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ORIGINAL PAPER

Application of RFID Technology in Patient Tracking and Medication Traceability in Emergency Care

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Abstract One of the most important factors that directly affects the quality of health care is patient safety. Minimize the occurrence of adverse events is one of the main challenges for health professionals. This requires continuous tracking of the patient by different areas and services, a process known as traceability and proper patient identification and medication prescribed. This article presents an information system for patient tracking and drugs developed for the Emergency Department of Hospital A Coruña. The systems use RFID technology to perform various tasks: (1) locate patients in different areas; (2) measure patient care times and waiting times; (3) identify unitary doses of medication; and (4) ensure the correct matching between the patient and the medication prescribed by the doctor. The hardware infrastructure as well as the optimal configuration of devices interconnected via a wireless network was determined by conducting a detailed coverage study. To support all the functionality needed, specific tools were designed and integrated with proprietary software applications. The RFID system was evaluated positively by staff from different professional profiles involved in its development or subsequent implementation.

Keywords RFID · Patient traceability · Adverse events · Medical information systems

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Introduction

Patient safety is one of the factors in the state of quality of health services and is considered a priority in health care. Assuring this safety is a task that is more and more complicated and which entails potential risks with no one method being capable of guaranteeing a total absence of errors. It has to be pointed out that in health care tasks, factors inherent to surroundings are combined with human behavior/actions.

Nowadays, one of the main worries in maintaining a high level of safety in health care environments is to closely follow the patient throughout their stay in a hospital, i.e., from their arrival until they are discharged, registering both waiting and care times in each of the areas subject to control as well as prescribed and administered pharmaceuticals. This process is known as patient traceability and is one of the means that can contribute to guarantee the patient's own safety.

The concept of traceability is normally associated with production and distribution processes. The Spanish Royal Academy Dictionary defines it as the possibility of identifying the origin and the different stages of a production and distribution process of consumer goods, as well as a documentary recording of all these stages. Such a concept can be perfectly applied to a medical environment in the aforementioned sense. It is especially interesting in Emergency Services that deal with a large number of patients per day whose stay at

the healthcare centre and model of administering medication tends to be restricted to short periods of time. The prime objective is to identify and locate patients at all times and inform relatives/careers in real time of their clinical situation. No less important would be its application in the prescribing and administration process of pharmaceuticals.

The implementation of patient traceability processes into hospital information systems should not suppose a substantial change to work methods of healthcare personnel nor an added inconvenience to patients. The biggest benefit to be gained by the traceability application to hospitalised patients is to largely reduce the occurrence of what are called adverse events. This is any situation causing harm occurring during the treatment process that does not originate in the "base" illness of the patient and can result in significant harm or even death. In previous studies, 38 % of adverse events appear during the prescription / validation / dispensation / administration of medication to the patient [5]. This process, which involves all types of medical personnel, is broken down into various tasks: the doctor prescribes the medication, the pharmacist checks and dispenses it, and finally the nursing staff administers it to the patient (Fig. 1).

The current importance of adverse events is shown in the appearance of studies at an international level dedicated to this subject [2, 3, 4]. In their book "To Err is Human" [1], Kohn et al. conclude that mortality attributed to adverse events is the third largest cause of death in the USA and that there is a one in eight million probability of risk of death in an air accident while the mortality rate is one in every 550 hospitalisations. Further studies show that the situation repeats itself in countries such as Canada, New Zealand etc. Despite this worldwide interest, there are few studies in Spain on the subject. The Estudio Nacional sobre los Efectos Adversos [5] (National Study on Adverse Effects), having analysed a sample of 5624 clinical cases in 24 Spanish hospitals, quantifies the proportion of events directly related to medical assistance as an 8.4 %. Patients from emergency observation units or short stay patients were excluded from this study. The EVADUR [6] report, concentrating on emergency services units in Spanish hospitals, analysed a sample of 3854 patients, of which 462 (12 %) presented at least 1 incident. Of those, 44 (1.1 %) were incidents that didn't affect the patients, 184 (4.8 %) affected but caused no harm, 277 (7.2 %) negatively influenced their health and 217 (43 %) incidents were detected in the patient tracking.

