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RFID-based Information System for Patients and Medical Staff Identification and Tracking

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1. Introduction

Radio frequency identification (RFID) technology is having a major impact on the health care industry. By attaching radio frequency tags to different entities (people and objects), RFID technology can provide identification, tracking, location, security and other capabilities.

The goal of this chapter is to show how RFID technology can be used to reduce medical mistakes, improve patient safety and enhance the quality of medical service in hospitals.

After briefly introducing the eHealth domain and some of the healthcare issues, this chapter describes how the RFID technology can be used in healthcare. Thus the third section describes some hospital use cases that could benefit from RFID technology. Also it briefly presents some of the existing projects that successfully implement this emerging technology in healthcare.

The next section shows how to use a medical staff and patients tracking application, called the RFIDHospitalTracker, to improve the quality of the hospital services. We have developed the RFIDHospitalTracker to support the high requirements for scalability, reliability and security. An overview of its distributed software architecture is given. Also, this section enumerates some open problems that still have to be solved before RFID technology will be fully embraced by the healthcare community.

The last part presents some of the future developments proposed by our research team. The conclusion summarizes the main achievements of this chapter.

2. Healthcare issues

The U.S. Institute of Medicine says that at least 98,000 people in the United States die every year because of medical mistakes. According to an investigative report called "Dead By Mistake" released by the Hearst Corporation, an estimated 200,000 Americans will lose their lives in 2009 alone due to preventable medical errors and hospital infections (Dyess, 2009).

Some of these mistakes involve errors related only to prescription medicine, such as (Lebowitz & Mzhen, 2007):

- prescribing the wrong pharmaceutical drug;
- not finding out a patient's medical history;
- not finding out whether a patient is allergic to a certain drug;

Source: Sustainable Radio Frequency Identification Solutions, Book edited by: Cristina Turcu, ISBN 978-953-7619-74-9, pp. 356, February 2010, INTECH, Croatia, downloaded from SCIYO.COM

- prescribing the wrong series of treatment;
- filling a prescription incorrectly with the wrong medicine or the wrong dosage;
- giving a patient someone else's prescription.

These kinds of medical errors can lead to serious injuries and death.

3. RFID in healthcare

RFID is now generating significant interest in the marketplace because of its robust application capabilities. Thus, RFID systems are becoming popular in logistics operations, inventory and materials management, and industrial automation, replacing optical identification technologies such as barcodes. But RFID technology can provide a number of benefits to the healthcare industry, improving overall safety and operational efficiency because it operates without line-of-sight while providing read/write capabilities. In fact, RFID can contribute to create the hospital of the future by improving patient care and safety, optimizing the workflows, reducing the operating costs, and reducing costly thefts. There are a number of ongoing trials and studies at hospitals and healthcare centers around the world utilizing and integrating RFID into their hospital information systems. One study estimates that the market for RFID tags and systems in healthcare will rise rapidly from \$90 million in 2006 to \$2.1 billion in 2016. Primarily, this will be because of item level tagging of drugs and Real Time Locating Systems (RTLS) for staff, patients and assets to improve efficiency, safety and availability and to reduce losses (Harrop & Crotch-Harvey, 2008).

By attaching RFID tags to different entities in healthcare industry (people and objects), RFID technology can provide some capabilities, such as: identification, tracking, location and security. These capabilities directly affect the major issues currently experienced by healthcare organizations while helping to drive down costs (BlueBean, 2007).

Next we present a short "state of the art" of the RFID-based healthcare applications.

Patient Identification

Patient identification error may lead to improper dosage of medication to patient, as well as having invasive procedure done. Other related patient identification errors could lead to inaccurate lab work and results reported for the wrong person, having effects such as misdiagnoses and serious medication errors (Sirivattha, 2003).

RFID technology is used in order to cut these clinical errors, to improve patient care and security.

Anti-Counterfeiting

Drug counterfeiting is an increasing global problem:

- patients lose because they are paying good money for inferior products, which not only is a bad deal economically but also can be a significant health threat as they can contain dangerous substances;
- pharmaceutical companies lose money because of counterfeit drug trade;
- government also loses due to significant loss in taxes and spending considerable resources to combat counterfeiting.

According to the Center for Medicine in the Public Interest, worldwide counterfeit sales are increasing at about 13 percent annually - nearly twice the pace of legitimate pharmaceuticals - and could become a \$75 billion industry by 2010 (*, 2009).

