# An RFID-enabled framework to support Ambient Home Care Services

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***Abstract* – The growing number of elderly in modern societies is encouraging advances in remote assistive solutions to enable sustainable and safe 'ageing in place'. Among the many technologies which may serve to support Ambient Home Care Systems, RFID is offering a set of differential features which make it suitable to build new interaction schemes while supporting horizontal system's features such as localization. This paper details the design of a passive RFID-based AHCS, composed by an infrastructure of mobile and static tags and readers controlled by a SOA (service oriented architecture) middleware. The technology possibilities, its drawbacks and integration problems in this application domain are described from a practical approach.**

## I. INTRODUCTION

Between 2006 and 2050, the number of people aged 60 and over will virtually double from 650 million to 2 billion, exceeding the population of children under the age of 15, a turning point in human history [1]. In particular, forecasts show that nearly 20% of the European citizens will be 65 years or over by 2020. Elderly will have higher life expectancy, but also more chronic diseases to cope with. This situation is already a challenge for social (health)care systems, required to offer high quality services while guaranteeing their economic sustainability [2]

For this reason, a remarkable research effort is currently being done in developing technologies to support Ambient Care (Home) Systems [3], architectures designed to provide different types of services both in sensing controlled areas (at home) and outdoors, to provide the elderly with assistive services. ACS may be built on by different types of devices and networks, which are supposed to continuously acquire health parameters, ambient information and other context data about the user. In practice, deploying the required infrastructure to make an ACS work is always a time and cost consuming task, which also implies dealing with legacy infrastructure and devices and has strong usability restrictions.

In this paper, we focus on the use of High Frequency RFID as supportive technology for AHCS (Section II describes previous works). In particular, we describe the design and integration aspects related to the deployment of an in-home RFID infrastructure (Section IV-V) which combines different and inexpensive elements: tags attached to fixed locations or to mobile objects, static readers attached to interactive devices (touch screens) and mobile devices (PDAs) equipped with RFID readers. This infrastructure is ready to provide horizontal functionalities to build assistive services (such as localization or activity recognition), at the same time that aims at enhancing the user experience in his daily living by developing the 'Internet of Things' concept [4] (Section III). The infrastructure is part of a scalable and versatile servicer-oriented framework, which allows rapid prototyping of assistive services.

## II. ANALYZING THE ROLE OF RFID TECHNOLOGY IN AHCS

Strategies for activity recognition, indoors localization, behavior modeling, medication intake control or new interfaces are some of the functionalities that have been addressed in literature by using RFID systems. Following we review different types of proposals which are mainly based on non-expensive passive RFID technology.

The recognition of activities of daily living (ADLs) is supposed to be the basis of promising clinical services, which may range from early diagnosis of mental diseases to treatment adherence control. To date, significant works using RFID include real but limited experiments with users, obtaining satisfactory results under controlled circumstances. For example, the Proactive Activity Toolkit [5] represents 14 activities as a probabilistic sequence of objects used and mines probabilistic models of activity use from plain English descriptions of activities. For experimentation purposes, a real house was instrumented with 108 passive tags, and 14 users wearing a glove with an RFID reader performed activities in order to try the system's inference robustness (73% of the activity instances that happened where correctly detected). Munguia et al. [6] present a system for ADL recognition based on synchronized battery-enabled state-change sensors. A couple of users validated the system during 14 days: 77 and 84 sensors were installed in the users' one-bedroom apartments. Activities such as toileting, bathing or grooming were recognized with detection accuracies ranging from 25% to 89%. In order to automate calibration processes, [7] describes a platform for passive RFID-based enterprise intelligence systems capable of combining mobility information from enterprise systems (e.g. calendar or presence) to automatically infer relationships amongst people, objects and workspaces.

Behavior monitoring is the next step after activity inference. Miura et al. [8] describe a deployment of RFID mats and slippers to analyze behavior of dementia patients in a group home. Nutritional behavior analysis is the objective of the Diet-Aware Dining Table [9], a table augmented both with weighing and RFID sensor surface optimally placed in a virtual grid to track what and how much its users eat. Some objects to checking medication intake compliance have also been created. For example, the RFID-augmented Context-Aware Pill Bottle [10] reminds the elderly when it is time to take their medication. The Smart Container [11] is a cabinet enabled with RFID readers, which helps to track stored medicines. Med-ic eCAP [12] records the time at which a vial is opened by the patient to remove the tablet or capsule.