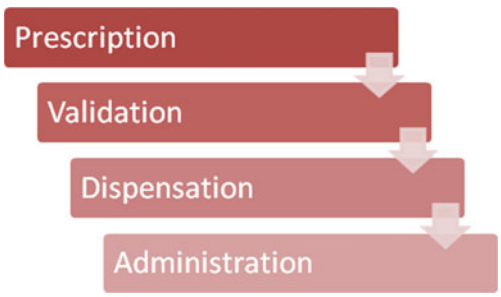

Fig. 1 Process of prescription/validation/dispensation/administration of medication to the patient

This growing concern has motivated the development of patient traceability systems that use new, clean, non-invasive technologies and that are integrated into the daily routine of healthcare personnel. Radio Frequency Identification (RFID) technology is the solution being adopted in the area of healthcare and in many others. Currently there are projects concerning RFID application in a healthcare environment for patient tracking and medication [7–9, 17–28], that have managed to integrate into daily clinical practice in hospitals but the majority have only been pilot schemes [10–14]. It is important to highlight that few solutions combine both tasks at the same time. As such, taking into account the importance for society to assure quality in a hospital environment, it seems essential to make the most of computerised technologies to viably implement said RFID technology. In this sense, this article presents an RFID technology application for patient and medication traceability in the A Coruña Hospital Emergency Service (CHUAC). Two key aspects distinguish this RFID system to other systems built:

- With regard to functionality, the system obtains the patient traceability from its location and minimizes the occurrence of adverse events by the unequivocal identification of the patient, the unit dose and the binomial "patient-medication" prescribed.
- With regard to technology, the system handles labels "WIFI-RFID" both active and passive, configured to operate at a frequency to avoid misidentification of patients or unit doses of the drugs while ensuring a precise location of objects / persons.

RFID technology

The diversity in characteristics of components with RFID technology allows for the building of a large number of different systems. However, the working method is the same for all: a tag attached to the object or person you wish to identify emits a radiofrequency signal with identifying information, a reader receives it and sends the data to a computer application which processes it. The process is shown in schematic Fig. 2.

The readers can be fixed or mobile like ones found integrated into PDA[1] devices. The labels can be active if they have their own energy source for transmitting, passive, if they use the reader as their energy source or semi-active if

[1] Pocket computer (Personal Digital Assistant)

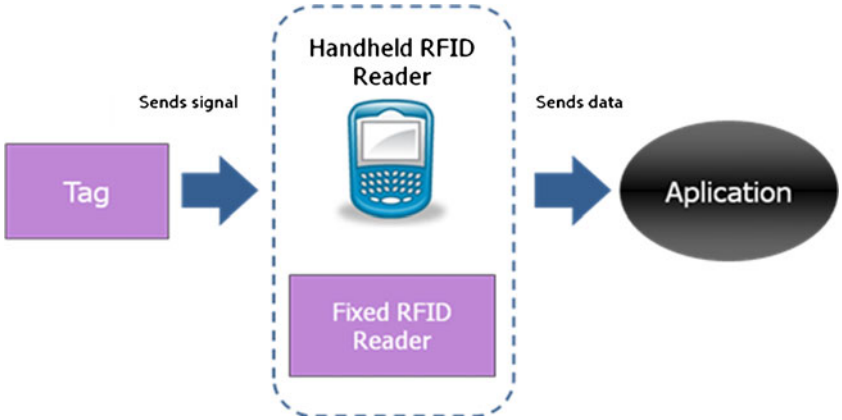

Fig. 2 RFID label data capturing

their own energy source is not used for transmissions but for feeding the internal circuitry of its microchip.

The success of RFID technology mainly consists of the large capacity that the labels have to store identifying information of the subjects or objects that carry them. Furthermore, this data can be coded and stored according to well known standards. The labels are not damaged by use, withstand extreme temperatures and hundreds can be read or written to simultaneously without the need for direct contact with the reader. These properties make RFID an ideal technology for use in traceability systems in healthcare environments, be it large scale like in hospital centers or small scale like in units or services, in our case, Emergency services.

Application scenario

The CHUAC Emergency Service is characterised by a large rotation of patients, short time spent in the service and with a pattern of short term medication due to the characteristics of the unit. All of this emphasizes the need to improve the identification of patients and of the pharmaceutical treatments with the aim of: 1) avoiding errors that cause safety problems for patients and 2) improving treatment follow-up when there are medical personnel shift changes, the patients move to other hospital units or other areas within the Emergency Services unit itself.