RFID technology is more and more used to help pharmaceutical companies, distributors, and hospitals to combat and deter drug counterfeiting.

Inventory Management

By increasing the efficiency of the supply chain and inventory visibility through RFID technology, hospitals can gain some benefits, such as (BlueBean, 2007):

- reducing out-of-stocks;
- procuring less inventory;
- decreasing lost and stolen supplies;
- decreasing the rate of non-charged consumables;
- reducing the time staff spends searching for inventory;
- optimizing the utilization of current inventory;
- improving inventory replenishment within hospitals;
- identifying inventory to be ordered.

Tracking Entities

An RFID system can be used to track people (patients, doctors, nurses), expensive and critical equipments in hospitals in real time:

- tracking patients - meet the need of patient identification and location to ensure patient safety when urgent medical attention is needed and to protect vulnerable patients (infants, Alzheimer's patients, etc.);
- tracking medical staff - identifying the location of caregivers in hospitals to ensure the most efficient response to emergencies;
- tracking pharmaceuticals from the manufacturer, distributor, and pharmacy to the point of administering medication to the patient;
- tracking movable equipment, furniture, medical devices, and other high-value items (surgical equipment, wheel chairs, etc.) - to provide ready access when needed and to reduce losses. For example, a bed could be moved through the hospital and as it passes through the rooms of the hospital it is detected by the RFID readers that send the information to the hospital server;
- tracking blood - RFID-based systems are used to track bags of blood to record transfusions and to minimize the risk of patients receiving the wrong type of blood;
- tracking documents - by attaching an electronic label on the cover, files containing important documents like prescriptions, clinical reports, medical bills, etc. can be easily traceable in hospitals.

Other Applications

- ensuring the proper identification of laboratory specimens, including biopsy samples and containers of blood or urine to reduce medical errors;
- managing controlled substances, pathogens, and other materials that pose a public health risk;
- restrict access to drugs, pediatrics and other high-threat areas to authorized staff.

Next we present some RFID-based systems that are already successfully implemented within worldwide hospitals. Case studies are presented from the following countries (alphabetically): Finland, Germany, Italy, Taiwan, United Kingdom and USA.

Finland: RFID and medication compliance

A Finnish company developed a system using RFID and mobile phones to make sure Alzheimer's patients take their medication.

Italy: RFID and blood transfusion

RFID technology is used to increase efficiency and safety in the management of the transfusion process in Italy's National Cancer Institute in Milan and Ospedale Maggiore hospital in Bologna. Thus, RFID tags are placed on blood bags and patient wristbands.

Staffs are provided with RFID ID cards and personal digital assistants (PDAs or handheld computers) in order to:

- register patients upon arrival;
- verify patient-blood group;
- recognize patients and transfusion units at any time.

Germany and USA: RFID and medication

At Jacobi Medical Center in New York, nurses use a Tablet PC to match the RFID tags on patients' wrists with bar-coded information on packets of medication. The match ensures that each patient receives exactly the right dose and only the medication that has been prescribed to him or her. It also automatically creates an electronic record of the nurse's visit, allowing the nurse more time to provide direct patient care (Crouse, 2005).

Germany's Jena University Hospital implements a system using RFID to track medication from the point of dispensing in the hospital's pharmacy to the drug's administration up to 24 patients in intensive care, in order to avoid drug errors (Vilamovska et al., 2008).

Taiwan: RFID and SARS

A number of RFID-related software applications were developed in Taiwan. Some of these applications focused on the use of radio frequency identification (RFID) technology to prevent spread of the severe acute respiratory syndrome (SARS) disease. These applications include computerized systems for monitoring the body temperature of healthcare personnel and patients in the hospital, track potential virus carriers and, when necessary, map their movements throughout hospitals and keeping track of people under quarantine in facilities separate from hospitals.

UK: RFID and hospital equipment library

The Royal Alexandra Hospital uses a hospital-wide RFID asset tracking virtual asset library in order to (Vilamovska et al., 2008):

- improve the use of its assets;
- ensure the availability of medical devices at the point of need;
- streamline routine scheduled maintenance;
- reduce health and safety risks resulting from failure to meet scheduled inspection plans.

USA: Tracking and tracing assets and equipment

Southern Ohio Medical Center has deployed the Radianse Reveal Asset Tracking platform to increase its efficiency of asset and equipment tracking.

