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An Online-Processing Critical Patient Monitoring System- An Interoperability Overview

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Abstract. With the increasing expansion of Healthcare Information Systems, platforms for interoperability and monitoring systems have become vital tools to support the clinical practice. Under this scenario, the creation of knowledge in real-time to feed decision support tools is essential. INTCare is one the solutions that adapts the way that information is gathered and processed in order to obtain that knowledge. Once new information arrives, it triggers the ETL (extract, transform, load) procces enabling real-time processes like data mining. However, the system fails in recognize if a patient is absent from bed or not. This problem led to the development of the Patient Localization and Management System (PaLMS), a Radio-Frequency IDentification (RFID) serving as localization and monitoring system.

This paper describes the PaLMS implementation as well as an intelligent Multi-Agent System for the integration of PaLMS into the hospital platform for interoperability named AIDA (Agency for Integration, Diffusion and Archive of Medical Information).

At the end, an usability evaluation was performed in order to assess the level of usability of the existing systems at *Centro Hospitalar do Porto*, such as the PaLMS, the INTCare and the AIDA platform. In terms of usability, the system got very positive evalutions, despite the fact some medical staff argued that they lose too much time elaborating the records.

Keywords: Ambient Intelligence Monitoring Systems, Intensive Care Unit, Multi-Agent Systems, RFID, Usability.

1. Introduction

The constant demand to improve the quality of the patient care and the patient safety in healthcare organizations boosted the adoption of Information and Communication Technologies (ICT). Along with the computerization of hospitals a new stage began, with new concepts, paradigms and methodologies to solve problems in this domain of knowledge. Despite the growth of the Healthcare Information Systems (HIS), the tools for data processing are not sufficient and new technologies should be implemented in order to support a new way of envisaging the future hospital.

The introduction of sensors and networked devices, in order to support the health professionals in the decision making process, has been increasingly frequent. This leads to the concept of Ambient Intelligence (AmI), which is considered a new paradigm that introduces new means of communication among humans, machines and the surrounding environment [44]. Due to the complexity and the heterogeneity of an hospital environment, it is expected a high success of AmI technology [41]. Thus the *Centro Hospitalar* *do Porto* (CHP) working side by side with a research group from the Minho University have been developing several solutions based on AmI [41,42,31,25,28].

The INTCare [41] is one of these solutions and it constitutes an Intelligent Decision Support System (IDSS) aiming at the real-time monitoring of patients in the Intensive Care Unit (ICU). After the implementation of this system in the ICU of the CHP, two problems have been detected. The first one was the abesence of automatic patients' identification in the INTCare monitors, once this process is performed by nurses on a manual basis inserting the Patient ID in the bed monitors.

Consequently, the sensors collected the vital signs of the patient but his identification process was not done, leading to a loss of data that potentially might be important for the decision support process. The second problem was whenever a patient leaves his bed in the ICU (for example to undergo an examination) the sensors that are collecting vital signs were not disabled, invalidating the data collection. These problems affect the quality of information, introducing incomplete or invalid information into the data set.

This paper presents an architecture to solve reported problems in order to avoid the existence of wrong data in INTCare. All the development and implementation of the Patient Localization and Management System (PaLMS) was performed with close communication with healthcare professional in real environment and using real data. This system of automatic identification of the patient's presence is based a Radio-Frequency Identification (RFID) technology, intelligent agents and Health Level Seven (HL7) standards. However, it is important that the components of the Patient Management System (PMS), the INTCare, the alert system and the bed monitoring system are fully capable of communicating with each other. For this, these systems were integrated into the hospital platform for interoperability - Agency for Integration, Diffusion and Archive of Medical Information (AIDA) [30]. The solution presented in this paper is considered universal once it can be implemented in different locations or environments. Thats accomplished through the use of RFID independent technology together with the database storage of information. The PaLMS enables, with high acuity, associating the patient and the data collected without introducing extra information, just by crossing information between the acquisition system (sensors) and the identification system (PaLMS).

Furthermore, this article presents an usability evaluation of the systems implemented at the CHP facilities. From this evaluation it was possible to find out the usability of the hospital systems in order to identify configurations and design changes that could improve the usability of the systems. It was also possible to define the steps to be taken in a way to address the identified issues, aiming to give the systems a better usability.

2. Background

2.1. Ambient Intelligence

Ambient Intelligence (AmI) is considered a new paradigm based on intelligent systems, which has been reconfiguring the communication among the human beings, the machines and the surrounding environment. In order to achieve the AmI, it is fundamental to enrich an environment with technology, more specifically with sensors and network-connected devices. These digital environments are able to identify people's presence and to understand the context where they are inserted. In this way, this type of environment is sensitive, adaptive and responsive to the people's needs, habits, gestures and emotions [10].

With the properties described above, the AmI becomes powerful in the healthcare industry where the demand for new technologies is increasing and its implementation improves significantly the quality of the healthcare services delivered. There are several applications that can be applied in this context in a hospital. These apps enable to increment the safety of the patients and professionals, to follow the patients' evolution after a surgical intervention, to monitor the patients and their movements in the hospital, to track equipments or health professionals (in order to locate them quickly, saving time), short-term monitoring (home healthcare monitoring), long-term monitoring (nursing home) and consequently to personalize the healthcare monitoring. Through these monitoring processes, these applications can also improve the prevention, allowing emergency interventions timely and efficiently and improving the patients' transportation and treatment. All these applications contribute to a better management of the hospital and the quality of the service delivered [52,7,59].

2.2. Radio-Frequency Identification

The Radio-Frequency Identification (RFID) is a technology that has been increasing in popularity in the AmI area. Therefore, its use in healthcare is a reality, performing an important role in monitoring systems. The RFID in hospital environment are used in patients tracking and identification with impressive accuracy [54,15].

The RFID equipment is composed by three main components: the transponder (tag), the antenna and the reader (Figure 1). Generally the tags are cards or bracelets containing integrated circuits that store information by an Electronic Product Code (EPC). This code is exclusive and distinguishable from any other EPC. So, it is possible to identify people or products by this code. The antennas emit radio-frequency waves, creating a reading field that enables them to collect the tag information from several meters away [2].

There are two types of tags: passive and actives. A passive tag requires no power supply and it is activated when it is in a reading field provided by an antenna. The size of this type of tag is usually small, providing a high degree of portability. On the downside, a passive tag has less detection range than an active tag and it is more susceptible to deteriorate due to its small size. An active tag has an internal battery, which enables a bigger detection range compared to the passive tags. Besides that, this type of tag has an antenna that enables the transmission of its own signal, independent of the energy provided by the antenna, unlike the passive tags. The active tags are more expensive and bigger than the passive ones and it is necessary to replace the internal battery periodically [2].