Currently, personnel responsible for the service have detected possible improvements in the following areas: (1) identification of medication (lot number, expiry etc), (2) validation and electronic recording of pharmaceutical treatment, (3) manual checking of agreement between prescribed medication and the patient, and (4) recording the administering of the medication. During the development of these activities, errors in identifying patients, stock management of medications, or even the prescription and/or administering of pharmaceutical treatments can appear. Another concern is that the system does not allow for alarm alerts in the prescription/dispensation/administering process that would assist in a safe use of medicine.

Development

The process of constructing a software system for the traceability of patients and medication based on RFID technology for the Emergency Service of the CHUAC followed a classic cascade cycle with feedback throughout the phases of analysis, design, implementation and testing. The project development cost, not including the testing phase, has been of 3840 h/man. The following is a detailed description of the tasks developed in each of the phases.

Analysis phase

The main objective of this phase is to obtain documentation about the operation of the workflow of prescription/validation/dispensation/administering of medication. With this, weak spots in the flow that could endanger patient safety and are conducive to the appearance of adverse events could be detected [15].

The analysis methodology is principally based on the carrying out of successive meetings with healthcare professionals from the Emergency and Pharmacy services in order to acquire existing knowledge (Fig. 3). This process is progressive and as a result of each of the successive iterations,

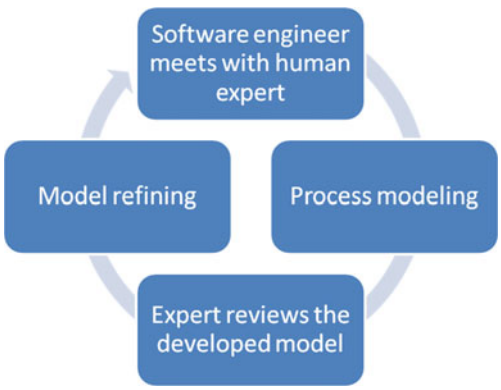

Fig. 3 Methodology of analysis of process of prescription-validation-dispensation-administration of medication to patients

diagrams obtained are presented to experts for their review and critique. A software engineer builds more refined models at each iteration stage, thus playing an active role, not only receiving information but also helping healthcare professionals to discover and decode the knowledge they have.

Figure 4 shows an example of the modeling of the workflow of administering medication to a patient.

As a result of the analysis phase, 17 models were built allowing visual detection of the following critical points in the clinical routine:

- In the prescription, the transcription of the prescribed medication, the recommended doses and their administration route.