Since 2004, Bon Secours Richmond Health System has deployed one of the largest RFID-enabled mobile asset management programs in US healthcare industry. The system is providing tracking and management services for critical mobile medical equipment for three Bon Secours Richmond hospitals (Vilamovska et al., 2008).

USA: Emergency Department workflow improvement

To improve the operation of its Emergency Department (ED), including cutting down patient waiting time, Memorial Medical Center in Long Beach (CA) and Shelby County

Regional Medical Center relied on a RFID-based people/asset tracking software. The new system provided unprecedented data on ED use and patient trajectories, and became the key tool in the quality improvement policies the hospital implemented (e.g. new triage procedures, staffing). These led to a decrease in the waiting time for the first triage nurse from 1hr 20 min to 9 min for incoming patients in Memorial Medical Center.

This leads to (Vilamovska et al., 2008):

- increased patient safety;
- better use of staff time;
- increased facility capacity.

For the future

Continuing advances in nanotechnology and robust wireless infrastructures are now making it possible to envision an environment in which RFID devices ingested or implanted in patients could actually (Crounse, 2005):

- provide real-time information on health indicators and vital signs;
- regulate the release of medications;
- monitor and report on the results of surgeries;
- communicate with other devices in medication labels to alert caregivers to potential allergies, errors in dosage, or drug interactions.

The researchers estimate that with the help of RFID technology, a single nurse could more effectively and accurately monitor the status of an entire ward of patients, with care automatically dispatched in response to changes in a patient's condition. And outpatients could be remotely monitored, receiving nearly the same level of attention as those within the walls of the hospital (Crounse, 2005).

The main benefits of adoption RFID technology in healthcare include:

- patient's safety improvement by preventing errors;
- resource use improvement;
- costs saving;
- security enhancement.

Although the adoption of RFID technology by healthcare community is a relatively slow process, its usage is expected to accelerate when RFID technology prices drop down.

4. RFID-based information system for patients and medical staff identification and tracking

Our team proposed an integrated RFID-based system for patients and medical staff identification and tracking, called RFIDHospitalTracker.

The different components of this scalable and robust distributed system are depicted on figure 1.

Relating to this architecture we can note that the integrated RFIDHospitalTracker system includes the following main components:

- RFID 13.56 MHz passive tags (so that both patients and doctors can be tagged with unique codes);
- fixed RFID readers placed at strategic points in specific areas of the hospital: offices, laboratories, emergency rooms, operating suites, etc.;
- Pocket PC devices or mobile phones with RFID readers attached;
- a database server that will store patients' tags, tag templates and tracking information;

