International Journal of Antennas and Propagation

Traceability of Goods by Radio Systems: Proposals, Techniques, and Applications

Guest Editors: Iñigo Cuiñas, Robert Newman, Mira Trebar, and Luca Catarinucci

Traceability of Goods by Radio Systems: Proposals, Techniques, and Applications

International Journal of Antennas and Propagation

Traceability of Goods by Radio Systems: Proposals, Techniques, and Applications

Guest Editors: Iñigo Cuiñas, Robert Newman, Mira Trebar, and Luca Catarinucci

Editorial Board

Contents

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 616138, 2 pages
http://dx.doi.org/10.1155/2013/616138

Editorial

Traceability of Goods by Radio Systems: Proposals, Techniques, and Applications

Iñigo Cuiñas,[1] Robert Newman,[2] Mira Trebar,[3] and Luca Catarinucci[4]

[1] *Department of Signal Theory and Communications, University of Vigo, Rua Maxwell, 36310 Vigo, Spain*
[2] *School of Technology, University of Wolverhampton, Wolverhampton WV1 1SB, UK*
[3] *Faculty of Computer and Information Science, University of Ljubljana, Tržaška cesta 25, 1000 Ljubljana, Slovenia*
[4] *Department of Innovation Engineering, University of Salento, Via per Monteroni, 73100 Lecce, Italy*

Correspondence should be addressed to Iñigo Cuiñas; inhigo@uvigo.es

Received 22 September 2013; Accepted 22 September 2013

Years ago, the simple need for goods (food, clothes, tools, and medicines) was the main concern for the majority of people. At that time, the quality of such goods was a minor issue. However, as economic growth provides ever more people with the surplus income to choose and, more importantly, improved communications technology provides information supporting that choice, traceability of these goods became a must. This traceability represents something similar to the identity card of a product: it is the information on what, where, and when anything happens along the production chain. Assuring the traceability sequence and its veracity represents a key factor in the competitiveness of many industries in the developed countries: it is a way to compete against low-cost products with less origin guarantee and processing information.

Traceability processes traditionally involved paper procedures, systematic tasks, and so were tedious and error-prone jobs, requiring manual checking each item of a product and the taking of notes about its production processes. Radio technologies could be a solution to systematize the capture of traceability data, its management, and, importantly, its sharing amongst partners in a value chain. Sensors, wireless networks (WiFi and WiMAX), radiofrequency identification (RFID), near-field communications (NFC), personal area networks (PAN), and so on are only some examples of possible radio technologies involved in improving traceability methods. A significant effort has been made in the analysis, research, and application of such technologies to traceability purposes, as the data provided to the consumer can be the main success factor for the producer. These efforts include antenna and sensor design, radio propagation studies, electronic development, and regulatory aspects, among many others.

The contributors to this special issue were invited to analyze the different aspects related to the application of radio systems on traceability tasks. We were interested in papers that theoretically or empirically characterize the use of such systems in traceability applications, propose new antenna designs, introduce applications to different productive sectors, evaluate the impact on the supervised processes, and describe or develop techniques to improve the track of the products during their processing.

Some papers in this special issue put the focus on the propagation problem in storehouses, factories, and fisheries, places at which wet and metallic objects are installed all around. All of the papers are based on actual systems, installed and tested in authentic workplaces. Some of them also provide innovative solutions as specially designed antennas, data loggers, or propagation tailor-made studies.

The work presented by I. Angulo et al. is focused on the difficulties of deploying radio-based traceability systems in environments as unfriendly as storehouses. Specific needs, as environment characteristics and time required to be handled by workers, are taken into account along this paper, exemplified in a prototype of a system for tracking pallets loaded with electronic devices. The prototype is based on UHF-RFID technologies.

The paper authored by L. Mainetti et al. presents a gapless solution to provide traceability along the complete fresh vegetables supply chain. They analyze critical aspects in the management of such supply chain, in particular, those related to the cultivation in greenhouses and manufacturing packaged vegetables. They proposed a solution based on combining RFID and NFC and supported by international standards as EPCglobal. The proposed system allows the end user to know the history of the purchased vegetables.

A novel antenna system with applications in location and tracking of small laboratory animals is the content of the paper written by L. Catarinucci et al. They analyze the propagation considerations, the effect of the animals (simulated by phantom mice) in the radio channel, and also the tracking algorithm, in a paper covering antenna design, prototyping, and testing.

The application of RFID technology in the fish supply chain combined with data loggers to provide continuity for traceability purposes in terms of cold chain control is the main topic of the work presented by M. Trebar et al. They provide actual tests of radio systems working in wet and cold environments, as fish farming industry presents, which are not so auspicious for electromagnetic propagation.

The paper offered by I. Expósito and I. Cuiñas is devoted to the limitations of the use of RFID (and, in fact, any other radio-based technology) for traceability at beverage factories. The presence of metallic elements and liquids at most of such factories appears to represent a problem when a radiowave has to be propagated within this kind of environments. An experimental analysis on propagation limitations is presented along the work, providing results of tests performed by a large variety of RFID antenna designs.

Iñigo Cuiñas
Robert Newman
Mira Trebar
Luca Catarinucci

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 875973, 9 pages
http://dx.doi.org/10.1155/2013/875973

Research Article

RFID Data Loggers in Fish Supply Chain Traceability

Mira Trebar,[1] Metka Lotrič,[2] Irena Fonda,[2] Anton Pleteršek,[3] and Kosta Kovačič[3]

[1] *University of Ljubljana, Faculty of Computer and Information Science, Ljubljana, Slovenia*
[2] *Fonda.si d.o.o, Portorož, Slovenia*
[3] *ams R&D d.o.o, Ljubljana, Slovenia*

Correspondence should be addressed to Mira Trebar; mira.trebar@fri.uni-lj.si

Received 15 April 2013; Revised 18 June 2013; Accepted 20 June 2013

Academic Editor: Iñigo Cuiñas

Radio frequency identification (RFID) is an innovative and well-recognized technology that supports all kinds of traceability systems in many areas. It becomes very important in the food industry where the electronic systems are used to capture the data in the supply chain. Additionally, RFID data loggers with sensors are available to perform a cold chain optimization for perishable foods. This paper presents the temperature monitoring solution at the box level in the fish supply chain as part of the traceability system implemented with RFID technology. RFID data loggers are placed inside the box to measure the temperature of the product and on the box for measuring ambient temperature. The results show that the system is very helpful during the phases of storage and transportation of fish to provide the quality control. The sensor data is available immediately at the delivery to be checked on the mobile RFID reader and afterwards stored in the traceability systems database to be presented on a web to stakeholders and private consumers.

1. Introduction

Consumers are more and more interested in receiving the information about the food they purchase and consume. They want to know more about the food composition, the origin of materials, the process history, and handling actions during the delivery. The main problem is how to control the food safety and quality with a traceability system in the production and distribution processes which the mandatory in European Union since 2002 [1]: "The food law aims at ensuring a high level of protection of human life and health, taking into account the protection of animal health and welfare, plant health and the environment. This integrated "farm to fork" approach is now considered a general principle for EU food safety policy." Furthermore, the document encompasses the importance of solutions that will fulfil all requirements: "It is necessary to ensure that a food or feed business including an importer can identify at least the business from which the food, feed, animal, or substance that may be incorporated into a food or feed has been supplied, to ensure that on investigation, traceability can be assured at all stages."

In a global environment it is very important to strengthen the food control to enforce risk-based food strategies and gain consumers' confidence. The EU project "RFID from Farm to Fork" (RFID-F2F) was funded by the European Union to demonstrate the use of radio frequency identification (RFID) in the implementation of an internet-based traceability system in the food and drink supply chain [2]. Several pilots were defined to maintain product and information flow upstream from the farm to the fork which enables the downstream query of information from the fork back to the farm [3]. Additionally, the cold chain analysis was based on temperature monitoring by RFID technology to improve the quality control.

Recently, many food traceability solutions and cold chain monitoring of temperatures are presented with the use of RFID technology, sensor, and wireless technologies. These systems are showing direct benefits in quality, safety of products, and supply chain optimization with fast product recalls of perishable food. Actually, one of the proposed real time monitoring solutions for cold chain distribution was using all three different technologies to meet the marketing requirements [4]. The results showed that retailers could use inventory and quality information for the promotion of products and prevent delivery of spoiled products to customers. Demonstrations of fresh fish logistics chain with RFID smart tag developed for real-time traceability and cold chain monitoring show important advantages in comparison to conventional barcode identification and monitoring methods [5]. The high frequency (HF) is considered as the best solution for the integration of foods with water conditions. RFID readers are operating at 13.56 MHz with limited sensor tags, mobile and GPS which can automate the tasks and, have significant impact on stakeholders [6]. A transparent solution collects the temperature measurements in processing and reading distances of tags up to 1 m and USB connections to a host computer. Quality control, efficient storage, and transportation of frozen fish can also be well covered with RFID transport with the theoretical support to establish data integration network for food quality evaluation. Temperature monitoring systems are very important in fresh meat chain as a highly perishable product with a short-shelf life and are often designed with wireless sensor networks which can be replaced with RFID data loggers with sensors [7]. A holistic examination of temperature monitoring systems is presented with the objective of making an important contribution to optimal solutions in meat supply chains. Besides, the improvement of systems is based on the real time monitoring and decision support systems that can prevent damage of perishable food products during transportation [8]. The warning functions are based on RFID data and are used to set up an alarm when something unexpected occurs.