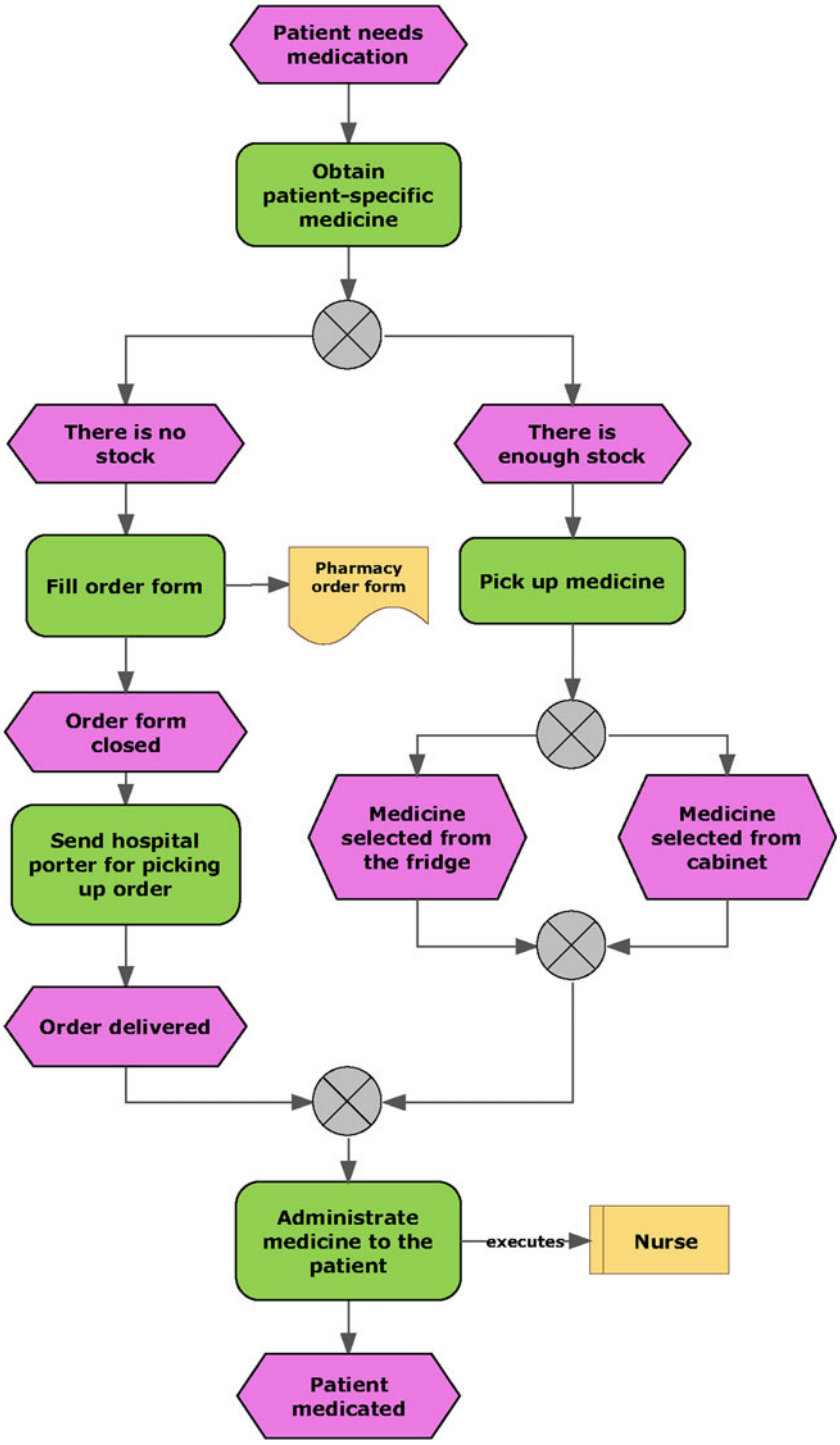

Fig. 4 Example of modeling of a workflow

- In the dispensation, the reception and correct location of medicine in adequate storage conditions, its replenishment in preparation areas and the elaboration of unitary doses for patients
- In the administration, checking that the medication is in perfect conditions and that the dose, the means and administration route to be used are correct.

Design phase

One of the most critical points in the development of a system is the defining of the hardware and software components that are to form its technical architecture. In order to achieve this, sufficient knowledge of the technology is needed to successfully make decisions regarding characteristics of RFID components such as, for example, their material, size, form, frequency of use, functionalities, etc. In this sense, a extensive market research was carried out to select the most suitable components, asking about 150 national and international companies specialized in RFID. In [16] the authors analysed different technical architectures currently available to design an RFID system to avoid the appearance of adverse effects and to obtain patient traceability, and advantages and disadvantages of each approach being considered were detailed. The proposed architecture divided the RFID system into two subsystems, one dedicated to obtaining patient traceability and the other to prevent the appearance of adverse effects.

Subsystem of patient traceability

Hardware components are shown in Table 1.

Figure 5 shows WIFI active tag, an access point and a passive RFID tag chosen for the system, all integrated into a wireless network.

Table 1 Subsystem of patient traceability: hardware components

Component	Manufacturer	Cost per unit	Task
Active tag with WIFI communication technology	Aeroscout	41€	To broadcast a signal for locating patients
Wireless access point (plus installation)	Cisco, Aironet 1130 AG model	1,000€	To interconnect WIFI communication devices and to serve as a reference point to calculate location of the patient.
Passive tag	Philips, size 15×15 mm and ISO 15693 approved model	0.3€	To broadcast RFID signal with patient identification data.