The readers are devices that, after exchanging information with the antennas, are capable of read, interpret and write in the RFID tags, and also exchange information with a computer or Information System in order to process the information collected [2].

2.3. Similar Implementations

The RFID technology has some features that facilitate the automation and simplify the identification processes of patients, professionals and objects. It also makes easy their localization and the processing of data related to them in a secure and fast way. All these advantages make the RFID an emerging technology for the healthcare as a part of the application of the AmI in health units such as hospitals[9].

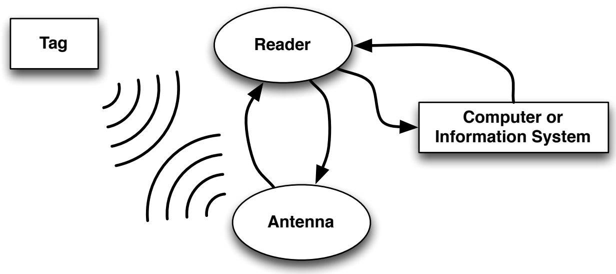


Fig. 1. Functioning of an RFID system with one **antenna** and one **tag**

There are some advantages with the implementation of this kind of technology in healthcare area [14]:

- The increase of security of the patients through their monitoring;
- The acceleration of processes by their localization quickly and efficiently;
- A better manage of the health professionals' time because they need to worry less about issues related to the search of patients and medical staff, buying time for provision of healthcare to the patients;
- The identification of surgical materials, medication and blood bags to facilitate and to make more efficient the surgical processes and the administration of drugs.

All these aspects increase the efficiency in the stocks management and improve the quality of the healthcare delivered to the patient at healthcare facilities. They aid also the healthcare professionals in the accomplishment of their tasks [55].

There are a lot works about the use of the RFID technology in healthcare environments. Vilamovska et al.[53] present a bibliographic study wherein the main goal of this technology is the localization of people and objects, despite they are implemented in different contexts. For example, there is a project to identify and to monitor newborn babies that aims to avoid identification mistakes, exchanges and abnormal body temperatures [8]. The identification and localization of objects like blood bags [51], endoscopes [57] and objects of high value [3] have been also studied. In addition, there are already a system for simulating the trajectory of a patient, health professional or medical equipment based on this technology [46]. RFID technology has also been highlighted in this area to support IDSSs [45] and to collect data in real-time about the patient [33].

Nevertheless, there are other technologies that enable the implementation of the AmI. The Wireless Sensor Networks are one example and this technology is already studied and implemented in healthcare environments [43,48]. According to Yang, this combination allows extending the communication process because By adopting a common communication standard, BSN (Body Sensor Networks) can be easily integrated with other WSN devices [58].

2.4. Interoperability and the HL7 Standard

With the growth of health organizations, the information became enormously complex, covering many different types of data. Patient administration, organizational information, clinical data and laboratory/pathology data are different and there is the need to manage the information from several HIS. The interoperability was the subject of several recommendations by the European Commission, considering it an important step towards highest quality and safest care of the patient, health systems, clinical research and healthcare [27].

However, the interoperability issue has been a challenge, there have been several alternatives to achieve it's various levels, meaning the syntactic and semantic interoperability. On the first level examples like Open Database Connectivity (ODBC), message queues, interfaces, and more recently web services introduce new alternatives. At the semantic level the ICD or SNOMED CT codification systems are good examples of work developed. Still, the problem of interoperability remains tricky, especially when it is introduced medical information on these solutions, which is quite complex.

The Health Level Seven (HL7) standard emerges as one of the main solutions when trying to circumvent the previous stated needs [4,24]. The HL7 protocol is a set of standard formats that specify the interfaces for electronically exchanging data between heterogeneous applications in hospital environments. The HL7 began as the main communication protocol, providing syntactic interoperability at the application level. Health Level Seven International is responsible for the creation and update of HL7 standards. This organization is accredited by the American National Standards Institute (ANSI), dedicated to providing a comprehensive framework for the exchange, the integration, sharing and retrieval of health information electronically, which supports the activity clinic and the management, delivery and evaluation of health services [16]. The number seven corresponds to the seventh layer of the communications model of Open Systems Interconnection (OSI)[60].

The purpose of HL7 is centered in the information syntax that is exchanged. The structure and design of this standard define that the data must be transferred through a message, being possible the implementation of HL7 in a client-server architecture [30,32]. The HL7 was developed with the purpose of every event that happens related to health, generates an HL7 event called trigger-event causing the exchange of messages between a pair of applications. When an event occurs in a system compatible with HL7, a HL7 message is prepared by collecting all the necessary data from the underlying application and it is sent to the requesting system [12].

These events may have different origins, can be based on an user request, due to a state transition and based on interactions. In addition, there are several types of messages, which varies depending on the type of request that an application wants to ask or to answer. The four most common types of messages are [49]:

- **Admit Discharge Transfer (ADT)** - provides important information about trigger-events (such as patient admit, discharge, transfer, registration, etc.). They communicate patient demographic and visit information, as well as the reason why the message is being sent. Some of the most important segments in an ADT message are the PID (Patient Identification) segment, the PV1 (Patient Visit) segment, and occasionally the IN1 (Insurance) segment.

- **Order Message (ORM)** - generally is used to transmit information about an order like cancellations, information updates, discontinuation, etc. An order can be defined as a “request for service” that is sent between applications, or in some cases within a single application.
- **Results Message (ORU)** - is sent in response to an ordered test called an ORM, and it contains the results of the test and conditions of the patient. It transmits observations and results such as reports of the clinical laboratory and imaging tests. ORU messages are also sometimes used to register or link to clinical trials, or for medical reporting purposes for drugs and devices.
- **Detail Financial Transaction (DFT)** - describes a financial transaction that is sent to a billing system and it is used for patient accounting purposes. This message might include things like ancillary charges or patient deposits, financial transactions, payment system, among others.

For the work presented in this paper were mainly used messages of the type ADT. The standards HL7 are a universal protocol, enabling the communication between the main Healthcare solutions. Our goal is develop a universal solution and by this fact HL7 was the protocol chosen.

2.5. Multi-Agent Systems

The Multi-Agent Systems (MAS) technology has proven to be very effective in providing interoperability in health organizations utilizing the intelligent agents characteristics such as modularity, scalability and adaptability [37,38,20,23]. Intelligent agents and agent-oriented programming are technologies based on a distributed architecture. These agent-based systems have been changing the conceptual analysis of problems.Some examples are the complexity, the distribution and the lack of interactivity of the systems [26].