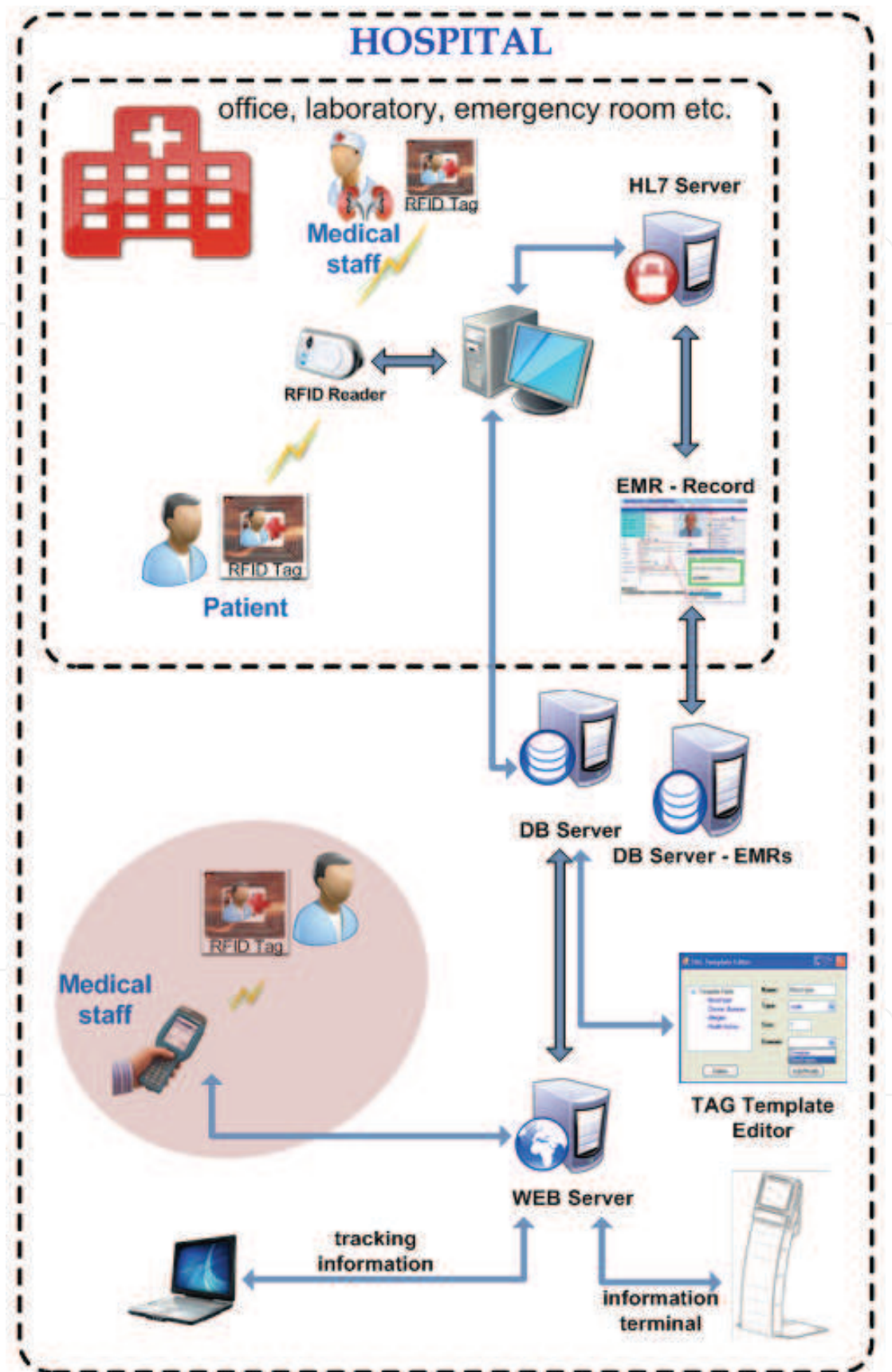


Fig. 1. RFIDHospitalTracker system architecture

- a web server that will allow database querying (to determine the location or the trajectory of a patient or doctor, etc);
- an EMR (Electronic Medical Record) server that will store the electronic medical records of patients in the hospital;
- information terminals that will allow patients to check their own medical records by scanning their wristbands;
- a HL7 server for interoperability with other clinical software already developed by other companies or organizations.

Next we present the way that RFID tags will be used for both patients and medical staff. The doctors, nurses, caregivers and other staff members wear an RFID card storing their employee ID number. These cards are used only for tracking purposes. Thus, they require a very small memory capacity. Every time a card is read by a fixed RFID reader, the actual location of the holder and current date/time are recorded into the central database.

On arrival, each patient receives a wristband with an embedded RFID tag storing a unique identifier, and some information about him (e.g. blood type, medical allergies, or other health history). In addition, all the patients' paper medical histories and other important documents are tagged with self-adhesive RFID labels containing patient identifier. With the help of this additional information, the risk of administering wrong medication in case of an emergency will be highly reduced. Moreover, the hospital staff will be able to take the best medical decisions according to the actual health state of the patient.

These wristbands and RFID tags are waterproof and heat-resistant and can be used in the darkish environments. Moreover, RFID tags memory can be erased and written more than 100,000 times. Thus, to reduce the cost of the RFID healthcare system these wristbands and RFID tags can be reusable after high-temperature sterilization.

The data format that will be used for writing additional information into tags can be defined through an advanced template editor (figures 2 and 3) which allows user to establish all the necessary fields (e.g. blood type, chronic diseases, allergies, etc.), their type (string, code, codes list). The template is created at the PC level and it can be transferred to Pocket PC devices or mobile phones through specialized web services. A typical tag template can have the following fields:

Field	Size	Type	Description
Blood type	1	Code	code for blood type - e.g. 3 (A Positive)
Chronic diseases	3	Code	a list of codes for chronic diseases - e.g. 1 (Asthma) 4 (Diabetes Insipidus) 5 (Bronchiectasis)
Allergies	100	String	a list of allergies - e.g. Penicillin Sulfa drugs Dilantin
Health history	150	String	the most recent health history - e.g. Appendix Surgery in 2002 3 heart attacks in last month coronary artery bypass surgery in 2009

Table 1. Typical tag template

Note that all types in column 3 of Table 1 are not built-in but application specific types. The use of codes has some important advantages, such as:

- less storage space is required for storing the same data: RFID tags with smaller memory capacity reduce the overall cost of the RFID healthcare system;
- increased security: a tag that stores codes means nothing for people outside the hospital;
- one definition, multiple uses.