Software components are as follows:

- Tag Management Suite (TMS): an application allowing the activation/deactivation and configuration of the tags.
- Cisco MSE Locator 3350: localisation engine used by manufacturer Aeroscout which calculates the position of the patients.
- Mobile View (MV): Application to define, eliminate or modify characteristics of the patients or tags under control, to obtain patient traceability and define alerts, along with many other functionalities. At the same time, it is an interface for the localisation engine as it allows for real-time locating of the patients.
- TraPa: Application to link the history number (NHC)[2] of a patient with the MAC[3] address of the tag that they possess. It integrates the patient information stored in the hospital system with the data available in Mobile View.

Subsystem for prevention of adverse events

Hardware components are shown in Table 2.

Figure 6 shows labeled medication in a small store room of the Emergency Services (the blue arrows show examples of passive RFID tags with foam padding).

Figure 7 shows the various RFID components mentioned.

Software components are as follows:

- Recording of labels: Application to record passive RFID tags with patient Clinical History Number (NHC) or medication details (code, name, lot number, expiry date, application route and advice).
- Medication management: PDA application for nursing staff to check the correct administering of a medication to a patient.
- Medication prescription: Application that allows doctors to electronically prescribe medication to a patient.

Implementation phase

The hardware infrastructure of the RFID system, amongst other components, is made up of access points. Through them the location of a patient can be pinpointed with a higher or lower degree of accuracy. One of the most influential factors in the accuracy of the localisation obtained by any system based on RFID technology is the establishing of an optimum number of access points and their physical

[2] The patient history number identifies the patient in a medical facility and permits the associating of the same to all documents generated during treatment procedures.

[3] MAC (Media Access Control) is an identifier corresponding solely to a card or network device. It is also know as the physical address and is unique to each device.

Fig. 5 WIFI active tag, an access point and a passive RFID tag

distribution. It has to be noted that determining the value of these two parameters is no trivial task and as such, a study of coverage in the area of interest should be undertaken prior to implementation of this technology.

For our needs, this analysis is mainly carried out in two stages:

- In the first stage, a design of the wireless network was simulated, in this case with Ekahau Site Survey 2.1 application. Factors that could diminish the WIFI signal, such as for example, the existence of elevators, the type of construction material of the walls, if rooms are diaphanous or not, etc., are established.
- In the second stage, an onsite checking of the results obtained in the first stage, including the checking of elements identified as interfering with signals was made. At the same time, new elements were added that were found to diminish WIFI signal at the time of installation and, later during the configuration of access points.

Table 2 Subsystem for prevention of adverse events: hardware components

Component	Manufacturer	Cost per unit	Task
Passive tag	Philips, with foam padding, size 15×15 mm and ISO 15693 approved model	0.4€	To broadcast RFID signal for the identification of unitary doses of medication
PDA	HP	500€	To check administration of the medication to the patient is as prescribed by the doctor.
RFID reader	Socket	200€	To read information on the passive tag attached to the unitary dose of medication or the patient tag.
Printer	Toshiba	3,000€	To print/record onto passive tags.

Once this coverage study was completed, it was concluded that a WIFI network of 14 access points strategically located with a distance between them of approximately 40 m was needed. Figure 8 shows the location of these devices (represented in green) in the CHUAC Emergency Service, as well as three areas that have better coverage (represented with a white background). The shaded areas on the map indicate that blocked zones have been defined to prevent the localisation engine placing a patient there as they are not medical areas.

The software infrastructure of the RFID system is made up of various applications that, taking into account their nature, can be placed into two large groups:

- Applications owned by RFID component manufacturers: Tag Management Suite, Mobile View and MSE Locator 3350 by Cisco.
- In-house developed applications: TraPa, Recording of passive labels, Checking of administration of medication to a patient and Electronic prescription.

The development of the software has been carried out following standards defined by the Commission of Technological Architectures of the Galician Health Service (SERGAS). These standards define documents for analysis and software development, specifies which multilayered architectures and programming languages are supported, and which analysis and development tools are permitted for the

Fig. 6 Labelled medication in the Emergence Services

Fig. 7 PDA, RFID /barcode reader and printer

creation of information systems in any agency of the Galician Ministry of Health. It has to be pointed out that the object of these standards is to facilitate lifecycle processes and although based on METRICA V.3,[4] they have been adapted to the structure of the organisation.

