

# An RFID-based application for handling the workflow of radioactive patients in a nuclear medicine department

Della Vecchia G.  
ICAR-CNR  
Via Pietro Castellino 111  
80131 Napoli, Italy  
gennaro.dellavecchia@na.icar.cnr.it

Esposito M.  
ICAR-CNR  
Via Pietro Castellino 111  
80131 Napoli, Italy  
massimo.esposito@na.icar.cnr.it

## ABSTRACT

Pervasive Computing technologies can be successfully used in hospital and clinical environments in order to provide smart and enhanced healthcare services and applications. According to this vision, the paper presents an RFID-based application for handling the workflow of patients injected with radioactive substances in a nuclear medicine department. Specifically, the application exploits the RFID technology to provide automatic and non-intrusive mechanisms for i) guaranteeing the appropriateness of the clinical workflow of the injected patients and ii) accessing all the clinical information of the injected patients by automatically querying the radiological information systems.

## Categories and Subject Descriptors

J.3 [Computer Applications]: Life and Medical Sciences – Health, Medical information systems. D.2.11 [Software Engineering]: Software Architectures – Domain-specific architectures.

## General Terms

Design.

## Keywords

Pervasive Healthcare, RFID, nuclear medicine.

## 1. INTRODUCTION

In the last decade, the advancements of wireless and mobile computing and the diffusion of pervasive healthcare technologies are significantly changing our perception of healthcare. We expect that the everyday activities of clinicians in our traditional hospitals can be extended with enhanced and customized healthcare services and applications which can be delivered at any time and any place.

Pervasive Computing can tackle such changes enabling highly heterogeneous hardware and software components to seamlessly and spontaneously interoperate, in order to provide a variety of smart healthcare services and applications. Most of them use various sensing capabilities which require that hospitals

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. MobiQuitous 2008, July 21-25, 2008, Dublin, Ireland. Copyright © 2008 ICST ISBN 978-963-9799-27-1.

be equipped with sensor technologies integrated in the whole system in a pervasive and non-intrusive way in order to not disturb the holder and enable interaction with healthcare services and applications in a transparent and unconscious manner. The Radio Frequency Identification (RFID) technology represents the fast growing example of non-intrusive sensing technology that can be applied in hospitals.

According to this vision, we aimed at exploiting the RFID technology to realize a smart healthcare application, focusing our attention on a sensible scenario occurring in the nuclear medicine department of an hospital. Specifically, in performing some nuclear medicine assessments patients have to be preventively injected with radioactive substances. Injected patients should stay in dedicated waiting room, use dedicated bathrooms, and wait a pre-defined time associated with the radioactive substance's decay both before and after the examination.

In this paper, we propose an RFID-based application for this scenario that aims at providing automatic and non-intrusive mechanisms to guarantee the appropriateness of the injected patients' workflow, in terms of supporting clinicians in handling the nuclear medicine test and in terms of safety within the whole hospital environment as well (while being still radioactive, injected patients may constitute hazard for other people present in the radiological department). Moreover, the proposed application is intended to provide access to clinical information of the injected patients by automatically performing a request to the radiological information systems.

The rest of the paper is organized as follows. Section 2 discusses the target scenario. Section 3 highlights our contributions and addresses related work. Section 4 describes the application and outlines its architectural model and some possible use cases. Finally, section 5 concludes the paper.

## 2. APPLICATION SCENARIO

In this section, we present our application scenario related to a nuclear medicine department whose layout is depicted in figure (1).

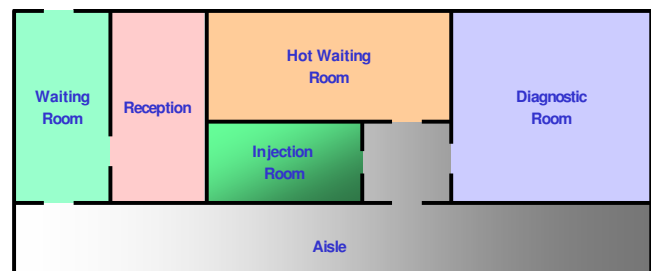


Figure 1. Nuclear medicine department

The nuclear medicine department consists of the following physical environments:

*Reception* – This is the place where the patient is accepted for a scheduled exam. Here a desk operator (Receptionist) registers the patient in the RIS (Radiological Information System).

*Waiting Room* – This is the room where accepted patients wait for their own turn.

*Injection Room* – This is the room where the patient is injected with radioactive substances before performing the exam.

