A Distributed RFID Based System for Patients' Identification and Monitoring

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Abstract — **The goal of this paper is to present a distributed RFID (Radio Frequency Identification) based system for patients' identification and monitoring. The system we propose is intended to reduce medical mistakes, improve the patients' overall safety and enhance the quality of medical services in hospitals. By using the RFID technology, the patients can be easily identified and the risk of administrating wrong medication in case of an emergency will be highly reduced. Our system is also able to integrate and exchange information with other HL7 (Health Level Seven) based clinical applications already developed by other companies or organizations.**

Index Terms — **EHR (Electronic Health Record), EMR (Electronic Medical Record), HL7, RFID, Tag**

I. INTRODUCTION

RFID technology has been considered one of today's "hottest" technologies due to its specialized capacity to track and trace objects in real time [1]. RFID technology is classified as a wireless Automatic Identification and Data Capture (AIDC) technology that uses electronic tags to store identification data and other specific information, and a reader to read and write tags [2]. Tags are small chips with antenna. There are three different types of RFID tags: passive (uses the reader's signal to be activated), active (battery powered) or semi-passive (battery-assisted, activated by a signal from the reader) [3].

RFID technology is also providing a high level of security and has some important advantages over similar technologies, such as barcodes. It has been successfully implemented in a variety of areas, such as: logistics operations, inventory and materials management, industrial automation etc.

The healthcare industry can also benefit from the RFID technology. Although most of the current RFID healthcare applications and systems are just in some experimental phases, the future is promising. Thus, some studies estimate that the market for RFID tags and systems in healthcare will rise from $90 million in 2006 to $2.1 billion in 2016 [4].

The main idea of any RFID healthcare system is to tag patients. Thus, an RFID tag attached to a patient needs to store some relevant information related to the carrier, such as: identification data, a list of chronic diseases that the patient is suffering from and the most relevant patient's medical history. But, the general rule with any memory based system has always been that no amount of memory is ever sufficient [5]. On the other hand, it is well known that RFID tags with large memory capacity are too expensive to be used in a system with thousands of patients and the only way to keep costs down is to use passive tags with small memory capacity. But, it is obviously that a tag with small memory capacity cannot store all the relevant information related to a patient. This problem could be solved by storing the vital information on the RFID tag and the additional information into a central database, based on a tag template. The IP address of the database server could also be stored on the RFID tag, so that the additional information will be available over the Internet to the medical staff. This way, the medical staff will always have access to all relevant information related to a patient.

Another important feature that an RFID healthcare system should provide is the ability to integrate and exchange information with similar systems. This could be achieved through the use of HL7 standards. HL7, which is an abbreviation of Health Level Seven, is a standard for exchanging information between medical applications. This standard defines a format for the transmission of health-related information. Information sent using the HL7 standard is sent as a collection of one or more messages, each of which transmits one record or item of health-related information. The HL7 international community 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 [6]-[8][8] .

II. SYSTEM ARCHITECTURE

Our research team developed a distributed RFID based system for patients' identification and monitoring, called SIMOPAC. This system enables real time identification and monitoring of a patient in a medical facility, on the base of CIP (Personal Electronic Identity Card). A CIP is a passive RFID tag that is storing relevant medical information related to its carrier. The CIP provides a quick access to the actual health state of a patient and helps the medical staff to take the best decisions, especially in case of an emergency. Thus, the risk of administrating wrong medication is highly reduced. The system is also able to integrate and exchange information with other HL7 and even non HL7 based clinical applications already developed by other companies or organizations. The different components of this scalable and robust distributed system are depicted on figure 1.

Related to this architecture we can note that the distributed SIMOPAC system includes the following main modules:

- User management;
- EMR viewer;
- Tags management;
- HL7 server.

These modules are shortly described in next subsections.

A. User Management

Needless to say, security is one of the most important aspects that should be taken into consideration when implementing such a distributed system. User management is a critical part of maintaining a secure system. Ineffective user and privilege management often lead many systems into being compromised [9].