Nowadays, RFID technology is already recognised as a technology of many opportunities in food supply chain to improve the information flow and food safety. An overview of opportunities and constraints is reviewed to show the widen adoption of RFID technology in agri-food sector [9]. However, we can read about numerous pilot solutions, but the number of real applications is still limited due to various management or economic issues as the cost of devices and RFID tags is rather high and the benefits are not sufficiently recognised yet. Food traceability issues with barriers, technologies, performances, and many other attributes are very important for identification and implementation of an effective traceability system. About 74 studies were reviewed to highlight researchers on what they should focus on [10]. The most important are standardisation of data, integration of activities, technological aspects, strategies, and effective communication between stakeholders.

Very often, one of the issues connected to the distribution process of perishable food products, either fresh or frozen, is the increased temperature in trunks during the exposure to sun [11]. The importance of time-temperature control was recognised in the potential spoilage of food that can lead to the incidence of foodborne illness. The study presents guidelines about how to ensure food safety for consumers at home and also other stakeholders during the transportation. This is a good example of cold chain implementation with RFID data loggers to provide warning systems which are available on the internet or even on smart phones.

The main objective of the work is to explore the use of UHF semi-passive RFID data loggers in the traceability system of fresh fish supply chain. The analyses and evaluation results of RFID systems and temperature measurements in the pilot solution are used to represent the cold chain results to stakeholders. Additionally, the importance and some benefits of RFID technology are associated with experimental experiences. The paper is structured as follows. Section 2 presents the basic descriptions of RFID technology with hardware and software solutions, applications for control in the traceability system during logistics process. Several test results are discussed in Section 3 to introduce the benefits in the supply chain of the sea bass from processing room to retail and private consumer which is followed by the conclusion.

2. Materials and Methods

2.1. RFID Systems. The logistics process with warehousing of fish is performed by refrigerated vans transporting boxes and consists of three steps:

(i) the transport of boxes from processing room to the cold store,

(ii) keeping boxes of fish in the cold store during the night,

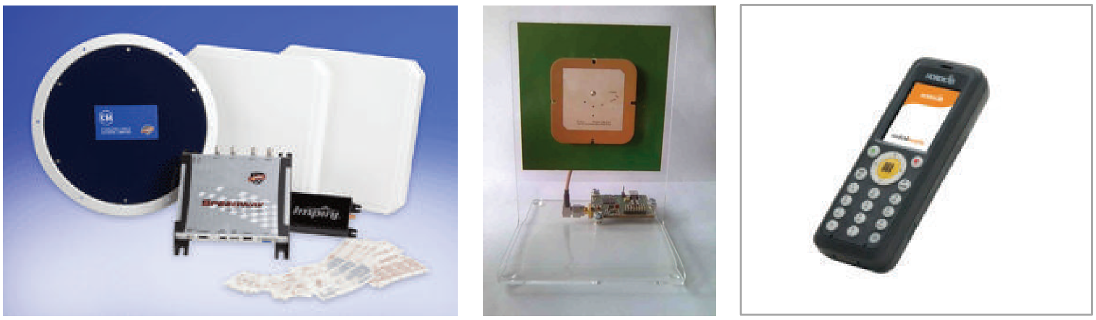
(iii) transport from cold store to the retail or private consumers.

RFID system in the ultra-high frequency (UHF), operating worldwide within the 860 to 960 MHz band, is used. It consists of a fixed RFID reader and two antennas from the producer Impinj (Figure 1(a)); product name is "Speedway Revolution UHF RFID Reader-R420" [12]. It is designed, to perform identification in a traceability system of boxes, as an RFID portal with two actions (receiving, shipping) based on an external button. Three light indicators are added to determine the present status of the portal: white—portal is on; green—receiving; red—shipping.

Furthermore, the cold chain was implemented with two types of RFID readers.

(i) Fixed UHF RFID reader (Figure 1(b)): UHF reader (reading range up to 1 m): ams AS3991 Low Power Evaluation Kit (ams AS3991 LP EVK) [13]. Reader is EPC Gen2 RFID integrated circuits incorporating physical layers of ISO 18000-6C. Adding a simple low-cost 8-bit microcontroller completes a high-performance Gen2 reader for handheld and embedded RFID reader applications. Built-in programming options make it suitable for a wide range of UHF RFID applications. New AS3992 reader generation offers functionality of the previous AS3991 chip and is dedicated to operation on the DRM link frequencies used in ETSI and FCC region.

(ii) Mobile RFID reader Nordic ID Morphic (Figure 1(c)) is a mobile computer which offers EPC G2 UHF RFID reader in a compact form with an output power of a 100 mW. Tags are typically read from a distance up to



(a) (b) (c)

Figure 1: (a) Impinj Speedway [12]; (b) ams AS3991 [13]; (c) Nordic ID Morphic [14].

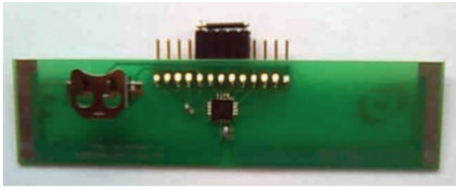
50 cm which is defined by manufacturer but can vary with the RFID tag type [14].

A prototype model of UHF RFID data logger is a semi-passive demo RFID tag as shown in Figure 2(a). The main module is SL900A chip, an EPC global Class 3 Gen2 compliant tag which is battery-powered smart label with cool-Log data logging commands [13]. Figure 2(b) shows the diagram of the chip dedicated to automatically track, monitor, time-stamp, and record information about any goods with shelf-life algorithm in the supply chain. The key features are the anticollision algorithm, the multilevel data protection, a smart power supply system and energy harvesting, and automatic sensors signal acquisition; programmable, scanning, and interrupt modes of data logging, a memory saving operation using multilevel limits selection, and innovative analogue nanotechnology architectures, based on low-leakage solutions. Chip supports logging data from an integrated temperature sensor with a typical nonlinearity of $\pm 0.5^{\circ}$C over the specified temperature range and from the two external analogue sensors. One of the most valuable features is the "interrupt triggered mode" on external sensor inputs that can be used for event-triggered logging, either from detecting the change of sensing parameter (the level of which is user defined) or from the external switch or microcontroller. At each trigger event the selected sensor values are stored. In addition to the sensor values, the real-time clock offset is also stored. Very important features of the smart label used in the described cold chain are temperature range -40°C to $+125^{\circ}$C, sensors measurement resolution 15 bit, temperature measurement accuracy $\pm 0.5^{\circ}$C, frequency 860 to 960 MHz, battery supply 1.5 V or 3 V, data logging from using on-chip temperature sensor and two external sensors, EPC Class 1 and Class 3 compliant, compatible with EPC Gen2, real-time clock for data logging, external sensor interrupt capability, serial peripheral interface, on-chip 9 K bit EEPROM, integrated dynamic shelf-life calculation, and advanced logging with 4 user-selectable limits. In additional to the Gen2 lock protection, the SL900A offers read/write protection using 3 password sets for 3 memory areas.

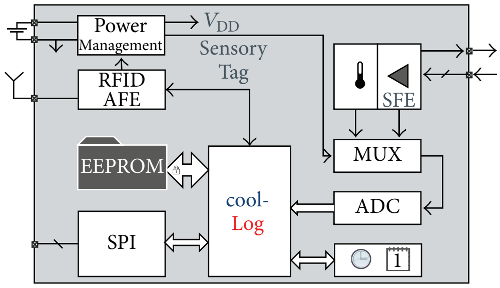
The analysis of RFID readers and RFID data loggers with temperature sensor (RFID-TL) was performed in the laboratory before the real implementation in the supply chain. The boxes of fish are made of Styrofoam; they contain the ice and also water when ice melts under higher temperatures. Furthermore, detailed tests of electromagnetic activities inside the styrofoam box were done to decide where to place RFID data logger. Several tests were performed to measure the maximum reading range of outside and inside the box, with and without ice. The position of RFID-TL regarding the reader is very important for handheld RFID reader with linear antenna which requires rectangular positions of RFID tag to be matched in polarization to obtain the best read range. It was acceptable to use the RFID reader for passive RFID tags and RFID data loggers with about 20 cm read range. The results show that the proposed RFID hardware could be appropriate for the purposes of a pilot. RFID temperature loggers and also RFID tags could be read through ice with Impinj reader [12]. Normally, many RFID tags attached to boxes were read as they pass near the reader antenna. For RFID-TL temperatures are read and checked in most cases by the delivery to the customer where they are removed from the box.

2.2. Fish Supply Chain. RFID traceability system was deployed in the northern part of the Adriatic Sea at the family owned fish farm [15]. The business process consists of complete supply chain of a very tasty, always fresh and high quality fish, "Piran sea bass." The main objectives of the fish pilot were the implementation of RFID technology as the "TRACK" function in the supply chain, including farm, processing, logistics and retail shown in Figure 3. The last step customer is also included but in the opposite direction as the "TRACE" operation to retrieve all the important information about the product.

A process of breeding sea bass from arrival of juveniles to the time of harvesting is monitored at the fish farm. The processing phase includes collecting orders, weighing, sorting, packaging fish into boxes, and applying cold chain control with aggregation of RFID-TL to the box. Each box is also labelled with RFID tag and printed information with QR (Quick Response) code and prepared for the transportation. After that, boxes are transported in the van to cold store and on the next day delivered to customers (retail, restaurants, supermarkets, and private consumers). At the delivery to the retail, RFID-TL is disaggregated from boxes which are then



(a)



(b)

FIGURE 2: (a) The ams data logger-SL900A; (b) EPC Gen2 C3 single-chip data logger scheme [13].