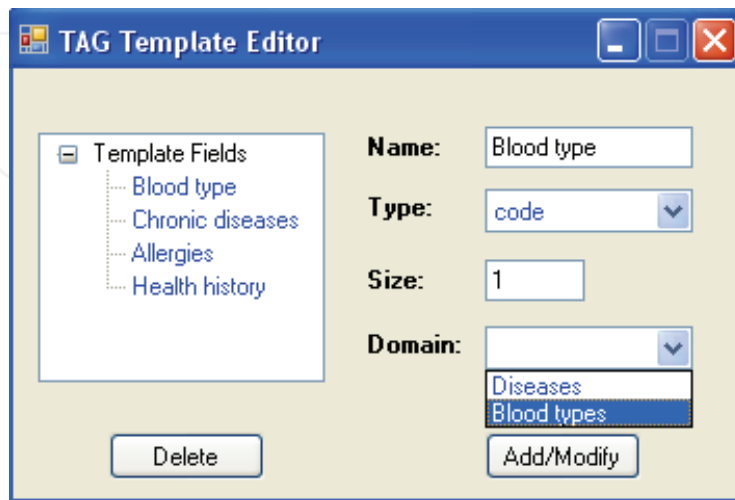


Fig. 2. Tag template editor

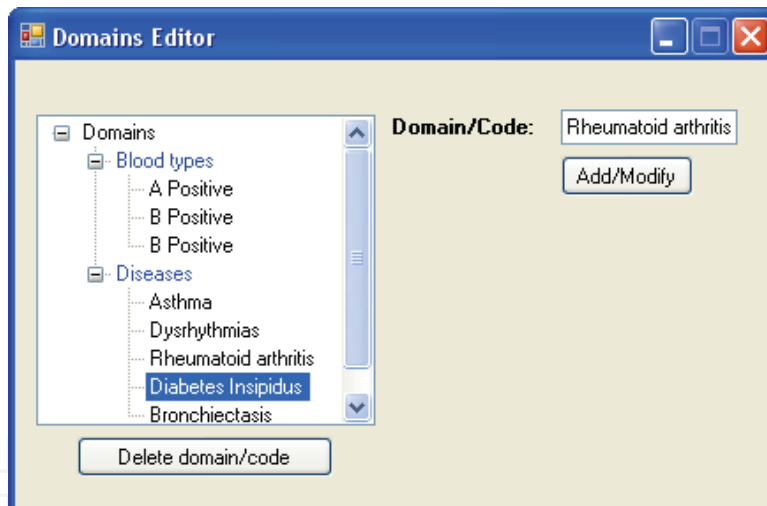


Fig. 3. Domains/codes editor

By default, an RFID tag does not store the name of the patient. To enable the tracking feature, the RFID tag is first linked with the patient's name. This is done by reading the RFID tag's unique ID and adding a new record (*TAG_UniqueID, PatientNAME*) into the central database. After that, every time the tag is read by a fixed RFID reader, the actual location of the patient and current date/time are recorded into the central database.

When a new patient arrives in the hospital, the following actions must be performed (figure 4):

- the RFID tag has to be linked with the patient's name;
- the RFID tag has to be linked with the patient's EMR, if any. This operation is done by adding a new record (*TAG_UniqueID, SocialSecurityNumber_EMRID*) into the central database. This way the hospital staff can access for review and update the desired

- patient's information from hospital EMR system, only by reading the patient's RFID tag embedded into the wristband;
- the additional information has to be written into the tag's memory so that the information will be available for reading/writing at any time both at PC and Pocket PC levels.

Fig. 4. Registering a new patient

The application located at the PC level can be used for the following purposes:

- to design tag templates;
- to register new patients;
- to remove an existing patient from the database;
- to track patients and hospital staff members;
- to read/write information stored on RFID tags;
- to display patient's EMR.