The User Management module was designed as a generalized system that allows management of all users and users groups within a distributed system with different modules, each of them with its own list of entities and privileges.

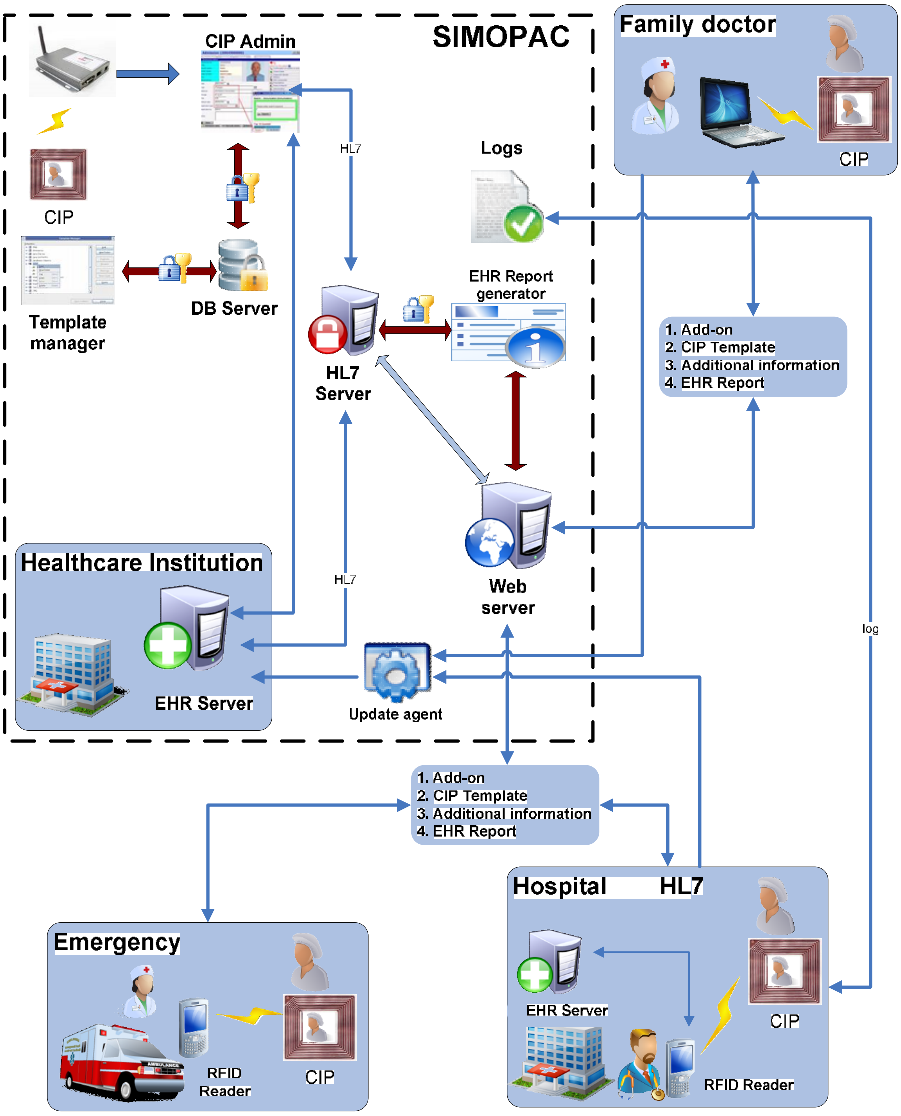

Figure 1. SIMOPAC system architecture.

Within the framework of SIMOPAC system, the User Management module provides the following main facilities:

- password based access to the User Management application;
- data encryption with the TripleDES algorithm for all important information that are being transferred over the Internet and stored into the central database (e.g.: user names, passwords, access rights);
- support for different levels of access rights. This means that users are granted different rights to the system's features;
- management of system registered users (users visualization, adding or deletion of certain users, profile modification, granting/revoking user privileges, etc.);
- modules and entities management.