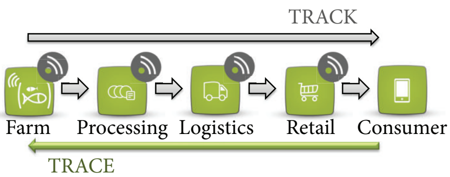


FIGURE 3: Fish supply chain.

placed in cold store until the fish is placed on the ice to be displayed for sale.

The use of RFID technology in supply chain is based on the standardized solution of EPC global network. The architecture is easy to use and it is easy to implement the mechanisms of the data interchange between servers, called EPC Information Services [16]. For the project GS1/EPC global format was selected which is currently used worldwide [17], is the format of choice when interacting with EPCIS, and allows to encode information suitable for business processes. The EPC (Electronic Product Code) uniquely identifies each single entity being traced. It is stored on the RFID tag and is a standard that defines EPC Gen2 tag data for products (GTIN—Global Trade Identification Number and SGTIN—Serial GTIN), EPC global Class 3 tag data for assets (GRAI—Global Returnable Asset), and locations (GLN—Global Location Number). The unique identification is composed of three parts: manager ID, object class, and serial number which exactly specify traceable units.

2.3. Cold Chain. The demonstration of cold chain experiments is done with RFID data loggers with temperature sensor (RFID-TL). It is comprised of the following steps:

(i) RFID-TL initialization and Start Logging;

(ii) placement of RFID-TL in the box (aggregation);

(iii) identification of RFID-TL on the portal;

(iv) removal of RFID-TL from the box (disaggregation);

(v) Stop Logging and collection of temperature measurements.

Cold chain control was implemented during the pilot deployment in year 2012. Test scenarios were setup for the following options:

(i) ambient temperatures when RFID-TL is placed on the box;

(ii) temperatures inside the box when RFID-TL is placed between or on the top of packed fish;

(iii) temperatures of the fish when RFID-TL is placed in the gutted fish which is covered with ice.

Figure 4 shows the logistic process with the control of temperatures that starts at the processing room in Seča when all orders are prepared for the transport. The boxes are placed into the van which delivers them to the cold store in Izola where the second phase of processing takes place. For customers that ordered gutted or fileted fish, the cleaning and packing processes are performed. After that all boxes are placed in the cold store. Next day, the boxes are delivered to the customers where the cold chain control ends, RFID-TLs are removed from the box, and sensors data is checked and uploaded to the traceability server.

The tests were performed on two types of packaging methods of fish in different boxes. An open white styrofoam box is used for retailers, restaurants, and supermarkets which buy larger quantities of fish that are completely covered with ice in the packing process. Another type of smaller boxes which are tightly closed is used for the delivery directly to customers at any location and ensures the required temperature conditions. The cold chain control is divided into three phases.

(i) Initialization of RFID data loggers is done in the processing room before the use. The mobile RFID reader is used to aggregate RFID data loggers with the box before their placement between the fish inside the box and outside the box. This is done before the box is filled with ice.

(ii) The identification of RFID data loggers is recorded on RFID portal in cold store to record their presence during the logistics process.

(iii) RFID data loggers are removed from the box at the delivery to the customer. They were disaggregated with the box, and temperature measurements were read and stored to the sensors database.

Figure 5 shows the first step in the cold chain process. Mobile RFID reader application reads the EPC code of RFID-TL (Figure 5(a)) and then the EPC code of a box (Figure 5(b))

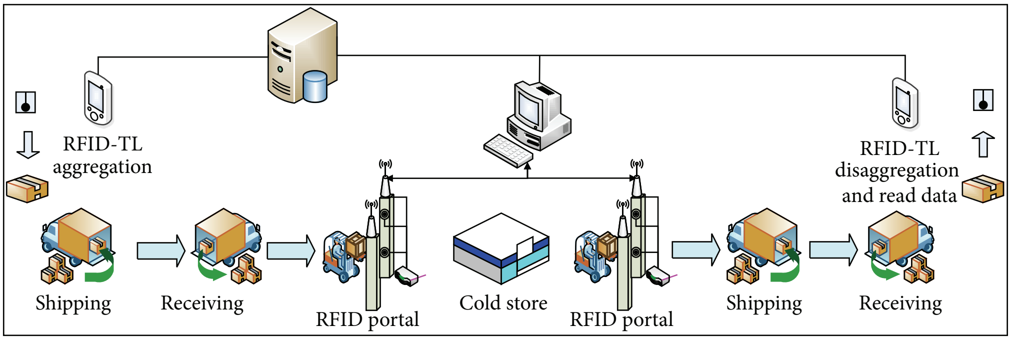


Figure 4: Logistics process.

to perform the aggregation of both codes in the EPCIS events sent to the database of traceability system.

In the next step, two RFID-TLs are placed in the white box to be used in the second step of the processing (Figure 6(a)) where three different options of measuring temperatures in the box are presented to analyse the results. We measured temperatures for two various ways where one RFID-TL is placed in the gutted fish (Figure 6(b)) and between the fish (Figure 7(a)).

Finally, the ice is placed on the fish to maintain low temperatures, the box is covered and closed with adhesive tape. Figure 7(b). shows how the second RFID-TL is attached to the box to be stored in the cold store. The fish box is after that transported to the cold store and on the next morning to private consumer where the process of disaggregation is performed, and RFID-TLs are removed from the box (Figure 8). A mobile RFID reader is used to generate events, to read temperatures from the user memory and to send data to sensors database. Furthermore, another application on mobile RFID reader supports the inspection of temperatures which gives the company immediate control of processes and handling conditions of delivery.

The initialization parameters of RFID-TLs were setup in advance on fixed RFID reader to use the same configuration in all tests. Log Interval for temperatures to be stored in the user memory was six minutes. Start Logging command was used at the beginning of each test to enable the cold chain control, and Stop Logging was used to stop recording temperatures.

2.4. Software Applications. Two applications were developed for the cold chain implementation to be included in the fish pilot: (i) initialization and examination of data for RFID-TL; (ii) aggregation of cold chain in the fish pilot. The third application on RFID portal was developed for the fixed Impinj Speedway reader [12] which was used as a part of traceability system and was also detecting the presence of RFID-TLs during logistics process with that application.

Initialization of RFID-TLs is performed on UHF RFID fixed reader [13] which is connected to the computer. The application is defined with a graphical user interface (GUI) to control initialization of each RFID-TL with constant specifications used in all tests. GUI is divided into two sections—the Tab section (current selected tab) and the Log section (communication data). Tab section consists of: (i) Settings—definition of RFID-TL parameters with start and stop logging; (ii) Plot—temperature graph.

The tab Settings (Figure 9) supports the following.

(i) Start Logging—set up of logging parameters and start logging temperatures.

(ii) Stop Logging—stop logging and storing temperatures.

(iii) Set Zeros—reset the user memory.

The predefined parameters for cold chain experiments in fish supply chain are as follows.

(i) Start Time: RFID-TL starts logging with Execute button (now).

(ii) Delay Time: 00:00 (no delay).

(iii) Logging form:

  (a) Dense—all measurements defined with Log Interval are stored in user memory;

  (b) Out of Limits—only measurements that fall out of specified limits are stored in the user memory;

  (c) Limits Crossing—measurements that cross the limits are stored in the user memory.

(iv) Log Interval (MM:SS)—specifies the period between two temperature measurements.

(v) Sensor Enable—temperature sensor is enabled or disabled.

(vi) The last four parameters are used to specify limits with selected logging forms Out of Limits and Limits Crossing.

Afterwards, in the experiments with the predefined parameters only Start Logging is required before RFID-TL is placed in the box to measure temperatures of the fish during the transport and warehousing. Stop Logging is used at the end of the control process to have RFID-TL ready for the next test.

(a) (b)

Figure 5: RFID-TL (a) is identified; and (b) aggregated with the box.

(a) (b)

Figure 6: RFID-TL (a) in a box; (b) into the fish.

The tab option Plot shows the graph of temperatures stored in the user memory on RFD-TL. Furthermore, all initialization parameters with the number of temperature measurements and other parameters are shown in Figure 10. The temperature measurements can be exported in an Excel sheet to be used for further analyses.

The second cold chain application was designed on hand-held RFID reader to define aggregations and disaggregations of RFID-TL inserted in the box. A simple GUI is used to perform reading of EPCs in two steps at the beginning and at the end of the cold chain activities. In the aggregation are first scanned EPC code of RFID-TL and after that EPC code of the box in which RFID-TL is placed. At the end, when disaggregation is performed a process of reading temperatures from the user memory on RFID-TL is added. In both cases, scanned EPCs are used as a part of pilot solution where data is uploaded to F2F project traceability server. Temperature measurements were also uploaded in the real time to the server and stored into sensor database. The results were used to realize all benefits from RFID traceability in the supply chain by identifying and tracking assets that performed cold chain control.

3. Results and Discussion

The UHF RFID monitoring system is affected by environmental conditions when RFID reader is used to read sensors data that was logged on RFID-TL during the logistic stage. Any conductive material or humidity may suppress the electromagnetic field strengths which affects the reading reliability. Possible solutions are multiple antennas placed in the area and using the DRM (dense reader mode) feature of modern readers [12]. Amplitude and phase (AM&PM) demodulation is also a useful feature to eliminate communication holes through automatic I/Q selection and frequency hopping [13]. The Impinj reader was capable of reading EPC code and temperatures of RFID-TL inside the fish box when passing the cold store gate. The battery assisted logging function on RFID-TL does not need any electromagnetic field and is therefore unaffected by the environment. RFID-TL is removed at the end of the monitoring phase from the box and the data is read out in the “clean” environment.