*Hot Waiting Room* – This is the room where injected patients should remain awaiting before the exam for a pre-defined time depending on the specific radioactive substance.

*Diagnostic Room* – This is the room where the proper nuclear medicine exam is performed.

The Injection Room, the Hot Waiting Room and the Diagnostic Room represent the hot area of the department where radioactive substances and patients are confined. In this environment, the typical clinical workflow of injected patients takes place as described below.

A patient scheduled for an examination is first registered to the nuclear medicine's Reception and then routed to the Waiting Room. A great deal of nuclear medicine tests require the preventive injection of a radioactive substance. In this case, once injected, patients have to wait a preset time associated with the specific radioactive substance both before and after the test, with the proviso that the examination must be performed while the injected substance is still active.

As a result, when a patient is called for the test, she/he enters the Injection Room and receives the radioactive agent, then leaves the Injection Room and enters the Hot Waiting Room where the person has to wait for a certain time for the agent to be effective. In any case, this waiting time must not exceed the decay time of the radioactive substance in order to not vanish the injection at all.

After waiting for the appropriate time, the injected patient is ready for the test, so she/he leaves the Hot Waiting Room and enters the Diagnostic Room where the examination takes place. Here, the routine procedure can be described as follows. First, the physician on duty has to retrieve the patient's clinical and diagnostic record -this documentation is related to the specific patient's pathology. The physician makes use of the patient's personal data to perform a request to the radiological information systems, i.e. RIS and PACS, in order to gain access to possible radiological images and assessments previously carried out in the nuclear medicine department. After perusing the patient's clinical history, the physician is ready to perform the test.

Once the examination has been done, the patient leaves the Diagnostic Room and returns to the Hot Waiting Room where she/he must wait for a while so that the radioactive agent can be considered decayed. Finally, the person may be allowed to leave the Hot Waiting Room and the nuclear medicine department as well.

It is worth stressing that when a patient enters the hot area and is injected, she/he must not leave that area until the decay of the radioactive substance. Otherwise, being the person still radioactive, a potential hazard condition might arise with respect

to other people in the nuclear medicine department. Moreover, only the clinicians, paramedics and injected patients can access and stay in the hot area, this meaning that the access should be inhibited to everyone else.

Nevertheless, in practice it often occurs that injected patients leave the hot area during the hot waiting time before and/or after the test and move around within the department.

This scenario reveals the need of mechanisms for i) identifying, locating and tracking people, ii) monitoring the waiting times of the injected patients, iii) accessing the radiological information systems and retrieving patient's clinical data. The following open issues can be pointed out.

First, the nuclear medicine department should be equipped with a positioning system capable of identifying and detecting presence and proximity of patients. This system should be integrated in the department in a pervasive and non-intrusive way. Namely, the injected patients should not have to carry bulky and annoying objects for being detected by the positioning system, whereas wearable and light objects might be utilized instead.

Second, it is a matter of fact that monitoring by hand decay times simultaneously for many patients is not a trivial task, which therefore is error prone and could lead, in extreme cases, to critical conditions.

Third, it is unquestionable that integrating new healthcare services and applications into a real world, fully operating hospital environment is a thorny issue, mainly because of the scarce, if any, compatibility with heterogeneous software and databases usually present in healthcare facilities. In particular, accessing the patient's radiological information requires services and applications able to interact with the radiological information systems, i.e. RIS (Radiological Information System) and PACS (Pictures Archive and Communication System). RIS is the Information System used by radiology departments to store, manipulate and distribute patient radiological data and images. PACS is the Information System in charge of storing, retrieving, distributing and presenting all the patient medical images. Generally, such images are compliant with the DICOM (Digital Imaging and Communications in Medicine) standard.

## 3. RELATED WORKS AND CONTRIBUTIONS

### 3.1 Related Work

In the last few years the pervasive healthcare literature has diffusely addressed RFID applications and services for hospitals.

In particular, several pilot research projects, investigating the feasibility of RFID for tracking patients, assets, pharmaceuticals and personal in hospitals, have been conducted [1][2].

In [3] RFID technology is used to identify patients while hospitalized, and control drugs assumption. In particular, beds in the wards are equipped with various RFID sensors which identify approaching tagged drugs so that the system verifies that the right drugs are given to the right patient. In [4] RFID technology is applied to improve the patients' care, reduce the operating costs, help avoiding severe mistakes and reduce costly thefts. In

particular, they realize an enterprise application for tracking entities within a predefined area, such as a building.