Figure 2 exemplifies the process of granting/revoking user privileges for different modules and entities of the SIMOPAC system.

B. EMR Viewer

This module, generically called VizEMR-PC, allows the identification of a patient based on his own CIP and displays some pre-configured information from the electronic health record of that patient. The patient identification is based on the patient's identifier that is stored on the RFID tag and printed on the CIP. VizEMR-PC module displays patient information in the language requested by the user.

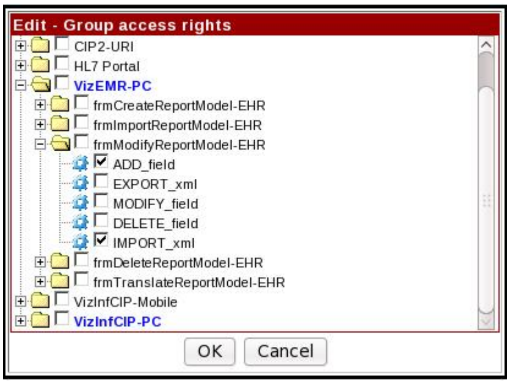

Figure 2. Granting/evoking privileges.

This module can be used when the CIP is read at a medical unit and the medical staff wants to obtain more information about the patient. VizEMR-PC provides the following main facilities:

- a specialized editor that allows the design (configuration) of a report template for the interest information from the electronic health record of the EHR/EMR system that is integrated with SIMOPAC. The report template is created only once by skilled health personnel and contains all or only some of the electronic medical/health record's fields. This template can be translated into several foreign languages to facilitate cooperation between medical units from different countries in order to assure a good care for a patient from another country.
- a report generator that will be responsible with the completion of the following tasks:
    - filling the report template fields with information taken from the electronic medical/health record of a patient by using HL7 dedicated commands;
    - generating a custom report in different formats (XML, CVS, MDB, etc.) in the language requested by the user.

In order to have access to VizEMR facilities, authorized users must first login to the application by entering their username/password. The client-server communication is secure; all the passwords that are sent over the Internet are first encrypted on the client-side. Also, the access to various facilities offered by VizEMR-PC is done in accordance with the privileges that were previously set for the registered user. Access rights are established by the User Management module.

C. HL7 Server

Our research team designed and developed a HL7 server to integrate the SIMOPAC system with other clinical applications/systems already developed by other companies or organizations. Thus, the main purpose of this server is to acquire clinical data about patients (from different servers and applications) by using the HL7 messaging protocol. Within the framework of SIMOPAC system, the HL7 server will be primarily used to obtain the EMR of a patient that was identified on the base of his RFID tag. There are two different ways of getting clinical data [10]:

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

III. ORGANIZING DATA ON RFID TAGS

At the RFID tag level the data was structured on the base of a template stored on a Web server. In addition to structured data, the tag is also storing some vital information that can be accessed from a simple reading of the CIP. The template will be available for download at the URL written on the CIP. The medical staff can have quick access to the information written on the CIP by downloading (from the same URL address) a specialized add-on application that is mainly used to communicate with the RFID reader.

A. Template Management

This section of SIMOPAC system is mainly focused on the creation of the templates that are used for information structuring on patients' CIP sheet. The patient's CIP sheet contains two different areas, each of them storing specific information about the patient. The first one contains clear-text information that is needed especially in emergency situations. This information uniquely identifies a patient and specifies if he/she is suffering from any serious illness. The second section of the CIP contains data that can be interpreted only with the same template that was used for writing the information into the RFID tag. In addition, medical staff can obtain a translation of this information, if the person that created the template and the CIP sheet has also translated them. The translation will be available in an XML format, so it will be easily transferred and read. On the base of these templates, the medical staff can create the CIP sheet that corresponds to one or more patients.