Cold chain tests are part of the logistics phase in fish supply chain which comprises of the warehousing in cold store and transport of fish which is completed in two days.

(a) (b)

Figure 7: RFID-TL (a) is placed between the fish; (b) closed styrofoam box.

Figure 8: Read RFID data logger.

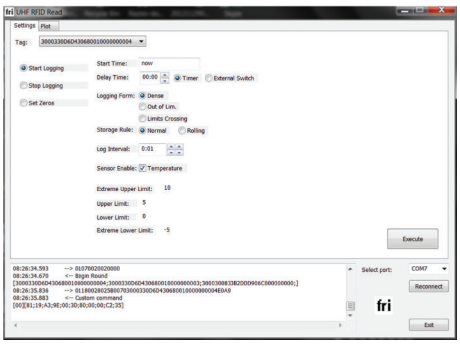


Figure 9: RFID-TL application-Settings.

Packed boxes are three times per week transported from processing room located in Seča to the cold store in Izola where they are stored over the night. Boxes are next morning transported from cold store to retailers, restaurants, supermarkets, and private consumers. The RFID implementation in cold store consists of the identification of boxes labelled with RFID tags and included RFID-TLs. Three automatic control functionalities are as follows

(i) shipping boxes from the processing room;

(ii) receiving boxes at the cold store;

(iii) shipping boxes from the cold store to customers.

The presented solution is implemented with RFID portal, placed on the cold store door and connected to the computer.

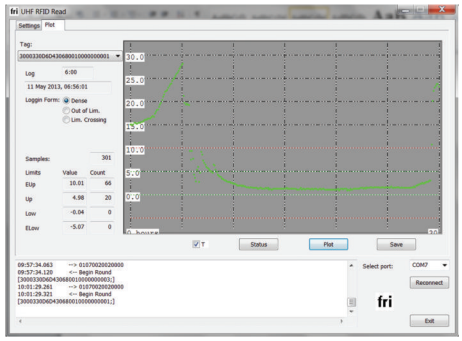


Figure 10: RFID-TL application—Plot.

RFID reader identifies each box with unique Electronic Product Code (EPC) which is stored in RFID label printed in the processing phase. Additionally, reusable RFID data loggers with sensors are added in the processing phase and removed from the box at the delivery to customers. Each device is also identified on RFID portal with unique EPC specified as assets by traceability standard and aggregated with the box EPC to link temperature measurements with the delivered box of fish. At each step, computer applications generate events to be uploaded to EPCIS repository on the server.

Several tests including monitoring of temperatures were performed during the evaluation of the traceability system to analyse the performance of RFID technology in fish supply chain. All applications were developed and programmed for the fish pilot deployment based on requirements of business processes. For RF communication of readers and tags low level protocol specifications were used. The data was stored in EPCIS based repository which was built on Fosstrak Open Source RFID Platform [18].

The results of two cold chain tests are presented in the graph (Figure 11) to analyse the temperatures for different placement of RFID-TLs which has an important meaning in interpretation of received results. The first test was done for the transport from Seča to Treviso. RFID data loggers were placed in the box between the fish to measure the temperature inside the box and on the box to measure ambient temperature. They were initialized on 23 April 2012

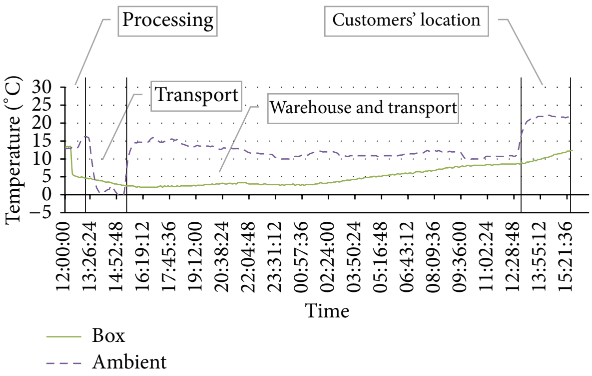


Figure 11: Temperature graph (Seča, 23.4.2012—Treviso, 24.4.2012).

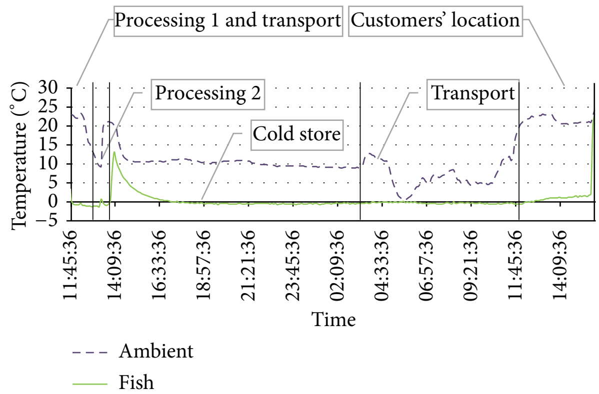


Figure 12: Temperature graph (Seča, 7.6.2012—Ljubljana, 8.6.2012).

before they were prepared with the fish order for the private customer to be sent to the home address. The delivery was made directly to the logistics partner in Italy where it was stored during the night and the next day delivered to the customer. Figure 11 shows the cold chain process with temperatures during the following.

(i) Processing—RFID-TL is close to the ice in the white box and temperature in the box very quickly reaches required temperatures between 0°C and 4°C.

(ii) Transport—the box was transported in a cooled van by the company from Seča to the logistics partner in Italy. Temperatures in the van were very low, approximately 0°C, and temperatures in the box decreased to the lowest temperature about 2°C.

(iii) Warehouse and transport—the box was stored in the warehouse (cold store) with temperatures between 10°C and 15°C which caused the temperatures in the box to start increasing which is extended also in the last part when the box was transported to the customer.

(iv) Customers' location—when the box was delivered to the customer it was left in the room with higher temperatures between 20°C and 25°C which caused also faster rise of temperatures in the box.

The ambient temperature caused melting of ice, and temperature in the box has slowly risen. In this case it is very important the position of RFID logger where it measures the temperature.

The second test was analysed for the transport from Seča where the box was received at the laboratory in Ljubljana. RFID data loggers were placed inside the fish and on the box to measure ambient temperature. The logistics process consisted of the transport from processing room to the cold store in Izola and on the next morning to the customer. Figure 12 shows the cold chain process with temperatures:

(i) Processing 1 and transport—RFID-TL is placed directly under the ice in the white box and temperature very quickly reaches temperatures under 0°C. During the transport in a cooled van from Seča to Izola the ambient temperature was also decreased.

(ii) Processing 2—the RFID-TL was removed from the white box, the fish was cleaned, and temperatures in the room increased approximately up to 12°C before the fish was packed into the new box for the private customer where temperatures were decreasing again after the packing process.

(iii) Cold store—the box was stored over the night where the temperatures were around 10°C. The temperature of the fish decreases and is all the time around 0°C.

(iv) Transport—the delivery of boxes was performed on the next morning in a cooled van from coldstore in Izola to customer locations. Ambient temperatures vary when the boxes are prepared for the transport and when the van is opened during the delivery process. This doesn't have any influence on the temperature of the fish which is all the time constant around 0°C.

(v) Customers location—when the box was delivered to the customer it was left in the room with higher temperatures, and temperatures of the fish continued to rise very slowly. The last temperature is recorded at the time of removing RFID-TL which caused the last measurement to be the same as ambient temperature.

The performance analyses of the hanheld RFID reader were done in real environment for aggregations and disaggregations where EPC code of one box and one RFID-TL were read one after another.

The proposed traceability solution and cold chain implementation in logistics and warehousing stage use the same technology based on UHF band which enables the use of the same hardware for two tasks which is not the case in [5] where high frequency RFID technology is used which is not compliant with GS1 traceability standard. According to the solution with sensor devices [8] and wireless sensor networks (WSNs) in our case these systems can be replaced with reusable RFID data loggers to save on the equipment cost. In comparison to other systems [6, 10], this paper presents an improved solution of item identification in the food supply chain which is upgraded with monitoring data. It is a standardised approach supported by GS1 organisation that includes all stages in the supply chain even if they are maintained with several partners. The most important benefit of this technology is the electronic collection of temperatures with data that can be shared worldwide. The implementation of cold chain requires reusable RFID data loggers with temperature sensors of $\pm 0.5^{\circ}$C accuracy. Additionally, the history information about the product will be supported by cold chain data and available to consumers.

4. Conclusions

The logistics phase of the food supply chain is very important to guarantee the food quality and freshness. The transport and warehousing of boxes were a part of the traceability system controlled by RFID readers at the end of processing and on the entrance door of the cold store with receiving and shipping processes. RFID portal performed identification of boxes and RFID data loggers that pass through the door. The results were used in other applications to verify customer orders.

The paper presented the analysis of cold chain as a part of traceability pilot performed with RFID technology from fish farm to consumers. The main elements and functionalities of such systems were evaluated, used in the fish supply chain, but they could be easily extended to other food sectors. Some drawbacks of the technology still exist due to the reason of high prices of RFID readers and passive tags when we are talking about small quantities of traced items in the supply chain. This is not the case with RFID-TLs which are reusable smart tags that could be successfully applied in the existing RFID system. Additionally, companies are not aware of the benefits, or they already have a barcode system which is working well.