Perhaps one of the most important facilities that such an application should provide is the ability to read/write RFID tags. The ability to read/write RFID tags was achieved through a specialized software component that is performing the following main tasks (Cerlinca & et al., 2008):

WRITE operation:

- establishing a connection with the RFID reader;
- encoding the data to be written on the RFID tag;

- searching for an RFID tag in the proximity of the RFID reader;
- writing the encoded data to the RFID tag;
- closing the connection.

READ operation:

- establishing a connection with the RFID reader;
- searching for an RFID tag in the proximity of the RFID reader;
- reading all the data encoded in the RFID tag;
- decoding the data;
- closing the connection.

Next we present some considerations regarding the use of mobile devices within the RFIDHospitalTracker system. Mobile devices can be successfully used in places where there are no fixed RFID readers. Thus, the hospital staff members (doctors, nurses, caregivers and other employees) have a portable RFID reader (for example, a handheld device, like Pocket PC or mobile phone, equipped with an RFID reader) and possibly with a wireless connection to the web. The mobile application that runs on such devices performs the following main functions:

- read and write RFID tags (figure 5 and 6). The tag selection window presented in figure 5 is useful in cases when there are more than one RFID tag in the proximity of the RFID reader;
- work in stand-alone mode (independently of the main servers);
- store huge data;
- integrate and exchange information with other components of the RFIDHospitalTracker system. The tag template and database tags are transferred to Pocket PC devices or mobile phones through specialized web services that are located on the web server. All data transferred between mobile devices and PC server is first converted from the database format into the XML format;
- ensure maximum security;
- employ a multi-user and user-friendly interface.

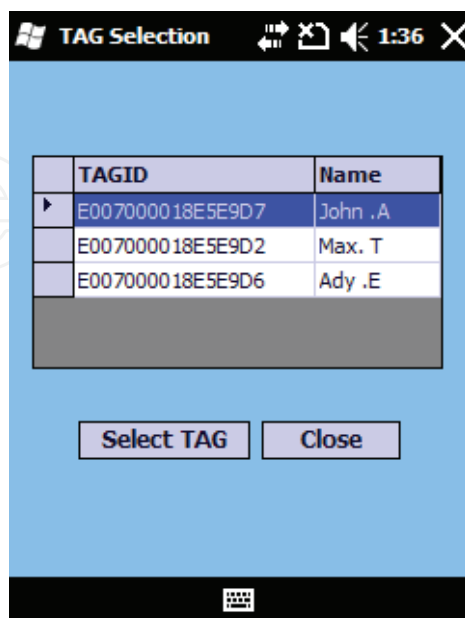


Fig. 5. Tags selection window

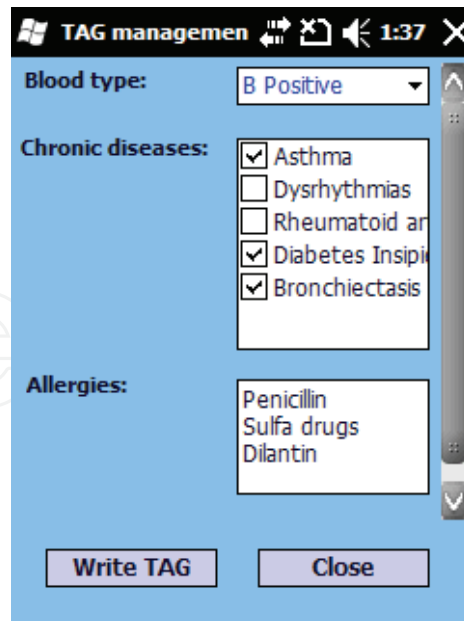


Fig. 6. RFID tags reading/writing

The mobile application cannot be used for tracking purposes or to add new patients.

Another important component of the RFIDHospitalTracker system is represented by the information terminals that will allow patients to check their own medical records by scanning their wristbands. A typical information terminal consists of the following components: an embedded PC, a display, a keyboard and an RFID reader. The application that runs on information terminals can be used for the following purposes:

- to read and display information stored on RFID tags;
- to display a patient's EMR;
- to locate hospital staff members.

RFIDHospitalTracker system is adaptable and scalable, enabling the hospital to deploy other tracking solutions for people (patients, doctors, nurses) and objects (medical devices and assets) without investing in new hardware or system architecture to support such solutions.