Another horizontal functionality which may be provided by using passive RFID infrastructures is indoor localization. Some of the systems referred above infer user's position (e.g. [8]). In [13], a mobile robot equipped with RFID antennas determines the locations of RFID tags, while [14] describe a RFID information grid system with a reader integrated in the user's shoe which is connected to a PDA via Bluetooth. In [15], an indoor positioning system for RFID tagged objects with mobile readers -whose position is unknown- and a number of landmarks is described.

Non-intrusive RFID hardware is a key aspect when deploying real AHCSs. Smith et al. [16] describe two approaches that extend conventional RFID: the iBracelet, a wrist-worn short-range RFID reader that detects object use via hand proximity, and the Wireless Identification and Sensing Platform (WISP), long-range RFID tags augmented with sensors that detect object motion preventing the user from wearing something. Mobile phones have also been considered: Riekki et al. [17] describe a framework for requesting services by touching tags with an RFID reader wirelessly connected to a mobile device. Häikiö et al. [18] demonstrates that the touch-based interface is easy to learn and adopt for elderly (regardless their physical or cognitive weaknesses) from the results of a ‘service trial’ using Near Field Communications (NFC) enabled phones to facilitate menu selection.

With respect to security and privacy, key issues for technology adoption [18] [20], it is well-known that RFID tags may be scanned by un-authorized people and passive eavesdroppers may have more coverage than authorized readers. Protection mechanisms such as locking tags or lightweight authentication [19] may be applied to AHCS RFID-based infrastructures in order to mitigate security risks.

Finally, as stated in [20], it is important to note that the deployment of RFID-based infrastructures requires having into consideration aspects beyond the technology itself, such as installation mechanics, aesthetics, health regulations or flexibility and scalability of the data management infrastructure.

## III. SERVICE REQUIREMENTS

Our inexpensive RFID infrastructure to be deployed at home should be capable of enabling a wide portfolio of ambient care services. In addition, the infrastructure should support horizontal functionalities such as localization, activity inference, usable interfacing and multiuser recognition, on which to build information, health, communications and infrastructure control services. Table 1 summarizes the initial service portfolio we aim at achieving: services are based on augmenting daily objects in order to facilitate virtual context-aware information delivery by intuitive interaction. For example, a allergic user will be able to check urban pollen levels by approaching his inhalator to a reader.

TABLE 1 – FUNCTIONALITIES AND SERVICES

| **Horizontal functionalities** | **Description** |
|---|---|
| Identification | Every tag and reader should be univocally identified. |
| Localization | Zone-based algorithm, supported by off-line tag mapping and reading-event association. |
| Usable interface | Touch-based, readers associated to inexpensive screens and mobile devices. |
| Multiuser support | Each user should be identified by his/her own RFID tag and mobile device |
| Activity inference | Machine learning strategy based on localization and interactions with tagged objects. |
| **Services** | **Examples for prototyping** |
| Information search | -Tagged bronchodilator inhaler: initiates a location-based pollen level consultation.<br>-Tagged umbrella: initiates a location-based weather consultation. |
| Personal comm. | -Tagged photograph: initiates videoconference with a relative or friend. |
| General support to health treatments | -Tagged pill box: Desirable dosage for a medicine, intake calendar checking and intake event storage.<br>-Tagged biometric device: video training on how to use it; data transfer to virtual personal health record.<br>-Tagged heart monitor: tracking daily motion levels in order to avoid sedentary behaviors. |
| Nutrition support | -Tagged food container: expiry date consultation, recipe search, recipe selection on dietary restrictions. |
| Infrastructure control | -Tagged RFID reader: device identification, manufacturing information, log report. |

## IV. AN ARCHITECTURE TO SUPPORT AMBIENT CARE SERVICES BASED ON HF-RFID TECHNOLOGY

**¡Error! No se encuentra el origen de la referencia.** shows the general architecture of our ‘Home Network Unit’ (HNU) to be deployed in the elder’s place. As detailed below, the HNU consists of a Home Network Infrastructure (HNI) and an OSGi-based middleware hosting acquisition and reasoning features.