The future work will be oriented towards the design and implementation of a monitoring system with RFID data loggers that supports shelf-life calculations and recognizes critical measurements that need to be examined.

Acknowledgments

This work has been supported by the European Commission (CIP-Pilot Actions), under the project “RFID from Farm to Fork” Grant Agreement no. 250444 and ARRS Program P2-0359 Pervasive computing.

References

[1] “Regulation EC/178/2002,” http://ec.europa.eu/food/food/foodlaw/principles/index_en.htm, 2013.

[2] “RFID-F2F (RFID from Farm to Fork) project web page,” http://www.rfid-f2f.eu/, 2013.

[3] I. Cuiñas, L. Catarinucci, and M. Trebar, “RFID from farm to fork: traceability along the complete food chain,” in *Proceedings of the Progress in Electromagnetics Research Symposium (PIERS ’11) Marrakesh*, pp. 1370–1374, March 2011.

[4] J. Shi, J. Zhang, and X. Qu, “Optimizing distribution strategy for perishable foods using RFiD and sensor technologies,” *Journal of Business and Industrial Marketing*, vol. 25, no. 8, pp. 596–606, 2010.

[5] E. Abad, F. Palacio, M. Nuin et al., “RFID smart tag for traceability and cold chain monitoring of foods: demonstration in an intercontinental fresh fish logistic chain,” *Journal of Food Engineering*, vol. 93, no. 4, pp. 394–399, 2009.

[6] J. Zhang, L. Liu, W. Mu, L. M. Moga, and X. Zhang, “Development of temperature-managed traceability system for frozen and chilled food during storage and transportation,” *Journal of Food, Agriculture and Environment*, vol. 7, no. 3-4, pp. 28–31, 2009.

[7] V. Raab, B. Petersen, and J. Kreyenschmidt, “Temperature monitoring in meat supply chains,” *British Food Journal*, vol. 113, no. 10, pp. 1267–1289, 2011.

[8] L. Wang, S. K. Kwok, and W. H. Ip, “A radio frequency identification and sensor-based system for the transportation of food,” *Journal of Food Engineering*, vol. 101, no. 1, pp. 120–129, 2010.

[9] C. Costa, F. Antonucci, F. Pallottino, J. Aguzzi, D. Sarria, and P. Menesatti, “A review on Agri-food supply chain traceability by means of RFID technology,” *Food and Bioprocess Technology*, vol. 6, no. 2, pp. 353–366, 2013.

[10] T. G. Bosona and G. Gebresenbet, “Food traceability as an integral part of logistics management in food and agricultural supply chain,” *Food Control*, vol. 33, no. 1, pp. 32–48, 2013.

[11] S. A. Kim, S. J. Yun, S. H. Le, I. G. Hwang, and M. S. Rhee, “Temperature increase of foods in car trunk and the potential hazard for microbial growth,” *Food Control*, vol. 29, no. 1, pp. 66–70, 2013.

[12] “Impinj Speedway,” http://www.impinj.com/Speedway_Reader_Evaluation_Kits.aspx, 2013.

[13] “ams R&D d.o.o,” http://www.ams.com/eng/Products/RF-Products, 2013.

[14] “NordicID Morphic,” http://www.nordicid.com/eng/products/?group=3&pid=33#, 2013.

[15] “Fonda fish farm,” http://www.fonda.si/, 2013.

[16] “EPC Information Services (EPCIS) Version 1. 0. 1 Specification,” http://www.gs1.org/gsmp/kc/epcglobal/epcis/epcis_1_0_1-standard-20070921.pdf, 2013.

[17] “GS1 Standards Knowledge Centre,” http://www.gs1.org/gsmp/kc, 2013.

[18] “Fosstrak Open Source RFID Platform,” https://code.google.com/p/fosstrak/, 2013.

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 263218, 9 pages
http://dx.doi.org/10.1155/2013/263218

Research Article

Towards a Traceability System Based on RFID Technology to Check the Content of Pallets within Electronic Devices Supply Chain

Ignacio Angulo,[1] Asier Perallos,[1] Leire Azpilicueta,[2] Francisco Falcone,[1,2] Unai Hernandez-Jayo,[1] Asier Moreno,[1] and Ignacio Julio García Zuazola[1]

[1] *Deusto Institute of Technology (DeustoTech), University of Deusto, 48007 Bilbao, Spain*
[2] *Electrical and Electronic Engineering Department, Public University of Navarra, 31006 Pamplona, Spain*

Correspondence should be addressed to Francisco Falcone; francisco.falcone@unavarra.es

Received 15 April 2013; Revised 4 July 2013; Accepted 19 July 2013

Academic Editor: Mira Trebar

In the last few years there has been a growing interest in smart solutions capable of dealing with the traceability of products and materials to improve logistical processes. Most of the existing solutions have been designed without considering the difficulties of deploying traceability systems in the storehouses currently working, not dealing with specific needs, such as environment characteristics or time required to be handled by workers. In this paper, in order to test the viability of its application, a first prototype of a traceability system capable of checking the content of pallets loaded with electronic devices is presented. It is based on ultra-high frequency (UHF) radio frequency identification (RFID) technology using passive tags. A holistic approach has been adopted to design the system: it begins with a radioelectrical characterization of the environment where the check points will be implemented, continues with the integration of a set of data acquisition and wireless communication devices, and ends with a logistics information system able to provide final user services. The combination of physical layer analysis with a top layer system view can aid the planning as well as operational phase of this type of RFID system within a logistic chain.

1. Introduction

Assuring the traceability of goods and its veracity represents a key factor in the competitiveness of many industries in developed countries. First, it is a way to compete against low-cost products with less origin guarantee and processing information. Second, in those markets regulated by governments, where all competitors are offering the same products at similar prices and service quality is a decisive factor, traceability of products represents a key factor to its improvement.

In the last few years there has been a considerable interest in the global concept of traceability of products and materials. Traceability processes traditionally required manually checking each item of a product and taking notes of its production processes. Thus, there is a growing need for smart solutions in logistics to deal with this challenge and improve the supply chain. Several research works have been developed which explore different aspects of traceability of goods [1, 2] applied to different types of industries [3, 4] and needs [5]. Even more important is the interest in sectors where traceability is not only a productive benefit, but a health or safety necessity. This is the case of food or pharmaceutical ones, where recently some work related to traceability of medicines has been published [6].

The main problem is that most of these existing solutions have been designed without considering the difficulties of deploying traceability systems in the storehouses currently working. Thus, they are not capable of dealing with specific needs that exist in certain sectors, such as the nondesired intrusiveness with the workers or the time required to be handled. Radio technologies could be a solution to systematize the capture of traceability data, its management, and, importantly, its sharing amongst partners in a value chain. Wireless networks, such as WiFi, or radiofrequency identification technologies, such as RFID, are some examples of possible radio technologies involved in improving traceability methods.

Radiofrequency identification (RFID) system is an autoidentification method that can read codes that were previously stored in small transponders/tags wirelessly. Unlike barcodes, RFID does not require imminent handling, no line of sight is required between the reader and the tags, and these ones provide greater storage (64 bits, 96 bits, and 496 bits). The tags can be active (battery powered) or passive. This technology uses attached tags for monitoring and identifying objects in an omnidirectional fashion, creating tremendous benefits in a very different kind of applications like traceability of goods, baggage management, livestock tracking, and supply chain management [7].

In this paper, in order to test its feasibility, a first prototype of a traceability system capable of checking the content of containers (pallet) loaded with electronic devices is explored. The system is based on a set of check points distributed along the agents of the supply chain which are able to identify every electronic device contained in each pallet. Thus, the system is capable of detecting, by comparison with previous readings, if some of them are lost during the distribution process, when, and the area where the theft or loss has occurred at the specific stage in the distribution chain. The identification is done by ultrahigh frequency (UHF) RFID technology using passive tags, adopting a nonintrusive approach. A logistics software system is responsible for gathering the data in each check point, which are sent using available WiFi networks, and detecting incidences.

The rest of the paper is organized as follows. Section 2 presents some problems that occurred during the distribution of electronic devices, the partners involved, and the specific scenario where the proposed traceability system would be deployed and finally gives an overview of the benefits that this system would generate. Section 3 includes a radioelectrical characterization of the environment where the check points will be implemented. Section 4 describes the current hardware and software tracking prototype implementation, considering the different parts which conform it: the RFID based check points, the logistics software system, and the set of data acquisition and wireless communication devices. And finally, conclusions and references end the paper.

2. Problem Description

Nowadays, when small or medium sized goods must be delivered in big quantities, pallets are the most used platform to bring them together. Goods can often be packaged individually or some of them are saved in the same cardboard box. Then, the boxes that must be delivered in the same destination are placed on a pallet and wound with plastic or another material (sometimes a wood protection box is used) with the aim of maintaining all the freight together during the transportation. In Europe, the maximum dimensions of the pallets are 1.8 m height and 1.2 m width.

Each element of the freight can be identified using different techniques, being barcodes the most common one. But this system is not useful if the pallet is already composed: the elements that are not in the edge of the pallet cannot be read because there is not a line of sight between the barcodes and the reader. Moreover, the reading of the barcodes is performed one by one, and this task takes a certain time. Another alternative is not to identify each element of the pallet but to assign one code to the whole pallet. In a database this code represents and relates all the elements of the pallet. The drawback of this technique is that in case one element is stolen or lost, this event is not detected until the pallet is unpacked and all the goods are checked.