Any technology implementation in healthcare must deal with privacy and security issues. Our system provides several security enhancements and options to ensure the security of data and communication between applications:

- all RFID tag data is encrypted using AES algorithm (the private key is generated using tag unique ID and a hash function);
- password-based access to all web services used for communication and synchronization between mobile devices and the RFIDHospitalTracker system.

The main benefits of the RFIDHospitalTracker system are:

- error prevention of identifying wrong person by medical staff;
- elimination of some current medical errors, such as: not finding out whether a patient is allergic to a certain drug or giving a patient someone else's prescription;
- fast location of patients and doctors in the hospital.

Barriers to RFIDHospitalTracker adoption

We have to mention that the using of the RFIDHospitalTracker system raises some problems (issues), such as:

- privacy and legal issues;

- direct costs, for example, implementation costs, maintenance costs;
- difficulties in implementing RFIDHospitalTracker system within a hospital, for example, tagging persons and placing readers in doorways at hospitals will require an initial deployment;
- people acceptance, for example, hospital staff has to feel comfortable with the fact that they can be tracked and located every time.

Before the healthcare industry fully adopts the RFID technology there are still some open problems to be solved, such as determining the consequences and side-effects of radio waves on the exposed humans and electrical devices that are common in an hospital (like pacemakers, heart monitors).

HL7 (Health Level Seven) Compatibility

Health Level Seven, Inc. (HL7) is the global authority on standards for interoperability of health information technology with members in over 55 countries (*, 2007). HL7's vision is to create the best and most widely used standards in healthcare. HL7 is an international community of healthcare subject matter experts and information scientists collaborating to create standards for the exchange, management and integration of electronic healthcare information (*, 2010). HL7 promotes the use of such standards within and among healthcare organizations to increase the effectiveness and efficiency of healthcare delivery for the benefit of all.

In order to support other clinical software already developed by other companies or organizations we have designed a HL7 server. The main purposes of this server are:

- to acquire medical data about patients using the HL7 messaging protocol;
- to request clinical data about a patient from different servers and applications;
- to allow the clients of the HL7 server that are not HL7 compatible to understand the HL7 protocol and request/receive data using simple and intuitive ASCII commands.

The HL7 server will be primarily used to obtain the EMR of a patient based on his RFID tag. There are two different ways of getting clinical data:

- using the standard HL7 messaging protocol our HL7 Messaging Server connects to a list of medical applications;
- using simple and intuitive ASCII commands any non-HL7 application can connect to the Messaging Server and request data about a patient (Table 2).

Fig. 7 presents some examples of the use of these commands for:

- logging in using server address and port, user name and password;
- setting the current patient;
- getting patient name, SSN, mother's maiden name, birth place, etc.

Future development

We will try to develop our application to track the interaction between medical staff and patients. Also, we'll add a software module that will optimize the patient treatment process by prioritizing and tracking patients from admission to discharge, based on medical priority and treatment.

Our research will focus on the development of various software modules to use the medical information collected via RFID. For example, once information such as body temperature of a patient is received, the hospital control center can immediately analyze it. According to configuration settings, for example, in order to keep some diseases from spreading, the control center could send essential information to medical staff via mobile phone. Also, temperature-monitoring tags could be used for refrigerators containing lab specimens, blood bags and other sensitive items to ensure safe conditions.

Command	Description
<code>login(<IP>,<Port>,<user>,<password>);</code>	Login to a specified HL7 application or server using IP:Port and, for authentication, a user and a password.
<code>usePatient(<SSN>,<Language>);</code>	Setting the current patient using his Social Security Number and a language.
<code>getName();</code>	Getting the name of the patient.
<code>getDateOfBirth();</code>	Getting the date of birth for current patient.
...	
<code>getLastObservations();</code>	Getting all observations about current patient from the current server.
<code>getSimplifiedLastObservations();</code>	Getting all observations about current patient from the current server and return it in a simplified way.
<code>getLastError();</code>	Will return the last error in the language selected by the <i>usePatient</i> command.