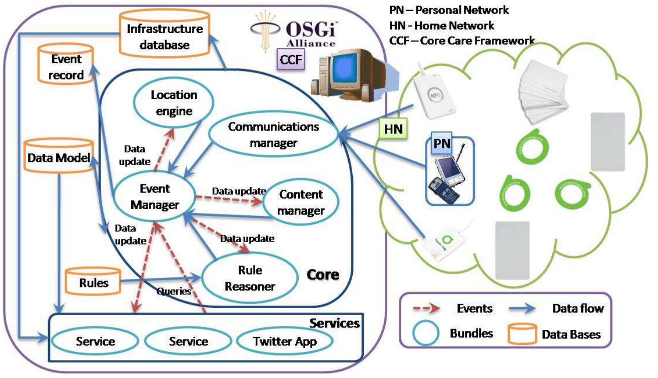


FIGURE 1- FRAMEWORK ARCHITECTURE

### 4.1 The RFID Home Network Infrastructure.

The HNI is built on an inexpensive infrastructure of readers and tags, and PDAs or mobile phones equipped with a miniSD RFID readers. An RFID tag is composed of an antenna, a radio transducer and a chip (with 1 Kb - 32 Kb of memory). Basically, there are three types of tags: active, semi-passive and passive ones; all of them may work at Low Frequency (120 – 140 KHz), High Frequency (13,56 MHz) and Ultra HF (860 – 960 MHz, depending on the country license). Active tags can also work at 2.4 GHz free band. Passive tags do not need any kind of battery; they are only activated if they receive a signal from a RFID reader. On the contrary, active tags and semi-passive tags need a source of energy; additionally, they differ from passive tags not only in size and price (30 – 90 € vs. < cents. €), but also in communication range (10-100 m in active case vs. 3 m max. in passive case) and in their reliability to work in adverse environments (in the vicinity of water or some metals). When considering its storage capabilities, it is possible to differentiate among only-read tags (just containing an identifier, EPC Class 0) and read/write tags (with memory space which can be modified or erased, EPC Class 0+ and Class 1 on). In the theory, a reader is only able to read one tag or card each time, but there are anti-collision protocols, (which allow a reader to identify various tags at the same time. In our case we are using read-only (Figure 2A, they can be stuck in any surface), Mifare Ultralight and read/write (Figure 2B) passive cards, Mifare Classic 1K and 4K.

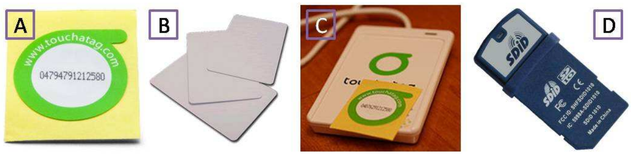


FIGURE 2 - A) READ ONLY TAGS; B) READ/WRITE CARDS; C) USB READER; D) SDID READER

The RFID reader is composed by an antenna, a transceiver and a decoder. The reader sends RF signals, which reaches the RFID tags in its coverage zone. Figure 2 (C-D) shows the readers we have used for our prototype. Read-only tags are readable by using both USB or mobile RFID readers. In particular, the USB reader we are using is the ACR122U NFC Reader, compliant with the ISO/IEC18092 standard for NFC, and supporting Mifare, ISO14443A and B cards and NFC and FeliCa contactless technologies. The proximity operating distance of ACR122U is up to 5 cm, depending on the type of contactless tag in use.

The mobile reader is in Figure 2-D. It is a NFC / HF RFID Secure Digital (SD) Card, able to read and write in a range up to 5 cm, depending on the antenna configuration and environment. Its usual power consumption is 100 mA if active, 30 mA if idle and 10 mA if standby (it varies with the host device). It supports NXP Mifare/Desfire smart cards. We are using it connected to a PDA running Windows Mobile (5.0 and 6.0).

Finally, the RFID Acquisition Layer (RFID AL) decouples data acquisition from application development. Our RFID AL includes software prepared to run in the mobile device (based on the open source C++ Brookyn code), which reads and writes data from tags and send them to the Home Network Unit, and specific acquisition software in the HNU to handle the USB reader.