This situation can be solved if all the elements are equipped with RFID tag and an RF reader is placed in the passing area of the pallet. With the RFID based system presented in this paper, all the elements of the pallet can be identified and registered in the traceability or stocking application (no line of sight is required to carry out the reading) at the same time slot. But in this scenario, the successfulness of the reading depends mainly on the propagation characteristics inside the pallet and the distance between the reader and the tags. The materials used to package the goods and their own physical composition determine the attenuation, absorption, and reflection of the RF signal detected by the RF reader once the RFID tag has been excited.

In the specific case of the consumer electronic market, large surfaces and group of stores concentrate mainly on the sales of these products. The products can be supplied from producers or from assemblers and are transported by logistics operators to selling points and coded and displayed on the shelves.

To make it easier and more competitive, large stores are pursuing initiatives to manage the traceability of high value goods. For example, as part of GS1 Italy's i.Trace initiative [8], MediaMarkt, a leading European electronics retailer, in partnership with DHL, Sony, and Samsung, recently completed a successful pilot of EPC-enabled RFID technology for high-value consumer electronics. In this pilot 14,000 units were tagged, including notebooks, digital cameras, video games, and mobile phones. A lift truck driver transports completed pallets through a dock door portal equipped with an RFID reader. By moving through the portal, the system automatically reads the tags and records the quantities and serial numbers of each stock-keeping unit (SKU) that is being loaded into the truck. At the store's receiving dock, inbound pallets are again transported through another gateway portal and are automatically received. A second gateway portal between the store's backroom and the sales floor automatically traces and records the individual serial numbers that are being moved to the store floor.

In the case of purchasing centers, the diversity of shops grouped further complicates the development of a solution that fits all. Sometimes the small size of the storage infrastructure complicates the installation of infrastructures so that, in the proposed system, the identification of the goods at the point of sale is carried out using a low-cost portable reader.

In this common scenario, the presented solution will be carried out in three phases.

(1) The main warehouse of the purchasing center will be provided with an UHF RFID portal in order to detect and validate the SKU of the devices sent by producers through their own logistics operator.

(2) The warehouse staff will validate each pallet or package shipped to stores through its own shuttle service using a handheld reader, deployed on every delivery vehicle.

(3) Inventory managers at the stores will validate the receipt of the requested units in each purchase order using the same reader related to the previous stage.

This solution also enhances the security of the supply chain leading to fewer losses, reduces the time it takes to process store shipments, and provides inventory managers with a method to detect "stock-out" events.

3. Radioelectrical Analysis

Channel performance directly determines the quality of the communication in terms of sensitivity, capacity, and latency. Therefore, a very clear understanding of the channel must be pursued to get high-quality and high-capacity transmission of the useful information to give an efficient service. In order to analyze the impact of an RFID system on a logistics company, a deterministic method based on an in-house developed 3D ray launching code [6, 9–12], tested in complex indoor environments, is used. The assessment on electromagnetic spectrum is of importance in order to model overall performance of the system under analysis in terms of coverage and capacity analysis. A 3D ray launching algorithm has been implemented in-house based on Matlab programming environment. The algorithm is based on geometrical optics (GO) and geometrical theory of diffraction (GTD). The rays that are considered in GO are only direct, reflected, and refracted rays. Abrupt transition areas may occur because of this, corresponding to the boundaries of the region where these rays exist. To complement the GO theory, the diffracted rays are introduced with the GTD and its uniform extension, the uniform GTD (UTD). The purpose of these rays is to remove the field discontinuities and to introduce proper field corrections, especially in the zero-field regions predicted by GO.

Within the considered scenario, several sources (which can emulate the transmitter antennas of the readers) can be placed, in which wireless power is converted into a finite number of rays launched within a solid angle. Parameters such as frequency of operation, radiation diagram of the antennas, number of reflections, separation angle between rays, and cuboids dimension can be fixed. The commitment between accuracy and computational time is acquired with the number of launching rays and the cuboids size of the considered scenario. The benefit of this approach in radioelectric estimation is the fact that the proposed 3D ray launching algorithm can be employed in order to compute RFID reader link balance within the completed indoor scenario, which is computationally demanding in the case of full wave simulation codes. Moreover, time domain results such as delay spread can be obtained, which can be employed for further uses, such as location applications.

In order to analyze the performance of the propagation channel in a typical scenario of traceability in a logistic company, a simplified pallet with boxes of different materials, which emulate different products, has been developed for the 3D ray launching code. The pallet has 1000 mm × 1200 mm × 200 mm dimensions. Figure 1 shows a schematic view of the considered pallet for simulation with ten rows of 16 boxes each. The transmitter position is depicted with a red point just above the boxes, emulating the transmitter antenna of the RFID reader which is integrated in the pallet truck.

Several simulations have been performed to analyze the impact of different materials of the products on the pallet. The properties of the materials have been taken into account considering their dielectric constant and the loss tangent at the frequency range of operation of the system under analysis. These properties are shown in Table 1. Table 2 shows the parameters used in the simulations in the 3D ray launching code.

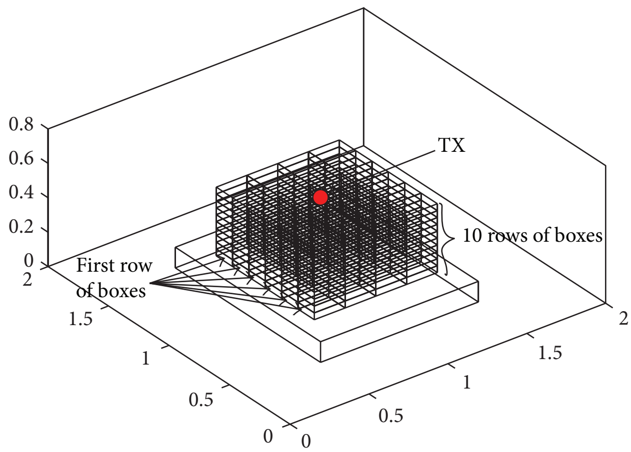


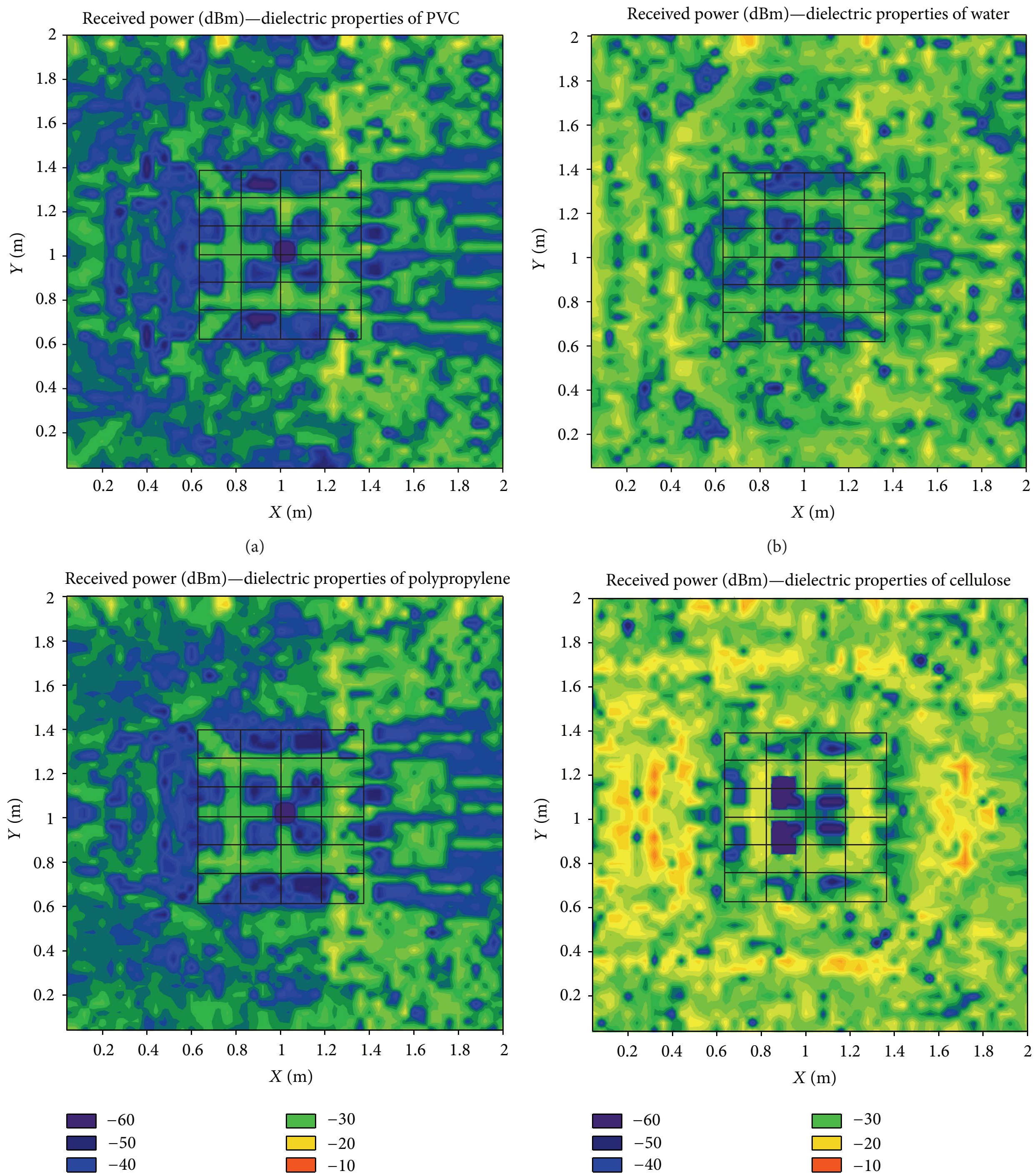
Figure 1: Details of the considered scenario for simulation.