Testing phase

Having completed the development of the RFID system, a testing phase is needed to check the proper operation of the required software applications and hardware devices. For this, a simulation is run of the route taken by a group of similar patients (suffering from a common pathology) through different areas of the Emergency Service (admission, triage, filtering, observation, critical care, etc.) and the prescription and administering of pharmaceuticals by the clinic personnel.

Preparation

For the development of a pilot test a number of essential hardware devices were chosen. In particular, the following were made use of:

- 1800 Passive RFID tags with and without insulating material
- 200 Active Aeroscout WIFI tags
- 400 Plastic bags
- 400 tamper-proof bracelets
- 2 PDAs
- 2 RFID readers
- 2 Printers

Prior to use, the tags need a process of configuration and fine-tuning of the working parameters, such as for example, the number of channels through which they will transmit, the retransmission period or the movement sensor. All this can provide large benefits to the system, for example, a notable saving in battery usage in the tag.

The tags are inserted into a sort of tamper-proof bracelets that will later be placed on each patient. As they are not sterilisable, they are introduced into plastic bags that allow them to be reused and they are all deposited into container ready for use.

Separately, all unitary doses of medication destined for the Emergency Service are labelled with passive tags. These tags contain essential information about the medication (code, name, expiry date, route and optionally, administering guidelines).

Development

The route of a patient through the Emergency Service starts with a registration of their personal details in the Admission department. This department prints a passive tag with the NHC of the patient that will irrefutably identify them throughout their hospital stay. Next, at the Triage area, the seriousness of their condition is evaluated. Nursing staff carry out the following actions:

- Attach a passive RFID tag to the patient bracelet
- Link the NHC of the patient and the MAC address of an active WIFI tag using the computer application
- Check that the RFID system correctly detects the patient location and that their personal and clinical details appear on the application
- Attach the tag onto the patients' bracelet.

Once this process is finished, the patient will go through various diagnostic, radiological, surgical and analytical tests. At each stage, clinical personnel can physically locate in real-time or consult the traceability for a particular period in time. Nursing staff will also be able to monitor electronic prescribed medication and check that it coincides with what is to be administered, know if it has already been administered, obtain additional information about the medication or find the expiry date.

[4] Methodology created by the Spanish Ministry of Public Administration for the systematization of activities that support the lifecycle of software.