One of the main advantages of template based information structuring is given by the fact that information to be included in the CIP is translated only once. Other advantages are listed below:

- the use of a single template for a specific target group (because everyone will have the same type of data included in the CIP);
- allows a better organization of data to be included in the CIP.

A template consists of a list of user defined fields. Each field is defined by name and data type. The common data types are shown in figure 3, to which more types can easily be added.

ID	Type	Display format
1	String	(A/_)
2	Integer	[+-](9)
3	Real	[+-](9)[.(9)]
4	Data	yyyy-mm-dd
5	Time	hh/nn/ss
6	DateTime	yyyy-mm-dd hh/nn/ss

Figure 3. Common data types.

As it can be seen in figure 3, each data type has, in addition to a name, a display format that will be used by a plug-in module for the correct displaying of the information stored on the CIP. The display format can be interpreted as follows:

- (A/_) - letters (A. … Z) and other displayable ASCII characters;
- [+-](0...9) – the symbol + or - (optional), followed by digits;
- [+-](0...9)[.(0...9)] – the symbol + or - (optional), followed by digits. The decimal point is optional and it is used for floating point numbers representation;
- yyyy-mm-dd – standard representation of dates (y - year, m - month, d - day);
- hh/mm/ss – standard representation of times (hh - hour, mm - minutes, ss - seconds);
- yyyy-mm-dd hh/mm/ss – standard representation of date-time values.

When the system contains at least one CIP sheet associated with a particular template, there is no possibility to edit that template anymore, unless another template is built on the base of the first one. After building the template, the next phase is the translation of the fields, translation that will be saved in an XML format and then stored into the central database. There is no restriction related to the number of translations that can be done. When a doctor consults a patient's CIP sheet, he can have access to the structured information as well. Regarding to the translation of the template's fields, the medical staff can choose between an automated translation (performed by the plug-in application, based on localization) and a translation that was downloaded along with the template associated to the patient's CIP sheet (see figure 4).

```
- <grammar xmlns="...">
    <name
      type="simopac.template">Sablon
      Cardiologie</name>
  - <languages>
      <RO>romanian</RO>
      <EN>english</EN>
    </languages>
  - <language name="RO">
      <field idx="1">Nume
        persoana</field>
      <field idx="2">Data nastere</field>
      <field idx="3">Grupa
        sanguina</field>
    </language>
  - <language name="EN">
      <field idx="1">Person name</field>
      <field idx="2">Birth date</field>
      <field idx="3">Blood type</field>
    </language>
  </grammar>
```

Figure 4. SIMOPAC – CIP sheet.

The access to the template is automatically performed through the add-on module that is downloadable from the official site of the SIMOPAC system. The URL is indicated on the printed label of the RFID tag (see figure 5). After being downloaded and lunched, the add-on module will perform the following actions:

- tries to find an RFID reader recognized by the system;
- if such a reader has been found, the add-on module accesses the SIMOPAC's database and downloads the template and its translation;
- based on this information and using the localizing function, the add-on displays the translated template filled with all data extracted from the patient's CIP (local RFID tag);
- after patient investigation, the add-on module sends all the results/findings to the logs' area of the SIMOPAC server.

Figure 5. An example of printed label of a patient S CIP.

The filling-in of the patient's CIP sheet, along with the creation/administration of the template(s) is the treating doctor responsibility. If the medical unit does not use such an EMR system, it is still possible to use the SIMOPAC system, but without the facilities obtained from an EMR system (e.g.: direct import of patients' related data).

IV. DATA COMPRESSION ON RFID TAGS

Generally, the memory space on RFID tags is limited to about 1-2 Kbytes. Thus, an efficient data compression method is needed when working with large amount of data. In order to reduce the amount of memory needed to store the structured information on RFID tags, we have designed and developed several techniques of data representation, as follows:

- representation of Floating point/Integer numbers on subintervals *[a, b]*, with step specified. This achieves a reduction in the number of bits needed for representation;
- representation of Date, Time and DateTime values by setting the startup date/time value;
- specifying the list of possible values for those fields that uses a small set of values;
- Huffman encoding of those fields that frequently use the same numerical values.