Intelligent agents are defined as computational artifacts that demonstrate certain properties enabling them to achieve common objectives as a group (MAS). Intelligent agents are able to act in an autonomous way, without the direct human intervention. Besides that, these artifacts are endowed with reactivity and pro-activity, because they are aware of the environment where they are inserted, acting according to that and they possess intelligent capacities to solve their problems and to achieve their objectives. The social skills are a very relevant property of an intelligent agent, because it allows the interaction among the agents in a MAS. The agents can even change their behaviours according to their interactions, with the purpose of achieving a main objective [26].

2.6. AIDA Platform

Several techniques based on Artificial Intelligence has shown a high potential when introduced into solutions applied in hospital environments. In fact, many of these solutions are already in production in Portuguese health institutions they are mainly centered in the areas of systems integration and decision support systems. The AIDA platform [38] is a successful example of these solutions and it is the central unit of interoperability in several large organizations as the CHP, the *Centro Hospitalar do Tâmega e Sousa*, the *Centro Hospitalar do Alto Ave* and the *Unidade Local de Saúde do Norte Alentejano*.

The Agency for Integration, Diffusion and Archive of Medical Information (AIDA) was designed to assist medical applications. It is a complex system, composed of a network of specialized subsystems understood as intelligent and flexible entities with a level of adjustable autonomy, in this work designated as intelligent agents. These entities are responsible for tasks such as communication between heterogeneous systems, sending and receiving of information (ex: clinical reports, images, data sets, prescriptions, etc.), management and storage of information and responding to requests correctly and timely [26].

The main objective of this platform is to integrate, disseminate and archive large amounts of information derived from heterogeneous sources, such as departments, services, units, computers and medical equipment, solving interoperability problems between hospital heterogenous information systems. In addition, it also provides tools to implement and to facilitate communication with humans through web-based services. This agent-based platform has shown great adaptability, modularity and effectiveness through the use of a basic MAS that has grown according to the particular needs of each institution [26].

3. INTCare System

Following the guidelines of Intensive Medicine a system called INTCare was developed. This system changes the environment, the information system architecture and the way the data is acquired, processed and stored in order to obtain new knowledge essential to the decision making process.

Now, the process of data acquisition and ETL (Extract, Transform, Load) are executed automatically and in real-time whenever new data arrives. Additionally, using online-learning, the entire process of inducing data mining models and computation of clinical data are also realized automatically and in real-time.

INTCare is a Pervasive Intelligent Decision Support System (PIDSS) [41] divided in two modules: one to monitor (insert, validate and confirm) the patient clinical data (e.g. vital signs, therapeutics, and fluid balance, scales and procedures) and other to create new knowledge (predict organ failure, patient outcome, medical scores and occurence of critical events).

INTCare is able to provide automatically and in real-time four different types of knowledge anywhere and anytime [41,42]:

- Probability an organ failure (cardiovascular, hepatic, renal, hematologic and respiratory);
- Probability of patient death;
- Critical events (oxygen saturation, blood pressure, heart rate, respiratory rate and urine output);
- Medical Scores (SAPS (Simplified Acute Physiology Score), SOFA (Sepsis-related Organ Failure Assessment), MEWS (Modified Early Warning Score), TISS 28 (Simplified Therapeutic Intervention Scoring System), Glasgow).

At same time the user is able to analyze the patient evolution during the admission (time comparison) using the vital sign and laboratory results to accomplish that.

Before the fully introduction of INTCare it was necessary overcome some problems. The main one related to the patient identification being a human task instead of an automatic one. In the reality when some patient arrived to their bed the nurses had to identify him in the vital signs monitors. Only after this procedure the data was collected with a patient identification.

When the patient arrives to an ICU the most important is to treat the patient and to put him in the best conditions possible. It is notorious that the nurses do not have time to make a correct identification of the patient in the acquisition system and with that a lot of data was lost.

In order to overcome this problem a RFID system was developed, to automatically identify the patient when he arrives to the bed. This solution allows to have a correct and automatic identification of which patient is in a specific bed without human intervention.

The RFID system is associated to bedside monitors (e.g. vital signs) and uses some procedures it is able to identify correctly the patient in the HL7 message (messages which contains vital signs and patient identification (PID segment)). The communication between the RFID system and the patient is ensured by the antenna present near the bed and a RFID tag put in the patient arm or leg. This tag contains a set of patient admission information (e.g. patient name, bed, patient id). This situation also allows to understand when the patient is not in the bed and consequently ignoring the data collected in this time and avoiding the storing of wrong data.

When the gateway receives the vital signs from the monitors, it sends a HL7 message Version 2 [17] containing the information collected, bed number but without PID to the vital signs acquisition agent and it parses the information. Then the RFID system verifies in the database what is the PID associated to the bed number present in the HL7 message and it sends the patient identification (d1, d2) present in the bed (v1) to be stored in the message. With this option it is possible to obtain a perfect match between the PID and vital signs values collected, completing the observation (OBX) HL7 message segment as well as the observation request segment (OBR). Finally, the HL7 message is stored in the database containing all patient information and values collected. Next, there is the formulation of a HL7 message (all the segments are descriminated on the 1):

```
MSH|^~\&|DHV |h2|h3|h4|||ORU^R01|h1|P|2.3.1
PID|1||d1||d2
PV1|1|U|v1
OBR|1|||DHV|||r1|
OBX|x2|NM|x3^x4^^^x5||x6|x7||||R|||x1^ v1||
```

4. Patient Localization and Management System

As mentioned in the Section 1, the Patient Localization and Management System (PaLMS) function is to automatically identify the presence of the patients in the ICU beds making a correct match between the acquisition system and the patient id, and managing their localization at the same time. PaLMS is an event-based monitoring system, which uses the technologies described in the Section 2, in other words, it is an RFID system that communicates with a MAS embedded in the AIDA platform that exchanges HL7 messages

Table 1. Variables in the exchange of messages between the agents

h1	Version ID	x1	Producer's ID
h2	Sending Facility	x2	Value Type
h3	Receiving Application	x3	Observation Identifier (cod)
h4	Receiving Facility	x4	Observation Identifier (cod2)
d1	Patient ID (Internal ID)	x5	Observation Identifier (descp)
d2	Patient Name	x6	Observation Value
v1	Assigned Patient Location (BED)	x7	Units
r1	Observation Date/Time		

among its agents in order to communicate with the PMS, the INTCare system and the alert system.

When a patient leaves the bed in the ICU for an exam or for the operating room or any other local, the patient's vital signs read and stored by the INTCare system are invalid. With the PaLMS, these situations are prevented through the intelligent environment created in the ICU beds, more specifically RFID tags (bracelets) and several antennas. Each tag represents a patient and each antennas group represents a bed (the implementation study will be presented in the Section 4.3).