In [5] two applications of RFID technology are reported. One application is related to an RFID-based nutritional assistance, whereas the other focuses on a wireless-enabled personal assistance system for independent living. Furthermore, some commercial solutions to identify and locate patients and doctors have already been presented [6].

In [7] an RFID-based application for handling electronic health records in a e-hospital is presented. The application relies on mechanisms and services for identifying, locating and tracking doctors and patients equipped with mobile devices and RFID tags, with the final aim of granting ubiquitous and transparent access to medical data gathered into standard Electronic Health Records.

These works put into evidence that the application of the RFID technology to identify and locate patients in a hospital department is surely not a novel idea.

Nevertheless, to the best of our knowledge, the pervasive healthcare literature has not yet addressed applications of RFID technology in nuclear medicine departments or for monitoring the workflow of injected patients in that environment: no system-oriented research appears to have been developed in that direction. Our research efforts have been primarily focused on the design of a methodology for the application of RFID technology in that specific scenario in order to guarantee the appropriateness of the clinical workflow of the injected patients. In particular, we intended to give clinicians a support for handling nuclear medicine examinations within a safety-aware context for the whole hospital. In addition, we also focused on the design of a solution that was capable to easily interoperate with heterogeneous software and databases already present in hospitals.

### 3.2 Contributions

This paper proposes a methodology for handling the workflow of patients injected with radioactive substances in a nuclear medicine department. Our goal is to make the nuclear medicine department able to i) identify, locate and track injected patients by using the RFID technology as positioning system; ii) monitor the decay time of the injected substances by using the RFID technology as identifying and positioning system; iii) access and automatically retrieve patients' radiological information and medical images from RIS and PACS respectively. In detail:

*Identifying RFID patients* – RFID tagged patients are univocally identified via the Radio Frequency Identification system.

*Locating RFID patients* – RFID tagged patients are located within the nuclear medicine department.

*Tracking RFID patients* – RFID tagged patients are tracked while moving within the department.

*Monitoring the decay time for injected patients* – The nuclear medicine department is provided with a transparent and unconscious mechanism for monitoring the decay time for injected patients. In particular, it exploits RFID tag automatically

identified via the Radio Frequency Identification system to label a RFID tagged patient as injected and start/stop a suitable timer.

*Accessing RIS and PACS* – The nuclear medicine department is provided with a transparent access to RIS and PACS. In particular, the access is context-aware, i.e. the required clinical information are automatically selected and retrieved depending on the Department's room which the RFID tagged patient is located into.

## 4. HANDLING THE WORKFLOW OF RADIOACTIVE PATIENTS

### 4.1 Application architecture

The application architecture consists of a set of components as shown in figure (2).

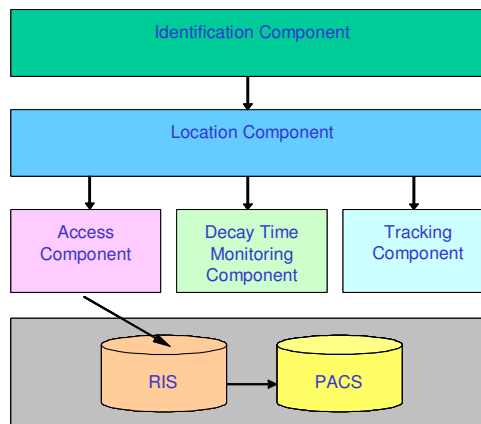


Figure 2. Application architecture

In the following, components are described.

The Identification Component, which relies on RFID technology, identifies an RFID tagged patient whenever approaching an RFID antenna. Identification takes place by means of the ID, which is unique, associated with the RFID tag.

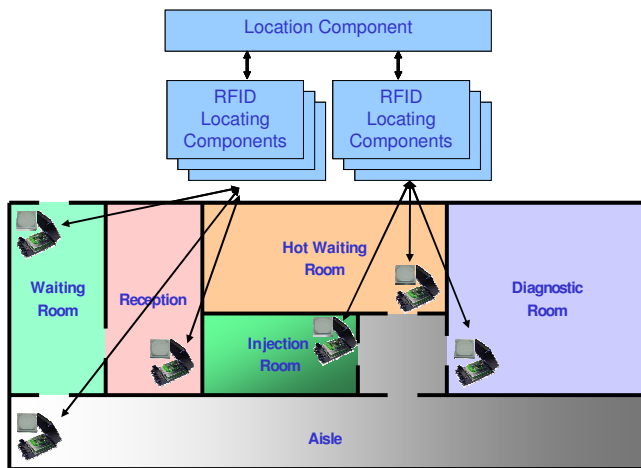
The Location Component is able to locate RFID tagged patients. It offers both locating and location functions, that is, respectively the mechanism to identify the position of specific patients and the mechanism to identify patients located at a specific location.

