with or without monitor, the application operates in two ways: as a graphical application for the monitor solution and as a mini web server, in order to be accessed by means of local Ethernet network.

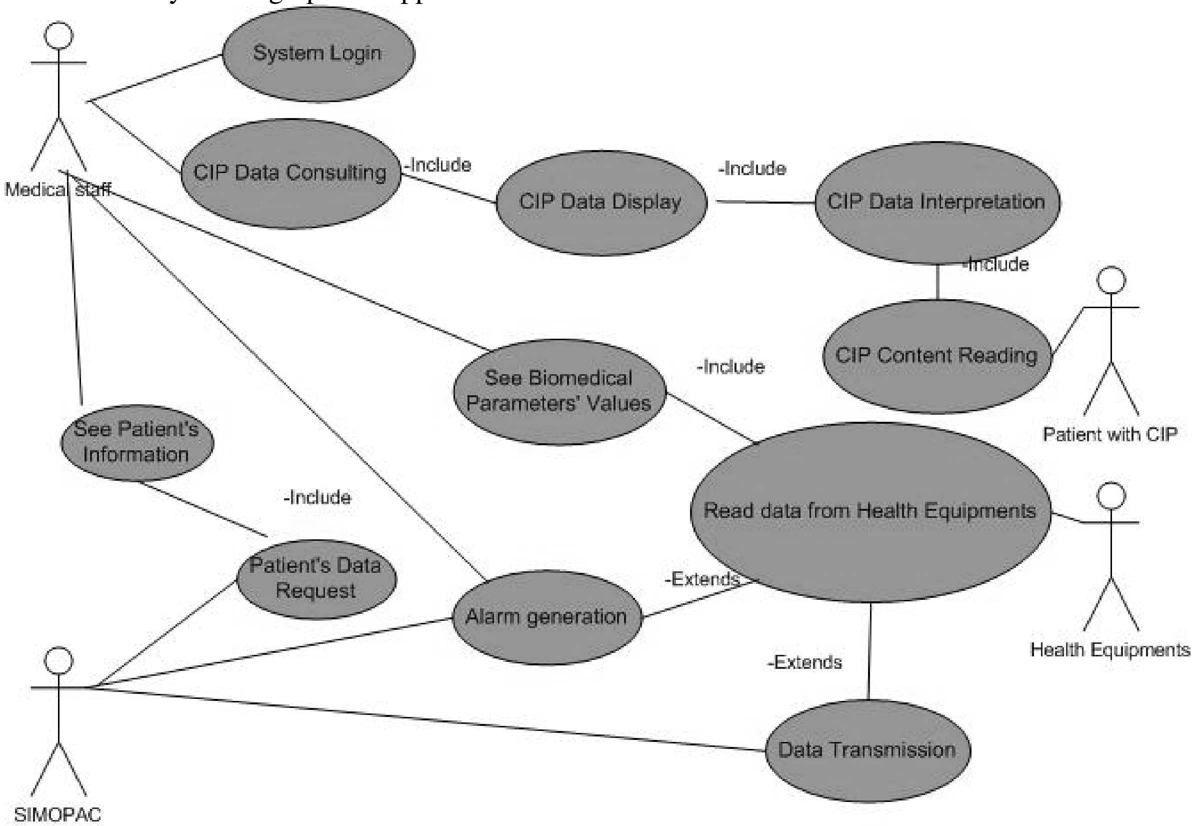

Fig. 4. The use case diagram of the intelligent device.

Also we propose an agent-based approach that will provide a high degree of flexibility and security. In our system, each human actor (physician, patient) will be assigned a specific agent. We will define the following agent categories (Fig. 5):
- Physician agent;
- Biometric agent;
- Patient agent;
- SIMOPAC agent.

We briefly present specific task performed by agent categories:
- Physician agent:
  - notify the physician that biometric results are available;
  - receive test results from the biometric agent;
  - receive alarm messages;
  - display test results data to the physician;
  - send test result to SIMOPAC agent;
  - receive and display desired information from SIMOPAC agent.
- Biometric agent:
  - read the connected medical devices and sensors which can detect the patients' vital signs, such as electrocardiogram (ECG), and body temperature;
  - process the medical information;
  - notify the physician agent that results are available;
  - send alarm messages as soon as the abnormal results are detected;
- Patient agent:
  - identify the patient;
  - read the CIP content;
  - send the information to physician agent.
- SIMOPAC agent:
  - construct and send HL7 messages;
  - send the desired information to physician agent;
  - update the SIMOPAC database with test results.

The considered agents will enable integration of our device in different healthcare systems by providing transparent and secure communication mechanisms based on standard protocols utilized within the healthcare area.

Another potential solution might be carried out by Rabbit processor [19], to which RFID readers and medical devices can be connected (Fig. 6). This solution can be accomplished in two ways:
  - with wireless connection, if RCM4400W is used;
  - with Ethernet connection, if RCM3000 is

used.