4.1. RFID Events

In order to manage the patient information included in the AIDA platform, the MAS integrated in PaLMS was developed based on the most common events in the patient's cycle in the ICU. These events are detected by the RFID system and they can easily be associated to HL7 events through the trigger-events [11], using the ADT messages, supplying interoperability to the PaLMS. In this way, the Table 2 presents these events and the corresponding ADT messages.

Table 2. Description of the events used in PaLMS and the corresponding ADT messages.

Event name	Description	ADT message
Admission Event (AE)	Event sent by PMS to the ICU informing the admission of a patient; An RFID tag is placed in his wrist; An EPC is associated to this patient.	ADT_A01
Transfer Event (TE)	Event sent by PMS to the ICU informing the transfer of a patient to another unit and the corresponding EPC.	ADT_A02
Discharge Event (DE)	Event sent by PMS to the ICU informing the discharge of the patient and the corresponding EPC.	ADT_A03
Leave of Absence Event (LoAE)	Event sent by PMS to the ICU informing the leave of absence of the patient (for example to take an exam in another unit) and the corresponding EPC.	ADT_A21
Return from Leave of Absence Event (RLoAE)	Event sent by PMS to the ICU informing the return of the the patient to the ICU and the corresponding EPC.	ADT_A22
Warning Event (WE)	Event sent by the RFID system to the ICU when the tag is not detected or when the tag is detected and the monitoring systems (e.g. vital signs, medical ventilators) are not connected to the patient/sending values; The corresponding EPC is also sent.	ADT_A20

ADT - Admission Discharge or Transfer; RFID - Readio-Frequency Identification; ICU - Intensive Care Unit ; EPC - Eletronic Product Code;

4.2. Agents Architecture

A fast and autonomous response are two key points under the PaLMS scenario. The usage of intelligent agents accomplishes these goals when reacting to messages that agents receive. The ADT messages from the HL7 standard that represent different events (Table 2) are among the most used by the PaLMS platform. In fact, some researchers have already implemented HL7 messages to exchange interoperable information among intelligent agents [30].

It was created a MAS with several intelligent agents, with the main objective of identifying and monitoring the patient's presence in the ICU bed and also ensure that the interoperability between PaLMS and the AIDA platform. The Figure 2 presents the communications of the agents in the PaLMS and also the information exchanged with the PMS module, the INTCare module, the alert module and the RFID system. All the modules are incorporated in the AIDA platform.

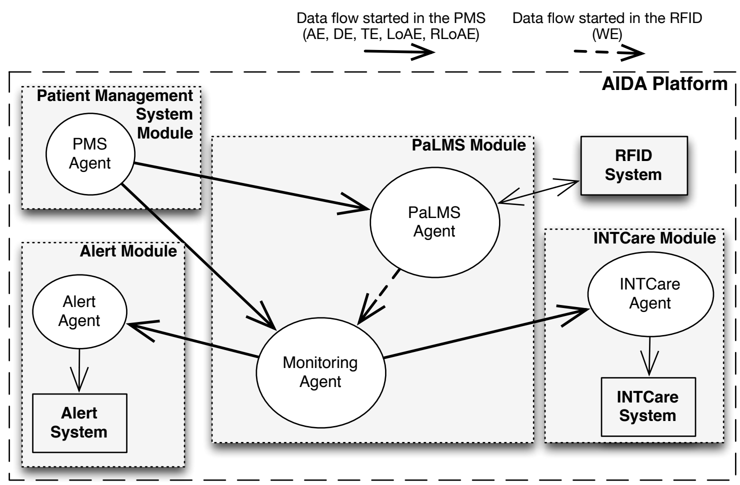


Fig. 2. Exchange of information among the three modules, the PMS and the RFID system included in AIDA Platform.

Analyzing the Figure 2, the MAS associated to PaLMS has five intelligent agents, the PaLMS is constituted by four modules and the RFID system and it is defined as a tuple $\Xi \equiv \langle \Delta_{PaLMS}, module_{PMS}, module_{PaLMS}, module_{INTCare}, module_{Alert}, RFID \rangle$, where:

- Δ_{PaLMS} is a set of bridge rules that establish the communication/interaction among all components of the PaLMS. This communication is based on the ADT messages associated to the events described in the Table 2;
- $module_{PMS}$ is composed by $\langle a_{PMS}, a_1, ..., a_n \rangle$, where a_{PMS} is the PMS agent and $a_1, ..., a_n$ are other agents included in the PMS, which perform other tasks in the AIDA platform;

- $module_{PaLMS}$ is composed by $\langle a_{PaLMS}, a_{Monitoring}\rangle$, where a_{PaLMS} is the PaLMS agent and $a_{Monitoring}$ is the Monitoring agent;
- $module_{INTCare}$ is composed by $\langle a_{INTCare}, INTCare\rangle$, where $a_{INTCare}$ is the INTCare agent incorporated in the PaLMS and $INTCare$ is the INTCare System;
- $module_{Alert}$ is composed by $\langle a_{Alert}, Alert\rangle$, where a_{Alert} is the Alert agent incorporated in the PaLMS and $Alert$ is the Alert System;
- $RFID$ is the RFID system (readers, antennas and tags).

Agents Description

- **PMS Agent**: this agent operates as HL7 message server once it sends and receives these messages through a client-server configuration. It is inserted in the PMS and manages the patient information related to admissions, discharges, transfers, absences and the corresponding return, which is sent from the AIDA platform through the PMS. In this way, this agent communicates with the PaLMS Agent in order to inform the RFID system what event happened. The PMS agent also sends instructions to the Monitoring Agent to execute the INTCare module or the Alert module.
- **PaLMS Agent**: this agent also operates as an HL7 message server and it acts according to the message received from the PMS agent:
  - ADT_A01 (AE): the health professional in the ICU will associate a tag to the patient and the identification process will be done. The RFID system starts the readings.
  - ADT_A22 (RLoAE): the PaLMS Agent instructs the RFID system to restart the readings.
  - ADT_A02, ADT_A03, ADT_A21 (TE, DE, LoAE): this agent informs the RFID system to stop the readings.
  - ADT_A20: event triggered by the RFID systems when the tag is not detected or when the monitoring systems are not attached to the patiente;

  Besides that, the PaLMS Agent exchanges messages with the Monitoring Agent in order to inform the INTCare and Alert modules properly.
- **Monitoring Agent**: it receives information from the PMS Agent and PaLMS Agent and it instructs the INTCare Agent and Alert Agent in order to start, to stop or to continue the INTCare System or the Alert System respectively.
- **INTCare Agent**: this agent communicates with the INTCare System in order to start, to stop or to continue the vital signs readings.
- **Alert Agent**: it turns on or off the alarm system according to the information received from the Monitoring Agent.