Table 2. Some commands used to obtain data from the HL7 Message Server

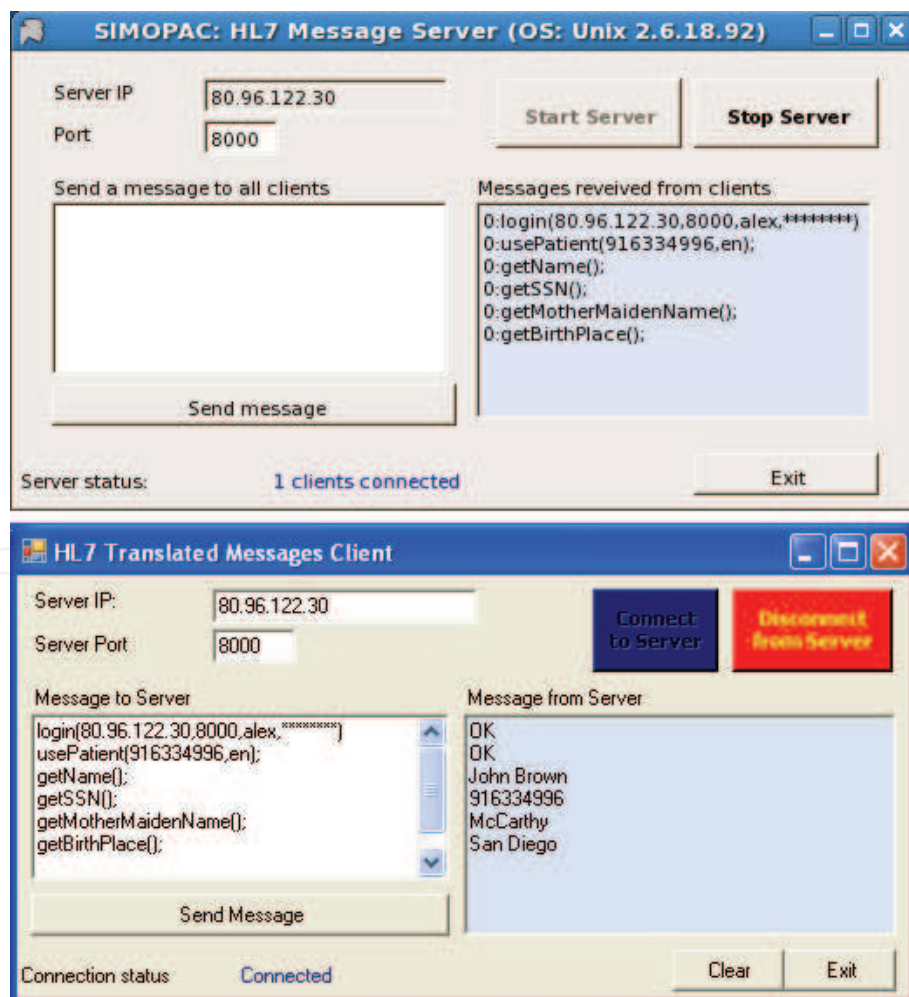


Fig. 7. The use of HL7 Message Server (Linux server and Windows client)

5. Conclusions

RFID applications can provide significant benefits to the healthcare industry to ensure patient safety and also to improve supply chain efficiency. In fact, healthcare is predicted to be one of the major growth areas for RFID. An analysis (Frost & Sullivan, 2005) estimates that the RFID in healthcare and pharmaceutical applications markets will reach \$2318.7 million in 2011.

This chapter presents some applications that integrate RFID technology in healthcare domain. It also presents an RFID-based integrated system for patients and medical staff identification and tracking, called RFIDHospitalTracker. Our RFID-based system could be used in hospitals with large patients flow, allowing hospital staff to read patients' identification tags (RFID cards), which can help avoid some medical errors, like giving patients improper prescriptions or someone else's treatment.

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Sustainable Radio Frequency Identification Solutions

Edited by Cristina Turcu

ISBN 978-953-7619-74-9

Hard cover, 356 pages

Publisher InTech

Published online 01, February, 2010

Published in print edition February, 2010

Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. A number of RFID applications proposed or already used in technical and scientific fields are described in this book. Sustainable Radio Frequency Identification Solutions comprises 19 chapters written by RFID experts from all over the world. In investigating RFID solutions experts reveal some of the real-life issues and challenges in implementing RFID.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Tudor Ioan Cerlinca, Cristina Turcu, Cornel Turcu and Marius Cerlinca (2010). RFID-based Information System for Patients and Medical Staff Identification and Tracking, Sustainable Radio Frequency Identification Solutions, Cristina Turcu (Ed.), ISBN: 978-953-7619-74-9, InTech, Available from:
<http://www.intechopen.com/books/sustainable-radio-frequency-identification-solutions/rfid-based-information-system-for-patients-and-medical-staff-identification-and-tracking>

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