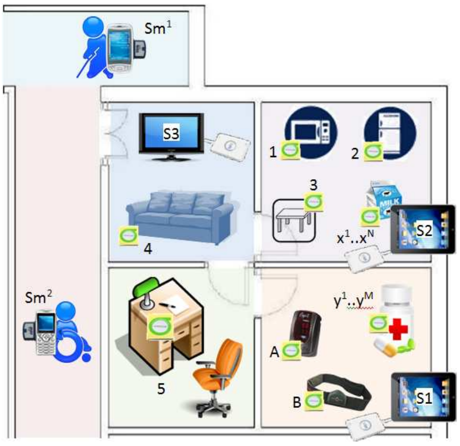


FIGURE 3 - RFID HARDWARE DEPLOYMENT

Figure 3 represents the simulated home environment deployed in our laboratory. In this scenario, we are assuming that the users may be carrying a mobile RFID reader (*Sm*$^{1,2}$; in this case, integrated in their PDAs) or not. There are some static RFID readers attached to TV (*S3*) and interactive screens (*S1, S2*) used to support content management and reading event-based information delivery. A number of static RFID tags (*1..5*) are attached to specific locations or fixed objects (microwave, fridge, kitchen table, sofa, desk) to enable the localization of the users. Finally, some other RFID tags are also attached to several kinds of items: medicines (*y1..yM*), food products (*x1..xN*) and biometric devices (*A - oxymeter, B – blood pressure*).

### 4.2 The Home Network Unit

An OSGi framework has been chosen to manage the information received from the readers and develop services that use it as input. OSGi provides a dynamic component model to run over Java. The modularity offered by OSGi makes easier reusability, testing, parallel development and comprehension of the different modules in which the different applications are based. The applications or components are deployed in the framework as bundles (jars files with extra manifest headers) and can be remotely managed, that is, they can be installed, started, stopped, updated and uninstalled without requiring a reboot.

Our middleware runs on the Eclipse Equinox implementation of the OSGi specifications (certified to fulfill R4 by the OSGi Alliance). Different modules have been developed to carry out the aim of the Home Care Unit:

- *Communications manager:* this module works as a gateway to receive information from the different readers, convert it into objects contained in the data model and throw events notifying the bundles subscribed that new information is available.
- *Rule engine:* it throws different events, related to a simple processing of the information. For example, some rules can be stored related to the personal profile of each user to support diet control and also to throw alarms or emergency notifications. In the first case, a person can put a food product on the reader and the system will tell him if that product fits in his diet. Another example will be throwing an emergency alarm when it is detected that a child has taken a medicine out of the cupboard.
- *Location engine:* it receives the information of a tag and determines the position of the user using the information of location stored in the infrastructure database of the system.
- *Content manager:* it links the identification of the tag that has been read with some information related to the object to which it is attached.

FIGURE 4 summarizes the flow of events and information from the reading of a tag to the presentation of some information on a screen. When the reader detects a tag it sends the ID number to the communications manager which calls the event manager. The event manager checks the type of tag that has been read and sends an RFID event to each service subscribed to this kind of tags. In this example, the content service module receives the notification of the event so it retrieves the link of the information to be shown on the screen that is finally presented by the visualization service for example in the web browser of the PDA. Other modules that can be invoked are the localization module or the rule reasoner, which uses the ID number, the infrastructure database and the rules database to get the information of the user context and show alarms or advice to the user related to the diet or the dosage of a medicine.

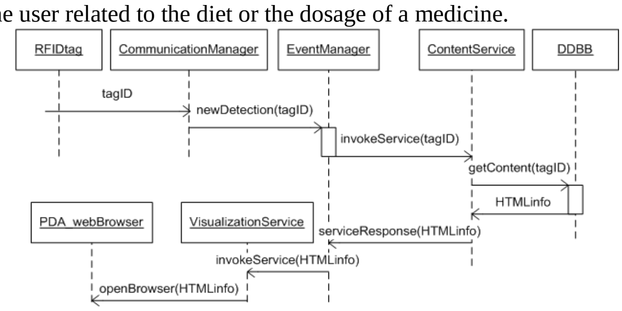


FIGURE 4 - FLOW OF EVENTS AND INFORMATION STARTED BY THE READING OF A TAG.

## V. INTEGRATION ISSUES

### 5.1 Data modeling and persistence

The HCU is built on a data model which defines communication interfaces and facilitates information sharing. Each element is assigned a unique identifier. As shown in Table 2, a database stores all the identifiers of the every element (readers and tags) in the deployment with its associated data. The information stored covers the type of object/person to which the tag is attached, the specific name of that object and other contents associated to it. It will be possible to store specific data about a person and his reference to a database containing his user context information, also about a mobile object defining a link to a website, and about a spatial point that will be used to infer location.

The identifiers used in this deployment are the ones stored in the cards by the manufacturer. In the future, we consider assigning to each tag a worldwide unique identifier following the Electronic Product Code (EPC) specification which is expected to become the standard for RFID global usage. This will allow introducing our deployment in the Object Name Service (ONS) which is equivalent to the DNS but for objects that have an EPC identifier.