Agents Communication The Figure 3 represents the communications established among the agents and the RFID system. The first sequence on this figure demonstrates the process when it occurs an AE or a RLoAE. In both events, the EPC is transmitted within the ADT message, in the patient identification field. In this way, the RFID system knows which tag that should be read. In fact, the EPC is embedded in the patient identification field in all ADT messages exchanged. Continuing the analysis of this sequence, the PMS Agent communicates with the Monitoring Agent in order to INTCare Agent instructs the INTCare system to start the monitoring of the patient's vital signs and similarly, the Alert

Agent turns on the Alert System. When the Monitoring Agent receives the acknowledgment (ACK) messages from both agents, it informs the PMS Agent through an ACK that all the system began to work properly.

The second sequence presented in the Figure 3 represents how the agents and the RFID system interact when it occurs a DE, a TE or a LoAE. The communications of this sequence are very similar to the previous one, what differs are the instructions transmitted to the RFID, INTCare and Alert systems.

The last sequence in the Figure 3 is related to the WE. In this case, the event is triggered by the RFID system when it does not detect any tag in the ICU bed. This situation can happen due to several reasons: the tag is hidden and the respective antenna can not detect it; the patient was taken urgently to the operating room or to the exam room; the bed was moved due to a cleaning situation; the patient fell out of the bed and the tag is not detected by the antenna (most unlikely situation because the antenna can detect the tag in the same, however, as future work, this event may identify patient's fallings, warning the ICU health professionals). Only in the situations when the patient leaves the ICU urgently or when the tag is not detected and the patient is not in the bed, the INTCare and the Alert systems should be stopped by a health professional. In the other situations, the readings should proceed and the Alert System should remain on. It is important to refer that there is not any situation wherein the antenna does not detect the tag and consequently, the monitoring of the vital signs is stopped or the Alert System turned off.

4.3. Implementation

The characteristics of a hospital environment are slightly different from any other environment for the application of RFID technologies. In the ICU, where the patients are in a critical state, it must be ensured that their data are not obtained by other systems monitoring the patient. Furthermore, these technologies should only serve to support the medical action and not be an obstacle to this. To implement a technology such as a RFID system in a hospital unit, it is necessary to ensure: the security and the privacy of the data [56]; the reliability of the readings [1]; the least possible cost [1]; minimal false alarms [1]; and to avoid interferences with medical devices [50].

In order to implement the PaLMS in the ICU of the CHP, it was indispensable to realize a study accompanied by experts in the field and health professionals (physicians and nurses) to ensure the patients' safety and the feasibility of the solution. The objectives of this study were: to determine the number and the position of the antennas; to check the reliability of the readings; to verify if there are interferences with medical devices; and to detect situations of wrong identification.

Passive tags were used due to its small size that enables a high degree of portability (the passive tag is placed inside a bracelet). Another reason to opt for passive tags is to limit the detection range. In other words, if the tags were actives, the detection range would be bigger and situations of wrong identification would occur (e.g. when an antenna detects a tag that belongs to another bed). The RFID reader was configured to send a command to verify the presence/absence of the tag every moment, providing an instantaneous response. The frequency of sending this command can be configured anytime.

Firstly, all the dimensions of the ICU room were taken as well as the arrangement of the beds with the purpose to analyze the best solution for the position of the antennas.

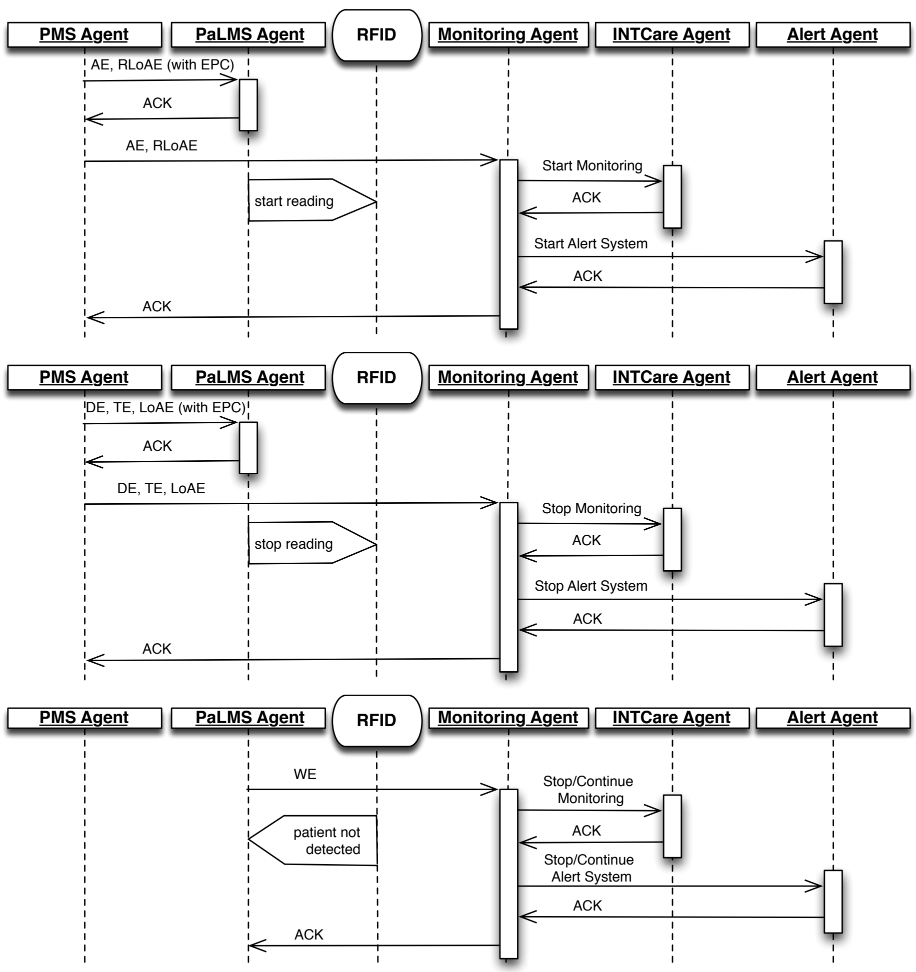


Fig. 3. Communication process between different agents and the RFID system and the reactions of the agents to each event

Four distinct solutions were tested in order to find the best solution for the number and position of the antennas:

Test 1 Two antennas near the wall, 0.95 meters high from the bed (the top of the bed is against the wall);

Test 2 One antenna near the wall, 0.95 meters high from the bed on the left side (because the tag is placed in the patient's left wrist);

Test 3 Two antennas suspended above the bed, in the central axis, near the area where the patient's arm is resting;

Test 4 One antenna with the same configuration as in the previous test.