When representing numerical values on subintervals, the template will store some additional information, as a 3-tuple *(left borderline, number of values, [step])*. If the distance between two consecutive values is different from 1, then it must be specified in the template, under the optional section *[step]* (see figure 6).

Field name	Field type	Left	Dim	Step
weight	INT	48	128	1

Figure 6. Internal representation for floating point/integer numbers.

When working with a Date field, the user can specify (in the template) the date from which the actual encoding within that field begins. Thus, the value 0000 corresponds to the start date. The start date will be specified as a 3-tuple *(year, [month] [day])*. As it can be seen, only the *year* is mandatory. When *month* is missing, it is assumed to be January. When *day* is missing it is assumed to be the first day of the month. The value stored in such a field represents the number of days elapsed from the start date (see figure 7). Time fields will be treated in a similar manner. The value stored in such a field represents the number of seconds elapsed from the start date (see figure 8).

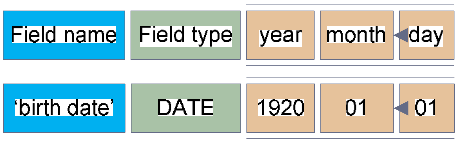

Figure. 7. Internal representation of data values.

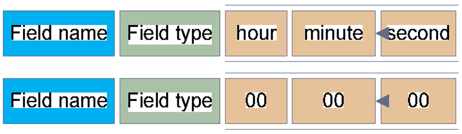

Figure. 8. Internal representation of time values.

Huffman coding, a variable-length coding method, was adopted to allow the data organisation on the RFID tag with a substantial compression ratio. Thus, certain fields encode information such as "diseases" and some of them may occur more often on patients' tags than others. Figure 9 presents an example of such a Huffman coding tree.

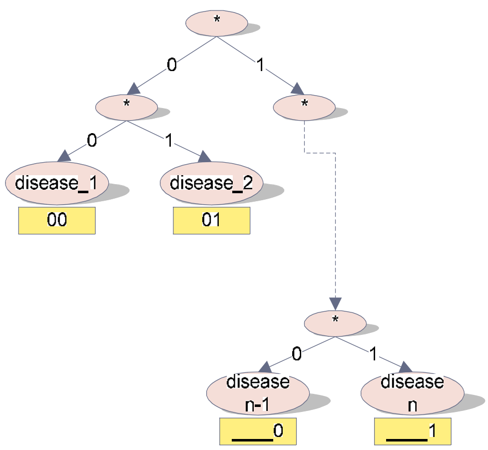

Figure. 9. Coding tree.

V. CONCLUSION

The proposed system provides an interface to different areas of healthcare, such as: emergency services, medical analysis services, hospital services, family medicine services, etc.

When the proposed system interacts with another full EMR system, the integration will be optimal. The HL7 server we have designed and developed can be used to obtain the EMR of a patient that was identified on the base of his RFID tag. Clinical data can be acquired from different servers and applications. In addition, any non-HL7 application can connect to our HL7 server and request data about a patient. Our system is able to integrate and exchange information with other HL7 and even non-HL7 based clinical applications already developed by other companies or organizations.

Through the use of tag templates that can be translated into several foreign languages our system facilitates the cooperation between medical units from different countries in order to assure a good care for a patient from another country.

Through the use of the RFID technology, the system we have developed is able to reduce medical mistakes, improve the patients' overall safety and enhance the quality of medical services in hospitals and other medical institutions. For example, the risk of administrating wrong medication in case of an emergency is highly reduced.

Our future research will focus on the development of various software modules that will use the medical information collected via RFID to optimize the patients' treatment process.

VI. ACKNOWLEDGMENTS

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