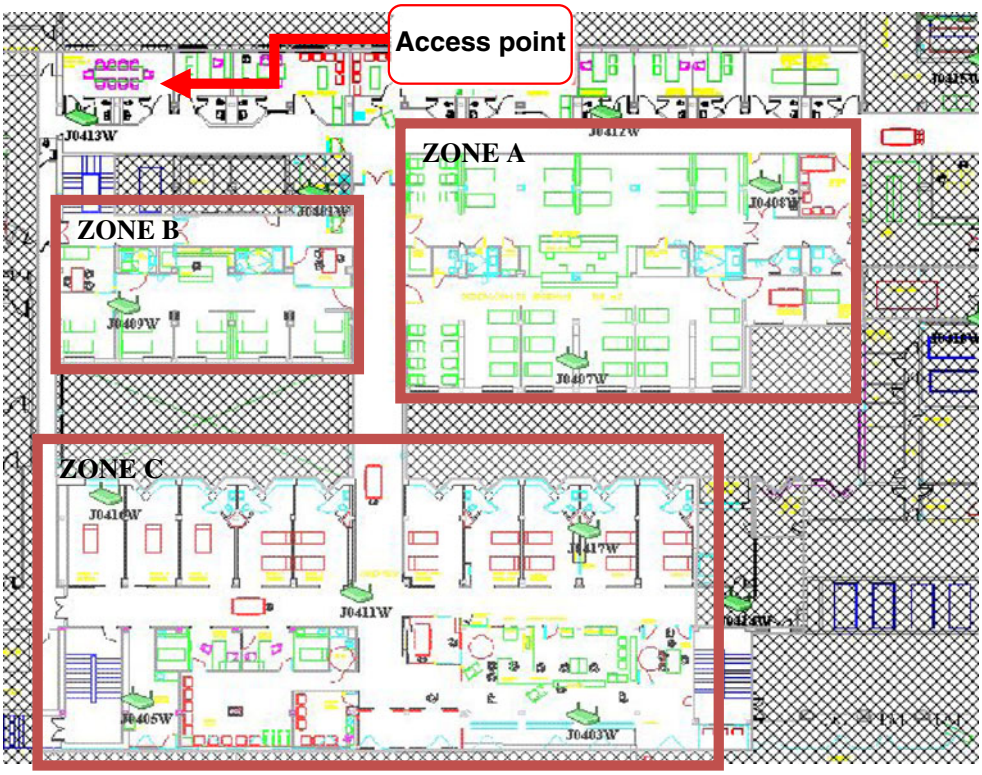

Fig. 8 Coverage in the emergency service

Evaluation

Upon completion of the testing phase, the RFID system was evaluated in order to gauge the satisfaction level of the medical and technical staff involved. The data analysis process has been carried out in two phases: first aimed at discovering the overall system behavior from the point of view of each professional profile and second aimed to get the score of the system in each of the thematic groups of the questions of a set of questionnaires. This process aimed to study possible weaknesses in the system and to take measures to improve it. As such, a series of questionnaires were drawn up for all personnel involved—doctors, nurses, pharmacists and computer technicians—with questions concerning the same subjects. Each question valued various aspects of the system using a 5 point Likert type scale according to level of satisfaction, where 0 equals a total disagreement and 5 a total agreement. The evaluation of these answers was carried out for each professional profile and for each subject section.

Questionnaire assessment

The assessment process of the questionnaires was as follows:

- Each response by the professional on a numerical scale of 1 to 5 is valued with a score between 0 and 1 point.
- Each subject section is valued with the mean score assigned to the questions of the section. This value indicates the global level of agreement of the professional.
- The global value of the questionnaire is calculated based on the weighted average values of each section. Specifically, a larger weight is given to the sections that make reference to the subjective perception of how the system was implemented, a common aspect in all the professional profiles. Next, come subjects in which the professional would have more experience and finally, the remaining sections.

Figure 9 shows the average results obtained for the different professional categories.

The results obtained in all the questionnaires were always close to one and therefore, it can be said that professionals are highly satisfied with the system. Specifically, doctors and nursing staff valued the RFID system most highly closely followed by the information systems manager. By way of contrast, pharmacy auxiliary staff was the group of healthcare professionals that valued the system the lowest. This is mainly due to their scepticism regarding the implementation of the RFID system into clinical practice with sufficient guarantees and the difficulties experienced during the testing of the automatic labeling of unitary doses of medication.

Evaluation of subject areas

The evaluation process of the different subject areas of the questionnaires was the following:

- Each answer from the healthcare professional on a numerical scale from 1 to 5 is valued with a score between 0 and 1 point.

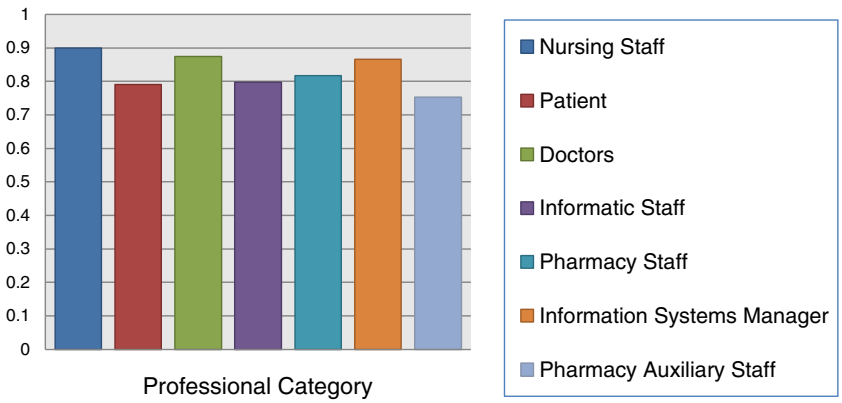

Fig. 9 Results of the global evaluation of the system

- Each subject section is valued with the mean score assigned to the questions of the section. This value indicates the global level of agreement of the professional.
- The global value of agreement between all the professionals with respect to a subject section is the weighted mean of the average values of that section calculated for each professional category. In specific themes, for example the viability of the RFID system, the individual evaluation of each professional will be weighted depending on their greater or lesser involvement, their competence or their professional experience.

Figure 10 shows the results obtained depending on the different subject sections.