The tests 1 and 2 failed the reading in some situations, specially when the patient was in an unusual position (the patients are usually lying with the back against the bed). On the contrary, the tests 3 and 4 detected properly the tags in all situations, except in an unusual situation when the patient completely covers the tag with his body (naturally, this situation also happened in the tests 1 and 2). The detection ranges of the tests 3 and 4 were identical, the tag was successfully detected in the central area of the bed (where usually the patient's wrist is located), in the top and even in the bottom of the bed. It is important to note that it is more likely that the patient moves his arm up, to the area of the head, than down, lifting the trunk to reach the feet with his hand. Furthermore in the tests 3 and 4 it was verified that the reading field provided by the antenna(s) is emitted in a spiral shape. In other words, the diameter of the reading field increases from top to bottom. The largest diameter of the reading field is on the floor and the smallest is near the antenna(s). In the bed area, it was verified a diameter that enables the tag reading up to 50 cm to outside the bed on both sides, which enables the patient to stretch his arm.

Once the tests 3 and 4 showed the same efficacy on the reliability of the readings, the test 4 (Figure 4) was selected to be implemented in order to save resources.

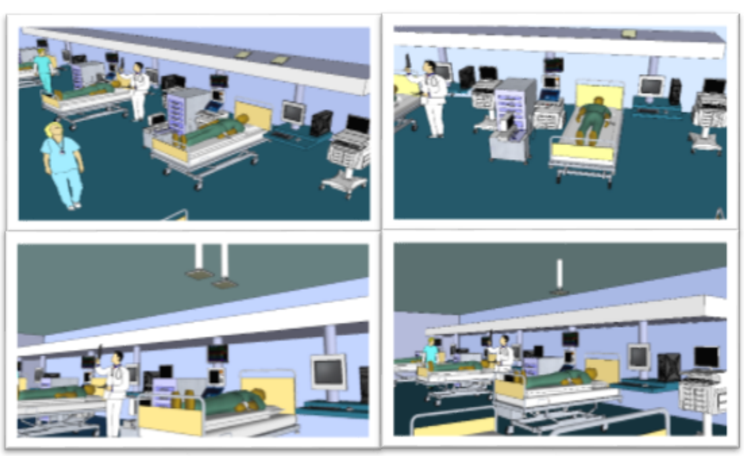


Fig. 4. Simulation of the location of the RFID antenna in Test 4

In this study, several tests were performed in order to find any kind of interferences with medical devices. The help of the physicians and nurses in this step was precious because it allowed to validate the presence or absence of interferences taking into account the values that were being collected by the sensors when the tests were being performed. Possible interferences with several devices such as: vital signs sensors, oximetry sensor, ventilation system, dosage of medication system, monitors of vital signs devices, INTCare monitors, other devices placed near the bed were analyzed. No interference situation was detected that compromised the readings of the tag. Besides that, it was possible to verify that a X-ray exam realized in the same room, did not interfere with the radio-frequency waves generated by the RFID antenna.

To verify situations of wrong identification, i.e. when an antenna detected a tag that belongs to another bed or when a tag is identified as another tag, it was performed two tests. In the first one it was used two different tags near one antenna, no abnormal situations were detected, each tag was correctly detected. The second test aimed to find situations where a specific tag was detected by the antenna of the next bed. It is important to note that the beds in the ICU of the CHP are apart 1.20 to 2 meters. Thus, this test consisted in moving slowly a tag from one bed to the next one, to verify where the detection was performed and by which antenna, and to detect the zone where no antenna detected the tag. The results were the expected, in the first bed the tag was detected by the respective antenna up to 50 cm outside the bed, then no antenna detected the tag and when the tag was coming to the second bed it was detected by the second antenna. Therefore, no antenna detected a tag that belongs to another bed, there was no false detection rate.

5. Usability

After presenting the main systems and technologies integrated at the CHP hospital, it is vital to understand what is usability. Ensure the usability of these systems is vital to assess the best quality.

5.1. Context

Increasingly the subjective user satisfaction is perceived as a decisive factor for the success and the acceptance of applications. The user comes to occupy an important place in software development, leading to new approaches having in mind that the usability of the final product is very important. Thus, the term usability emerges, acquiring extremely importance because today more and more people rely on technical devices to implement their tasks, whether at work, at home or elsewhere. Nowadays investing in the usability of a product and as important as investing in their functionality [39].

The Human-Machine Interaction (HMI) [18] can be defined as an area of knowledge related to the design, evaluation and implementation of interactive computing systems for human use and study of major phenomena surrounding them. It has the capacity to provide important information in understanding the processes involved in physical interaction and cognitive interaction between human beings and the entire computer system. Usability is a central term in HMI.

Several authors have made efforts to explain the meaning of usability term, the most significant are the visions of Shackel [47], Nielsen [34,35] and ISO norm [19]. Shackel devised a perceptual model based on product acceptability. For him, the usability is one of the components of acceptability of a product, since acceptance is directly dependent on the utility, the ability to delight, the cost and usability. He defines the usability as the ability to something in human functional terms to be used easily and without great efforts by a specified user range, after a specific training using the user support, to complete a number of tasks involved in a certain specified environmental context [47]. Meanwhile, Nielsen has identified five key attributes (learning, efficiency, memorization, errors and satisfaction) with which the usability is traditionally associated. These attributes are known as the five components which define the quality of usability, and typically designated as the dimensions of usability [34]. The best definition of this term comes from the ISO, which states that usability is the extent to which a system can be used by specific users to achieve specific goals with effectiveness, efficiency and satisfaction in a specific context of use. This description stands out from others because it emphasizes the relationship between usability and context of use, i.e. usability is not an isolated property of the product, but it depends on who is using this, with what goals and in what context of the use and the environment the product is being used [19].

The healthcare community and the medical technology industry are aware that medical equipment needs to have higher usability. Ensuring the usability of the existing systems is vital. However, due to the complexities associated with the number of work processes supported, as well as the range of users and work contexts, completing a comprehensive usability evaluation of these systems is a time consuming and resource intensive process. Therefore, selecting the suitable usability evaluations is extremely essential, as they assess the quality of interactive software systems.