Table 1: Different material properties.

	ε_r	σ (S/m)
Polyvinyl chloride (PVC)	4	0.12
Polypropylene	3	0.11
Drinking water	20	0.01
Cellulose	1.1	0.035

Table 2: Parameters in the ray launching simulation.

Frequency	868 MHz
Vertical plane angle resolution $\Delta\theta$	1°
Horizontal plane angle resolution $\Delta\varphi$	1°
Reflections	6
Transmitter power	0 dBm
Cuboids size	4 cm



(a) (b) (c) (d)

Figure 2: Received power (dBm) for the first row of boxes in the pallet for different material products considered. (a) Polyvinyl chloride (PVC). (b) Drinking water. (c) Polypropylene. (d) Cellulose.

Figure 2 shows simulation results obtained by means of in-house 3D ray launching algorithm for the received power for the bidimensional plane for the first row of boxes in the pallet which is depicted in Figure 1. The received power is shown for different material products considered, emulating different pallets of the same product for traceability applications. It is observed that the material properties have a great impact on the radiowave propagation. For all cases, the received power in a tag which could be positioned in each box of the first row can be read because the received power is greater than the reader sensitivity. However, it is highly important to consider this radioplanning assessment because

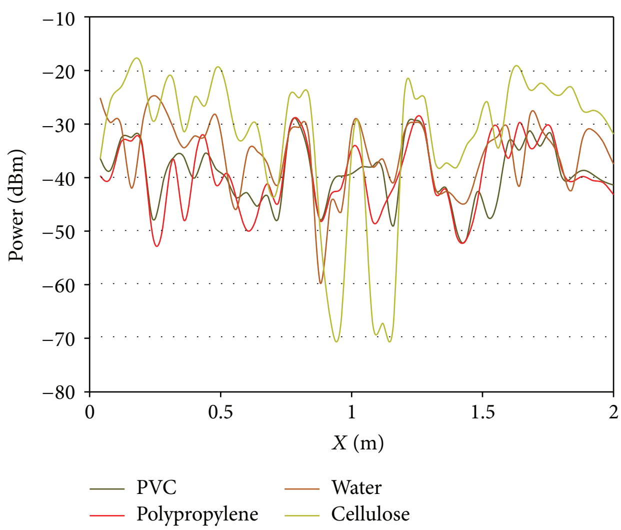


Figure 3: Radials of received power for different materials for the center of the first row of boxes.

the different dielectric properties of the materials could lead to unread tag cases and give errors in the traceability application.

The comparison among the different materials considered for the first row of boxes along the x-axis, for $Y = 1.1$ m is represented in Figure 3. It is observed a great variability between the different positions of the receiver. It is also shown that, for the cellulose material, the received power is slightly higher than for the other materials.

To validate previous predictions, measurements with a real pallet have been performed. Figure 4(a) shows the real pallet with the transmitter antenna just above the column of boxes. The tag antenna, Confidex Carrier a Class 1 Generation 2 passive UHF RFID Transceiver, was located inside the boxes randomly on the top of wrapped electronic circuit boards. The reader and antenna features are detailed in the next section. Figure 4(b) shows a schematic view of the considered pallet for simulation.

Figure 5 shows the comparison between simulation and measurements, exhibiting good agreement with a mean error of 0.67 dB. The received power levels have been obtained by embedding a very short monopole connected to an Agilent Field Fox N9912A spectrum analyzer. The results indicate that the received power decreases with the distance to the transmitter due to the impact of the electronic circuit boards inside the boxes.

From the previous results, a clear dependence on the location of both reader and potential tag placement on the overall radiolink balance can be observed. Moreover, as the material properties of the elements which host the RFID tags as well as the intrinsic properties of the tags (i.e., tag radar cross-section and chip level mismatch) also have impact on the received power, it can be a limiting factor in the compliance with reader sensitivity. The simulation results for a single pallet with goods can be in principle extended to a large indoor scenario (warehouse, office building, etc.), and estimation of RF power levels for the complete indoor volume can be obtained. The estimation of the potential values of received power from the RFID system can be now employed in order to assess the reading range within the complete scenario under analysis and therefore aid in the deployment phase of the RFID readers within such scenario.

4. Traceability System

The proposed system requires active collaboration of manufacturers and assemblers of electronic devices tagging marketed devices individually through an UHF RFID tag. The use of standards such as EPC Gen 2 [13, 14] facilitates the future integration of the different manufacturers. Receiving docks in distribution warehouses must include RFID portals to detect and make an inventory of the contents of pallets shipped from the manufacturer. Likewise orders shipped from the warehouse to the final distributors are also registered using the same portals or handheld RFID readers for validating the correct reception.

According to radioelectrical analysis results shown in Section 3, a prototype of the system that uses exclusively handheld RFID reader has been implemented in order to validate the solution.

4.1. Hardware System and Communications. As mentioned previously, each delivery vehicle is fitted with a handheld reader to detect the SKU included in each pallet during load moments in the store and the store receipt. When transportation in the last stage of the distribution chain is carried out by third party carriers, the low cost of the portable reader (600€) allows end stores to have their own equipment to validate the receipt of orders.

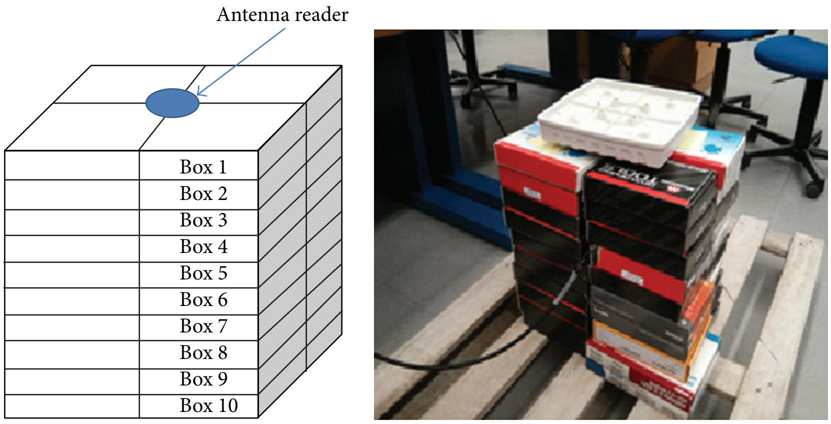
To reduce the cost of this device and for the ease of use by different actors involved in the supply chain, the portable RFID reader lacks user interface and internet connection, requiring to be controlled from a mobile device as shown in Figure 6. In this sense it has been developed a mobile application for Android OS that allows interfacing the reader from a friendly interface that requires no training.

Once the user authenticates, the steps to perform the validation of a pallet are as follows.

(i) *Identify the pallet*: this task can be performed using the keyboard by entering the code of the pallet or, if the mobile device includes a camera, using the QR code included in the pallet identification label.

(ii) *Enable reading*: the reader device activates its receiving antenna and the device starts sending all labels of electronic devices that are identified.

(iii) *Validate reading*: finally, the identification of the pallet along with all the labels from electronic devices that have been identified is packaged in an XML file and sent, using 3G or WiFi, to the central server. Then, the central server processes the data and returns a message indicating a correct validation or reporting the tags and description of unidentified devices forming part of the pallet.



(a) (b)

FIGURE 4: Radials of received power for different materials for the center of the first row of boxes.

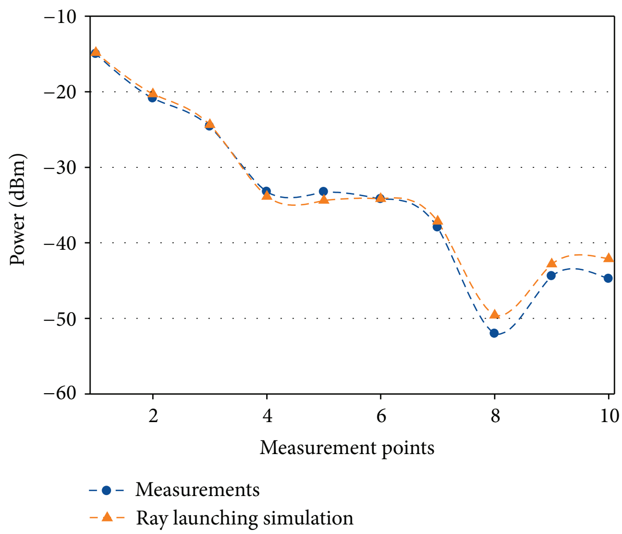


FIGURE 5: Comparison of simulation versus measurements for boxes 10 to 1 in the pallet.