TABLE 2 - STRUCTURE OF THE INFRASTRUCTURE DATABASE

| Identifier | Type | Associated object/person | Action information |
|---|---|---|---|
| FE5D2D9A | Person | Mary | <DB reference> |
| DED7309A | Object | Pill box | <link> |
| AE5E319A | Location | Fridge | <x, y, z, kitchen> |
| ACR122U0 | Reader | | < x, y, z, living > |

Apart from this database's table, there exist two additional structures: the first one containing the *rules* used by the reasoner module and the second one, an *event record* designed to store all the events that are thrown in the framework to facilitate controlling the smooth running of the system or managing unsettled situations.

### 5.2 Implementation details of the RFID Acquisition Layer

Figure 5 shows an excerpt of the Java program which supervises the USB reader to obtain the information of a card in its area of coverage. It uses some SmartCard related classes: firstly, it lists all the CardTerminals type objects connected to the computer. Then the CardTerminal to be used is selected by the command *getTerminal("Name of the terminal")*. At this moment, the reader is ready to get the information from the card, so the program will be waiting until any card is present. Then, a new connection *type=1* will be created with the new card, making it possible to send APDU (Application Protocol Data Unit to communicate smart cards and readers) commands to give instructions like ‘read card UID’, ‘write info’ and ‘read info’ through a basic logical channel. In our case, it will be only taken the card or tag UID using a specific APDU command. Once all the commands are executed, the program waits until the card is removed and the process is repeated.

```
TerminalFactory tf = TerminalFactory.getDefault();
CardTerminals ct = tf.terminals();
List<CardTerminal> l = null;
Card card = null;
try {
    l = ct.list();
} catch (Exception e) {
    System.out.println("Error listing Terminals: " + e.toString());
}
// Lectura del modelo del dispositivo
System.out.println("List of PC/SC Readers connected:");
ListIterator<CardTerminal> i = l.listIterator();
String reader = null;
while (i.hasNext()) {
     reader = i.next().getName();
     System.out.println("Reader: " + reader);
}
// IMPORTANT: change this to the PC/SC Name of your reader!!
CardTerminal c = ct.getTerminal(reader);
System.out.println("Terminal fetched");
try {
    while(true){
        c.waitForCardPresent(0);
(...)
```

FIGURE 5 – EXCERPT OF THE CODE FOR THE COMM. MANAGER.

## VI. CONCLUSIONS AND FURTHER WORK

RFID technology may have a relevant role as support for AHCS. As it has been explained in the previous sections, inexpensive passive RFID technology can be deployed to offer localization, activity detection and identification functionalities. Nevertheless, the accuracy and results of passive RFID alone are somehow limited, mainly due to contact requirements. For this reason, creating hybrid infrastructures which combine HF RFID with active RFID or Zigbee sensor networks and inertial systems may enhance the performance of activity detection strategies. This may simplify dealing with multiple users in the same smart space: an active (ZigBee or RFID) node (e.g. integrated in the PDA) can be permanently worn or carried by the user, so he is easily identified when next to another node of the same wireless sensor network. In the ZigBEe case, transmission power configuration may be used to reduce the area of coverage of the network nodes.

RFID interoperability issues are still open. Although OSGi and Java make the framework to be independent of the machine where it is deployed as long as it can support a Java runtime environment, some hardware related migration issues have been faced. For example, the drivers of the different RFID readers must be installed in the operating system where the framework runs; for Linux, a beta version of the driver is provided by the manufacturer and it does not work with the oldest version of pcscd daemon. Besides, mobile readers present also driver compatibility problems for new versions of some operative systems (the drivers of the SDiD reader do not currently support Windows Mobile 6.0). Nowadays, smart phones and PDAs are mainly equipped with a microSD slot and, although RFID microSD cards are available to enable for instance bank payments, it is difficult to find a RFID reader for this kind of slot. Nevertheless microSD to SD adapters can be used in order to attach a SD reader.

Apart from improving the service portfolio, our further work also includes the design of a module to detect non-catalogued tags that can be added during the operation of the system. In this way, when a new identifier is detected the framework will launch a service which interacts to the user to add and store in the database the functionality desired. Besides, the storing capabilities of the RFID tags can be used to make aware of its type and be able to send this information along with its identifier, so the framework will know which type of tag is without having to check the database.

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