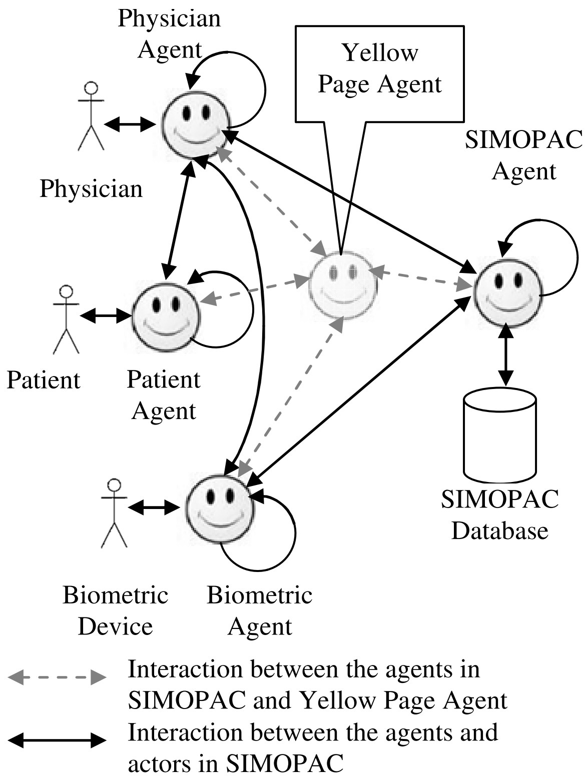

Fig. 5. Agents overview.

A display having a keyboard (as seen in Fig. 7) can be attached to these modules.

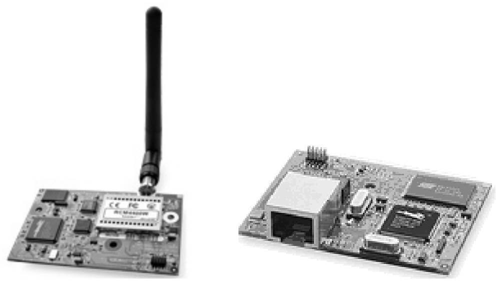

Fig. 6. RCM4400W RabbitCore and RCM3000 RabbitCore modules.

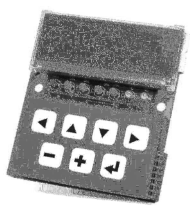

Fig. 7. Graphical LCD display with 7 keys.

In order to determine the cost of solution, the prices related to motherboard, the power supply or RFID reader should be taken into consideration

The benefits of the solution:

- can use the µC/OS-II operating system – to allow the real time tasks execution;
- can operate as a "mini web server", which might be used for remotely visualisation of patients' records;
- allow the connecting of RFID readers at 6 serial ports;
- displaying the information, by using an LCD display and 7 keys;
- low price.

The disadvantages of the solution:

- low storing capacity;
- cannot execute complex tasks;
- limited memory of code and data.

In order to develop the software application on the device having RCM3000 module, the C language and Dynamic C compiler can be used. Dynamic C is a compiler especially created for the processors that are based upon Z80 processor (as Rabbit 3000 processor situation). This offers facilities of debugging towards source code or machine code level. It also includes libraries that allow the implementation of web servers, ftp servers, communication by means of sockets, communication by means of serial ports, using the files system for the flash memory, sending of e-mails. Dynamic C takes care of memory managing, but also allowing that memory to be managed by the programmers. In order to allow the real time tasks execution, the µC/OS-II operating system will be used.

5 SIMOPAC Benefits

The great advantage of SIMOPAC is represented by the availability of vital medical information through patient cards and the usage of health information standards (such as HL7) to store, transfer and retrieve users' health records. All technical solutions have subordinated to two major goals:

- Healthcare providers can give patients and their family members personal cards with their critical health information;
- Healthcare software and device developers can develop personalized services for individual users by employing the patient's health information in the system.

The development and deployment of SIMOPAC offers numerous benefits. Thus, it:

- ensures the electronic access to clinical information among disparate health care information systems;
- facilitates the access to and the retrieval of clinical data with the view to providing safer, more timely, efficient, effective, equitable and patient-centered care;

– can reduce redundant procedures, tests, etc.
– sees all data easily, using a simple and user-friendly interface;
– eliminates transcription;
– helps public health authorities to perform rapid analyses and produce health reports on any population segment.

6 Conclusions

Most hospitals store patient medical data that cannot easily be shared with other systems because of disparate data types. As the RFID technology is becoming cheaper and cheaper, it is for sure that it would be used in everyday life soon. Our research team proposed to integrate the RFID technology in healthcare domain, by defining CIP term. We proposed an RFID-based integrated system that will aggregate health-related data across more hospitals according to recognizable standards; it will make it available for emergency departments in hospitals and public health officials. This solution could help save lives by giving hospitals and paramedics up-to-date information, on scene, when responding to a medical emergency situation. Thus, in emergency medical situations, SIMOPAC offers EMS providers life-saving medical information via the CIP containing up-to-date medical information of vital importance to those entitled to make fast and accurate patient care decisions. A low-cost intelligent embedded system is proposed in order to achieve real time information concerning the patients' biometric data, which might be used in different points of the healthcare system. The research team proposed the use of agents to provide a complementary solution to hardware system, in order to integrate it in different healthcare systems.

Endowed with a lot of features the developed system resolves the problems associated with patient identification and monitoring in today's healthcare system.

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