5.2. Main Methods to Rate the Usability

There are several methods for evaluating the usability of a system, which can be grouped according to certain criteria, for example, engage or not the participation of users. However, the most popular categorization consists in an inspection of the system, a user survey or if it is a test of the system [13,22,6,36].

The evaluation methods of usability of the survey type, serve to usability evaluators obtain information about the preferences of users, their needs and their understanding of the system through conversations among themselves or asking users to answer a number of questions. Among this type of usability evaluation methods stand out the discussion group (focus group) interviews, surveys/questionnaires or in situ observations.

The inspection approach consists essentially to analyze those aspects of the usability of an interface to be used by users. This analysis is done usually by usability professionals, may also be made by software developers, users and other professionals. The most common inspection methods are the cognitive walkthrough, the feature inspection, the heuristic evaluation and checklists.

The last type of usability evaluation method, testing, requires representatives of end users are invited to perform typical tasks using the product (or prototype). This type of assessment involves several users (five to seven serve for relevant information, more than seven is not justified in terms of identifying usability problems) and one or more usability experts. The representatives must complete various tasks while the usability experts observe tasks. Several variations of the method of testing coexist, such as coaching method or thinking aloud protocol.

5.3. Usability evaluation

With the purpose of promoting better use by health professionals of embedded systems in CHP, were performed usability evaluations in order to identify most of the usability issues associated with them. It is important to note that these evaluations were performed after the PaLMS implementation. In this way, the AIDA platform, the INTCare system and the PaLMS were the target of two evaluations.

A survey was chosen as the embodiment of a method of inquiry. With this method a recognition of setbacks that users face when using these systems is expected . A method of inspection was put in practice, the heuristic walkthrough, where a series of common tasks to the users in order to identify the major usability problems evident in the systems were performed.

5.4. Survey

The first method used, the survey was implemented due to the well known capabilities of getting a direct response by the participants. With this method, usability evaluators can acquire and understand information about the tastes, dislikes, needs of the systems users. Thus, the main objective of this review is to know what physicians and nurses think about the system. The survey was constructed with twelve questions, eleven multiple choice and one (the last) is an open-ended question, where the user is encouraged to report aspects that could be modified on the systems. The first question serves to identify the workgroup in which the reporting falls (physician or nurse). The other ten questions, described in detail at table 3, are concerned about the usability of the systems and the users would validate their agreement according to Likert scale, this scale was divided into five different levels: from completely disagree to completely agree (see table 3) [29].

Table 3. Questions from the Likert Scale.

Question Number	Description
1	Do you think you lost too much time in data input?
2	Do you think you lost too much time visualizing data?
3	All the windows have a title describing its content?
4	The structure of the systems is simple and clear, avoiding unnecessary complications?
5	The design of the systems is aesthetically pleasant?
6	The language used is simple and appropriated?
7	Is it possible to reduce the registration time by copying or modifying existing information?
8	Does they contain unnecessary data?
9	When appropriated, there as default values?
10	The prompts, warnings and messages appear in a prominent location?

In total 300 surveys were distributed in various departments of the CHP to be answered.

5.5. Heuristic Walkthrough

The second method of evaluation of usability applied was the heuristic walkthrough method that belongs to the inspection methods group. This method was chosen because it is an assessment that does not involve high costs or resources. At the same time enables the identification of possible usability problems (whether severe or minor), based on not only the principles of usability but also in tasks performed by users. It does not require extensive training of the evaluators. In this type of method the first decision to make is choosing the number of evaluators, it must be between 3 and 5 people who must have knowledge both on the usability and in the area where the systems will be used. However finding people having high experience in usability and clinical experience is an extremely difficult task. Thus it was decided to merge the two types of evaluators: usability experts and clinical experts. The heuristic walkthrough method uses the structure and technique of the cognitive walkthrough method and the heuristic evaluation method and it is an approach bipartite, i.e. remain two distinct stages during the evaluation: the Task-Oriented Evaluation and the Free-Form Evaluation.

First Step: Task-Oriented Evaluation This first phase enables assessors to become familiar with the system interface. It is stage analogous to the cognitive walkthrough method to the extent that evaluators try to complete a series of tasks common the user tasks. Therefore, it is appropriate at this stage to design a list of prioritized tasks, which should cover the most frequent or indispensable tasks. This list can still include extra tasks that may lead assessors through each part of the system.

After the acquisition of task lists, assessors are ready to undertake the first phase of the evaluation. They are free to explore any task they deem appropriate, without a specific order and for as long as is necessary. The prioritized tasks enter this stage, since these are the ones that will guide the evaluators to choose the appropriate tasks in this assessment. Furthermore, these tasks will ensure that the first experience of the evaluators with the systems will be oriented to the task, even as users have learned to use the systems.

With the exploration of the tasks evaluators are encouraged to consider four questions focused on thinking that derive from the Cognitive Walkthrough method [21]:

- Will users know what they need to do next?
- Will user notice that the correct action is available?
- Once users find the control , will they know to use it?
- If users perform the correct action , will they see that progress is being made toward completing the task? Does the system provide appropriate feedback?

Using these four questions, the evaluators will try to compose a “story” of success for each phase of the task. When a story can be told with success, the evaluator assigns that task common characteristic for success. Otherwise, this builds a failed history and the evaluator provides which of the criteria mentioned above failed and the reason for which the user may fail.

Second Step: Free-Form Evaluation Completed the phase oriented to tasks, evaluators advance to the second stage of the method. This step is quite similar to the method heuristic walkthrough. During this phase, the evaluators rely on an established set of heuristics for evaluating the usability problems associated with the system interface.

There are several heuristics that can be adopted at this stage. However, the most used heuristics are the ones of the Jakob Nielsen. These heuristics are the most widely accepted in such evaluations and therefore they were adopted in this evaluation. The referenced author on the work “Heuristic Evaluation” defines a complete list of heuristics that will be used through this work.

In this second phase based on heuristics, the evaluators are encouraged to perform a task or any set of tasks that they deem to be appropriate to explore the system interface. At the end of the evaluation, the results are presented. Since each evaluator conducts its review independently and each usability problem that is identified and documented, it is necessary that at the end of the evaluators get together so that usability problems are consolidated and analyzed. During this meeting, the issues are prioritized based on the anticipation of their frequency and severity. Possible ideas to overcome such problems are also discussed in this phase.

5.6. Results and Discussion

As already mentioned above, two different methods were used, so it is necessary to analyze them independently.