The architecture of Location Component consists of two sub-layers, as shown in figure (3):

- **RFIDL locatingComponent** – This component is in charge of locating RFID tagged patients. An RFID location is identified by the area covered by the RFID antenna of a specific reader. When an RFID tagged patient is sensed by the antenna, the RFID reader generates an event that is caught by the RFIDL locatingComponent which, in turn, updates the LocationComponent. There are as many RFIDL locatingComponent as RFID locations, each component being associated with a specific reader.

- LocationComponent – This component is in charge of handling global location states obtained by combining information coming from below components. Whenever an RFIDLocatingComponent detects an RFID tag, it communicates such information to the LocationComponent, which, in turn, compares it with the last known position for that patient and notifies the application in case of change.

Several RFID antennas and readers have been set in different physical rooms. Each RFID reader/antenna pair represents a specific location, which corresponds to the physical area covered by the RFID antenna, and has its own RFIDLocatingComponent that catches events generated by the hardware device whenever a RFID tag is sensed by its antenna. Such events are in turn redirected to the LocationComponent as location information.



**Figure 3. Location Component Architecture**

The Tracking Component receives location information from the Location Component in order to track patient movements and update his/her position within the environment. The Tracking Component simply stores location changes for all patients.

The Access Component provides clinicians with ubiquitous access to RIS and PACS. This component integrates handlers of standard health information systems RIS and PACS and queries them to check if there are other exams previously performed by the patient and, in case of a positive match, the resulting information are communicated to the application..

The Decay Time Monitoring Component provides clinicians with a transparent mechanism for monitoring the decay time of radioactive substances in injected patients. It exploits the location information provided by the Location Component to label a RFID tagged patient as injected.

Specifically, the component starts monitoring the decay time of a specific radioactive substance injected in a RFID tagged patient when that patient is detected leaving the Injected Room and entering the Hot Waiting Room. The component verifies that the time the patient spends while in waiting state does not exceed that decay time and alerts when time has come to perform the test. Moreover, the component verifies that, after the test has been

made, the injected patient does not leave the Hot Waiting Room until the monitored decay time is approximately over.

## 4.2 Use cases

The proposed RFID-based application has been devised to be used in the nuclear medicine department scenario depicted in figure (1).

In particular, a patient scheduled for an examination is first registered at the nuclear medicine’s Reception and his personal data is inserted into RIS. Here, she/he is equipped with an RFID wearable tag associated with the patient’s RIS by the application.

When the patient is called for an exam, he first enters the Injection Room where she/he gets injected. His RFID tag is identified by the RFID antenna positioned in that room and the patient is located.

When the person leaves the Injection Room and enters the Hot Waiting Room, the application detects that proper change of location and labels the patient as injected. Contextually, the application starts monitoring the decay time of the specific radioactive substance injected. If or when the time spent by the awaiting patient is getting too close to the planned decay time the application generates an alert to notify this circumstance to the clinicians.

If the injected patient tries to leave the Hot Waiting Room, the application generates an alert to inform the clinicians that an unauthorized injected patient is leaving the hot area.

After waiting the appropriate time, the injected patient is ready for the examination and, upon its completion, is authorized to leave the Hot Waiting Room. When she/he enters the Diagnostic Room, his RFID tag is identified by an RFID antenna and the application uses this information to automatically perform a query to the radiological information systems, i.e. RIS and PACS, in order to obtain possibly radiological images and reports previously stored.

After the examination, the patient leaves the Diagnostic Room and returns to the Hot Waiting Room. She/he can leave the Hot Waiting Room when the application informs that the decay of the radioactive substance is approximately over.

Finally, the tagged patient is checked-out at the nuclear medicine’s Reception and her/his RFID tag is released, ready for a new assignment.

Figure (4) reports the explicit application functionalities here described:

- Register Patient – This functionality enables the association patient/RFID tag.
- Locate Patient – This functionality allows to locate a patient.
- Get Patients – This functionality is intended to get a list of patients located at a specific location.
- Un-register Patient – This functionality enables the Receptionist to de-associate a patient and release the RFID tag for a fresh assignment.