It is important to highlight that all the subject sections are valued fairly highly by professionals but the highest values relate to a positive global opinion of the RFID system of 0,958. From this, one can deduce that RFID system complies fully with the expectations and needs of the computer and healthcare staff of the CHUAC.

In contrast, the lowest score was for the subject of viability of implementing the system into clinical practice. Having examined the individual replies and the comments of the professional staff, it can be concluded that this is fundamentally due to the lack of automation of labeling of medication and the current prices of labels for the unitary doses of medication, only justified in the case of labeling of expensive medication or of medication that is highly aggressive to patients.

Conclusions

This article presents the development of a computerised system using RFID technology to obtain patient and medication traceability in the emergency services of a hospital. The main aim has been to minimise and prevent, in as much as is possible, the appearance of adverse events caused by the act of medical assistance itself and resulting in significant harm to the patient.

The information system, developed by the Servicio de Urgencias of the Hospital A Coruña (A Coruña Hospital Emergency Service), satisfies the following demands: (1) locate and identify the patient within 1 to 4 meters; (2) identify unitary doses of medication; and (3) assure the correct association between the patient and the medication prescribed by the doctor.

The global system is divided into two traceability subsystems, one whose objective is the patients and the other devoted to medication. Via different types of RFID tags, active in the case of patients and passive in the case of medication, the

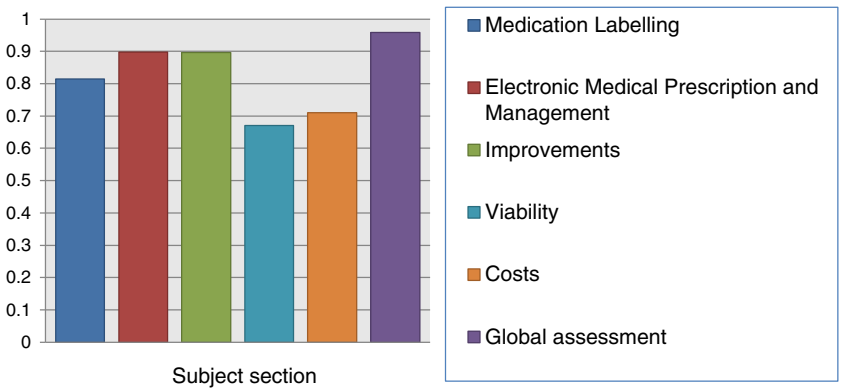

Fig. 10 Results of the evaluation of questionnaire subjects

system locates a patient in a specific area and correctly identifies the unitary dose of medication prescribed by the doctor. Radiofrequency signals emitted by these devices are picked up by various access points on a wireless network installed in the department. The number and distribution of these access points was determined by corresponding coverage study.

The system was positively evaluated by medical personnel who assure that its introduction into clinical routine would as such have a very high success rate. Add to this the expected benefits to Emergency and Pharmacy departments in clinical and management aspects such as a lowering of the number of adverse events in the treatment and medication processes or the measuring of patient waiting and treatment times.

The development and implementation of the system requires a high economic investment in terms of hardware components—tags, readers and access points—proportional to the size of the working area and to the number of subjects—patients or medication—subject to traceability. No less expensive are the applications owned by manufacturers for the configuration of components, the tracking of objects and the analysis of data. Other costs generated by the use of the system are the staff needed to manually label the unitary doses of medication though they are acceptable in the case of expensive medication and of medication that is highly aggressive to the patient.

Following the corresponding testing phase, and with a view to a practical clinical use, the need to make small changes in current working clinical procedures has been detected. Though they were not an obstacle, they did however make it necessary to have a period of adjustment for healthcare professionals.

A number of difficulties have arisen in the development of this project which we will discuss. First, the task of extracting and decompile the expertise to develop a set of models of the patient care process. Clearly, the acquisition of expertise is a very laborious and complex task, and much more in the medical setting. Moreover, in this case, the resulting models cannot be generalized to other hospitals or services. Second, the study of current RFID technology. There is not enough documentation on how to develop such projects by the RFID component suppliers. And third, the optimal configuration of patient traceability subsystem, highly dependent on the care unit or hospital. Several variables such as the distribution of zones or building materials that affect the accuracy of the location of the patient and the strategic distribution of access points. This determines that most of the system has to be designed and developed specifically for the particular environment where the system will be put into production.

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