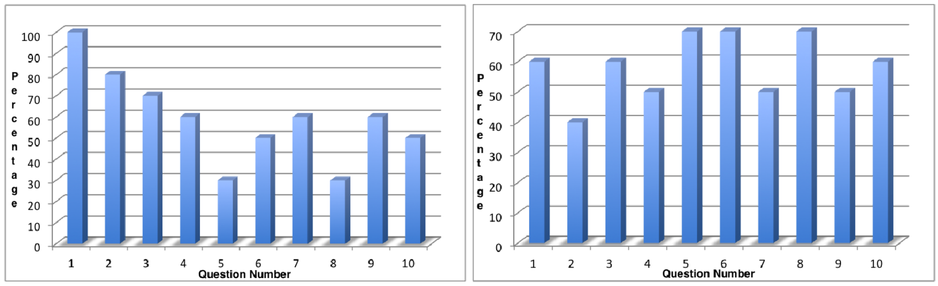
A total of 63 answers from the physicians were obtained. It was possible to note that all the physicians think they lost too much time introducing data. The great majority also thinks that the time spent to consult information about the patient is excessive. The design of the systems was also an issue that was possible to be assessed. The design of the systems obtained a classification of only 30%. These are the overall results from the survey answered by physicians. The whole percentage of appreciation for the ten questions can be seen in the Figure 5a.

More reactions from the nurses were obtained: 104 answers. In this way, a total of 167 responses to the survey were obtained on the overall. It was possible to realize that nurses do not think alike physicians. They do not lose so much time as the physicians with data. Furthermore, they affirmed that the design is pleasant (70% of satisfaction). Another interesting issue was that half of the nurses do not use speedup tools like copy and paste information already available. The full percentage of appreciation can be seen in the Figure 5b.

The last question that asked for the opinion of the users to what they would change in the systems, it did not have the best feedback from physicians neither from nurses. The majority of them did not reply to this question. Of those who have answered, the most aspect pointed out was the slowness of the systems.

The heuristic walkthrough evaluation, performed by the evaluators, allowed the identification of some usability issues. The main issue identified concerns the visibility of the system. When users perform an action that requires some processing, there is not a clear feedback of what is happening. The user does not know if the action is processing or if nothing is happening. In these situations, a notification should appear. This notification can be a single hourglass where the user is informed that has to wait, but the ideal is to appear a message informing the progress of the action, the time remaining to perform the action and information about what kind of processing is happening. No more issues were found related to the visibility of system status. The heuristic match between system and real world did not show any issue too.

Despite the fact that physicians and some nurses feel that they lose too much time with records, the usability of the systems shows a high level [40]. Therefore, the mission of the healthcare providers is facilitated by these systems. To understand better their difficulties, a study *in situ* should be done. An usability testing method, more precisely a think aloud



(a) Physicians **(b)** Nurses

Fig. 5. Responses to the survey

protocol, should be effective to understand what are the major problems that healthcare providers face at recording and visualizing data, in order to improve the usability of the systems.

The design of the systems was another negative aspect pointed out by physicians, but well appreciated by the nurses. For achieving a high level of usability, the design should be aesthetic and minimalist, which would fulfill the physicians' expectations for the systems. However, there are some legal requirements that preclude the desired aspect, which have not been overcome yet. To avoid this, new methods of information organization and presentation have to be researched with the aim of providing a more usable interface and meeting the legal requirements as well.

With this study it was also possible to see that nurses do not use the offered shortcuts. Two suppositions can be taken from here. On one hand, the usability of the shortcuts can be so bad that nurses cannot realize their presence or even do not know their existence. As physicians did not criticize about it, this option is not very worthwhile. However, some investigation should be done to ensure great usability of shortcuts. On the other hand, the motive for nurses not using shortcuts can simply be the fact that they do not know how to use them. This option is most certainly the right one, so something needs to be done. Workshops, trainings or demonstrations should be a helpful tool to show nurses the existence of speedup tools as well as how to use them.

Despite the fact that the system has good usability, some issues were identified, so it is necessary avoid those. Nevertheless, it is necessary to see all the implications that the revision entails [5]. The efficiency of the systems can be affected with some alterations. Furthermore, as these systems deal with the patients' health, there are legal requirements to have into consideration.

6. Conclusions and Future Work

The INTCare system is an intelligent decision support system, developed in order to make a real-time monitoring of the patients and predict clinical events in the ICU. After the implementation in the CHP, two major flaws were identified. The identification of the patients in the monitors of the INTCare automatically and whenever a patient left his bed in the ICU, the monitoring system (INTCare) keeps collecting data. In order to circumvent these problems an architecture that prevents wrong data acquisition was developed. This architecture was tested through the PaLMS whose function is precisely to identify automatically the presence of the patients in the ICU beds.

It may be concluded that is possible to develop a system for the detection of the patient's presence in a bed using a RFID system. Indeed, the PaLMS was implemented in the ICU of the CHP and integrated in the interoperability platform (AIDA) successfully. Thus, PaLMS was considered a functional project for the goals proposed. The proper identification of the patients in the ICU allowed to calculate automatically, in real-time and through the values of the vital signs, several indicators. Furthermore, the PaLMS implementation in the INTCare system is enabling the development of a system that stores, monitors and compares the vital signs values of the patient throughout his period of internment. For example, this system can provide to the health professionals the information about the evolution of the mean arterial pressure of the patient during his internment.

The communications within the MAS through HL7 messages showed no disadvantage, on the contrary, it ensured the interoperability in the system. Few notes can be given for the optimization of the RFID data acquisition process. RFID must be accurate in its readings, or the alert system could shut down with the patient still in bed, this is a situation of danger to his health recovery. The implementation study allowed to find the best configuration for the number and position of the RFID antennas. It is important to emphasize that the intervention and accompaniment of physicians and nurses (responsible for the ICU) in the course of this study were fundamental to achieve the best solution.

Also, this paper presents a possible usability evaluation to the AIDA and the monitoring systems. Two different methods were chosen: inquiry method (survey) followed by an inspection method (heuristic walkthrough). They prove to be very cheap methods and easy to perform, which provided immediate and reliable results about the usability of the systems. This is an important issue to the hospital, as they want to assess the best working condition to their health professionals. Providing usable systems are one of the many conditions to achieve that. In the future, it is intended make an evaluation focused on the inclusion and interoperability the PaLMS system into the AIDA platform based on metrics that evaluate this performance.

As future work, RFID tags can be applied to nurses too, because when they are treating the patient (e.g. personal hygiene) the values collected by the INTCare sensors can easily be doubtful once they are moving the patient. In this way, whenever an antenna detects a nurse, the PaLMS will detect this situation and the monitoring systems would be warned to discard the values collected if these were abnormal. Moreover, another monitoring systems using RFID can be applied to other hospital units, to monitor patient's movements inside the hospital or in a specific unit, to track a specific physician that is needed urgently or to track and to manage equipments.

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