- Show RIS Information – This functionality provides clinicians with ubiquitous visualization of the radiological patient’s information.
- Show PACS images – This functionality provides clinicians with ubiquitous visualization of the radiological patient’s images.

In addition to these functionalities, other implicit features are supported by the proposed application. Namely, the application has a pro-active and context-aware behavior in several situations. For instance:

- the radiological information are automatically retrieved and selected by properly querying RIS and PACS;
- the decay time of a specific radioactive substance injected in a RFID tagged patient starts being monitored when that patient is detected leaving the Injected Room and entering Hot Waiting Room;
- alerts are generated either when an RFID tagged patient tries to leave the hot area while the injected substance is still active or when the injected substance is decaying and the patient has not been called yet for the test.

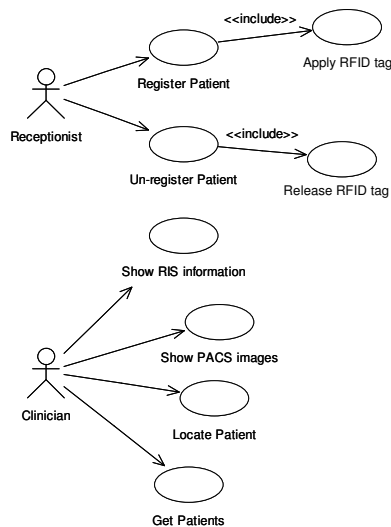


Figure 4. Application Use Cases

In particular, some of these context-aware responses can be enabled according to specific needs and, obviously, disabled too.

It is important to observe at this point that, as far as this application is concerned, no security & privacy issues have been considered, leaving the addressing of this yet critical matter for future work.

## 5. CONCLUSIONS AND FUTURE WORK

The advancements of wireless and mobile computing and the diffusion of pervasive technologies are leading towards new operating paradigms. Such approaches can be very effectively adopted in healthcare institutions, enabling highly heterogeneous hardware and software components to seamlessly and

spontaneously interoperate, in order to provide a variety of smart services and applications.

In this perspective, this paper has presented an application of the RFID technology for guaranteeing the appropriateness of the injected patients’ workflow in the nuclear medicine department. The application offers mechanisms either for identifying, locating and tracking injected patients equipped with wearable RFID tags or for granting ubiquitous and transparent access to clinical information embedded in the radiological information systems.

Future work will aim at integrating new sensor and positioning technologies, in order to improve the completeness and accurateness of the localization. Ideally, a positioning technology should provide complete and accurate location information, but in the real world scenario such a solution does not exist and, consequently, multiple technologies should be used and conveniently integrated.

Moreover, we are investigating suitable solutions for combining Pervasive Computing with mobile healthcare technology in order to gather other important data which can have an impact in healthcare applications. As a matter of fact, various bio-sensors exist that provide health related information such as ECG, blood pressure and sugar level or physical activity. We intend to apply these bio-sensors in conjunction with other sensing and positioning technologies, such as RFID technology, in order to provide smart and integrated mechanisms for monitoring the health of high risk patients.

Finally, further development of this work will also address issues tied to the integration of some mechanisms for security and privacy enforcement.

## 6. REFERENCES

- [1] Bacheldor, B. 2007 Tags Track Surgical Patients at Birmingham Heartlands Hospital, RFID Journal, available at: <http://www.rfidjournal.com/article/articleview/3222/1/1/>.
- [2] Bacheldor, B. 2007 HCA North Florida Expands Its RTLS to Track Patient’, RFID Journal, available at: <http://www.rfidjournal.com/article/articleview/3615/1/1/>.
- [3] Bardram, J. E. 2004 Applications of Context-Aware Computing in Hospital Work – Examples and Design Principles’, ACM Symposium on Applied Computing.
- [4] Fuhrer, P. and Guinard D. 2006 Building a Smart Hospital using RFID technologies, In Proceedings of ECEH06, Fribourg, Switzerland, Andreas Meier; Henrik Stormer (Eds.), GI-Edition - Lecture Notes in Informatics (LNI).
- [5] Droes, R. M., et al. 2007 Healthcare Systems and Other Applications, IEEE Pervasive Computing.
- [6] Swedberg, C. 2006 PCTS, Radianse Team for Hospital Tracking Solution, RFID Journal, available at: <http://www.rfidjournal.com/article/articleview/2632/1/1/>
- [7] Coronato A., Della Vecchia G., Gallo L., 2008 An RFID-Based Application for Handling Electronic Health Records in eHospitals, to appear in International Journal of Computational Science and Engineering.