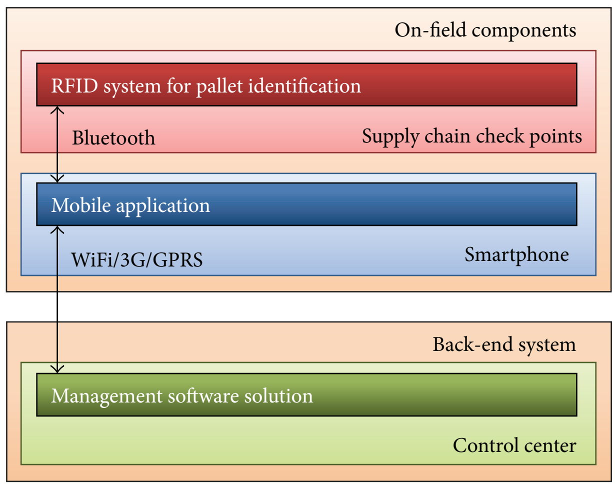


FIGURE 6: Interaction between the on-field and back-end System components of the proposed system.

The reader device prototype has been implemented trying to minimize the cost without compromising reliability in readings. It consists of three major subsystems.

(i) *RFID reader*: the prototype has been implemented using the M5e compact embedded reader from ThingMagic. The reader provides support for EPC-global Gen 2 (ISO 18000-6C) tag protocol with anti-collision [15] and DRM capabilities. Despite its small size (7 × 10 cm), it provides reading settable transmit level, adjustable from 10 dBm to 23 dBm. In addition it supports 860 to 960 MHz UHF RFID carrier frequency range to accommodate worldwide regulations and provides a maximum tag read rate of over 200 tags per second and maximum tag read distance of over 20 feet (6 m) using a 12 dBi antenna.

(ii) *UHF antenna*: a commercial antenna has been used in the implementation of the prototype. Selected UHF antenna provides a gain of 6 dBi and includes a 2-meter cable to make easier the access to the pallet from different angles.

(iii) *Embedded platform*: an IGEP v2 industrial processor board manages the information provided by the reader and the communications with the mobile device. This card features an ARM Cortex A8 processor running at 1 GHz and 512 megabytes of RAM and connects with the reader through a UART port to 115200 baud. The connection to the mobile device is carried out via Bluetooth. When the embedded platform receives the order to start reading from the mobile device, it sends the appropriate command to the RFID reader and stores all the identified labels in a data collection. Finally, when the phone sends the validate command, the reader is turned off, and data collection is sent to the mobile device.

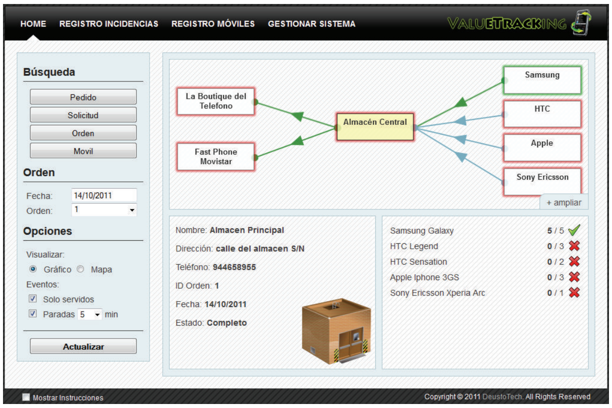


Figure 7: Management solution control panel web interface.

4.2. Logistics Software System. The developed software solution fulfills the mission of giving support to the proposed prototype architecture. To accomplish this, it is based on two independent but interrelated components: the mobile application and the management solution deployed on the central server.

The functionality offered by the mobile application has already been described in the previous section, performing mainly coordination and communication tasks, serving as an accessible entry point to the system, interacting and thereby integrating the functionality of the various components involved in the traceability process.

To achieve this, mobile application's software has the required configuration to allow interconnection via Bluetooth with reading devices in order to receive data from the performed RFID readings at each check point, as well as connectivity via web services with the centralized management solution.

In order to obtain the identification data for the shipment which is being processed, a QR reading service has been provided. As a result, approaching the QR code printed on the bill of delivery to the mobile application speeds up and largely automates the acquisition of relevant data (shipment code, participant identifier, priority, etc.) that would otherwise be introduced manually by an operator, with the waste of time and the increase in the probability of making mistakes which this would entail.

Finally, the mobile application presents a user-friendly interface through which the user is informed of the discrepancies in the actual and previous reading of pallets, indicating the potentially stolen items and generating and sending any incidences to the centralized management solution. The complete schematic of interaction between the readers and the management system is depicted in Figure 6.

This management solution is the key software component of the proposed solution as it complies with the necessity of maintaining, updating, and managing in an efficient way all the information received from the various participants in the supply chain, as well as providing the tools needed to facilitate an effective data sharing between heterogeneous devices and components.

The management software solution thus relates to a centralized application, deployed in a powerful back-end system, providing the system with data management and communications capabilities. This includes the development of a user control panel, Figure 7, whose main functionality is described as follows.

(i) *Supply chain traceability*: it provides both graphical and tabular information related to the current status of the shipments made by the system. It allows a complete pallet traceability, updating data, and informing the user when the readings and/or incidences from the supply chain check points are received. The application also offers search and filter functionality based on relevant criteria: order number, delivery date, dealer/shop identifier, model, and so forth.

(ii) *Incidence management*: incidents produced (resulting from a mismatch between subsequent readings) will be specifically managed by the system, registering them in the database and counting with various states (open, managed, closed) that enable its effective treatment by the administrator.

(iii) *Electronic devices traceability*: section rose to facilitate control and traceability of particular devices based on its specific brand, model, or EPC code. Historical device traceability, any incidences arising, and general shipping data will be also presented.

(iv) *System management*: specific section for the internal management of the system that enables CRUD (create, read, update, delete) operations on the participants of the supply chain as well as other internal management operations such as user registration and privilege management.

Besides the business capacities treated in the previous point, the architecture of the management software solution is divided into other functional layers following a modular structure that facilitates reuse, minimization of the coupling, and allowance for future functional enhancements in the prototype, Figure 8.

(i) *Web services layer*: It is developed by .NET technology, using WCF RIA services; this layer is responsible for coordinating requests made to the system from the different field elements. The use of this service layer promotes a safe and effective way for data communication between the components, managing at the same time system security by giving the necessary permissions.

(ii) *Data persistence layer*: Within this layer all information transferred between the different elements of the system was modeled. Microsoft SQL Server 2008 DBMS has been used in this context. The information related to each shipment is received and stored at the time the reading is performed at each check-point of the supply chain. In case any incidence was reported, this will be registered and stored in the database.

(iii) *Communications layer*: information relevant to the application is in the database; however, access to such

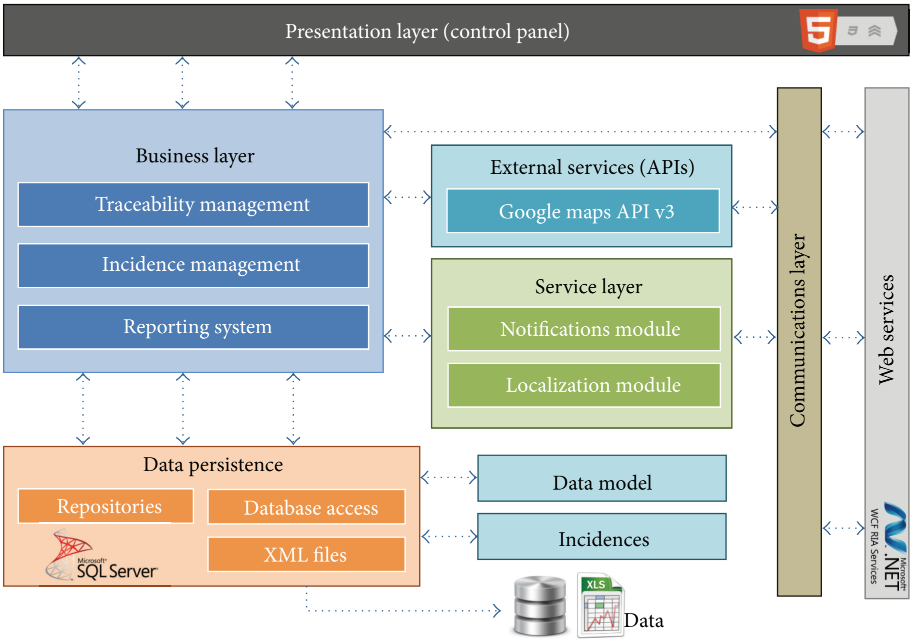


Figure 8: Architecture of the management software solution.

information is done through web services. This technical decision allows both data and application logic to be accessed from other devices, thereby ensuring the scalability and interoperability of the whole system. Security is also increased since data access does not occur directly but through the services, providing greater control over database queries.

The network will be controlled at all times under a firewall that prevents unauthorized access. The set of services developed allows full interoperability between the different components of the system, which is a major benefit in broadening the number of devices compatible with it and enabling their development in the future.

5. Conclusions

In this work, the use of RFID technology in order to improve logistic processes involving merchandise in pallets is presented. By the use of deterministic in-house 3D ray launching code, the influence on the election of material parameters as well as the arrangement of the different items within the pallet is obtained, which strongly conditions the performance of the system in terms of reading capacity. The complete system has been implemented in order to test the viability of its application in order to enhance logistical processes. The combination of physical layer analysis with a top layer system view can aid the planning as well as operational phase of this type of RFID system within a logistic chain.

References

[1] V. Kapsalis, C. Fidas, L. Hadellis, C. Karavasilis, M. Galetakis, and C. Katsenos, "A networking platform for real-time monitoring and rule-based control of transport fleets and transferred goods," in *Proceedings of the 13th International IEEE Conference on Intelligent Transportation Systems (ITSC '10)*, pp. 295–300, Funchal, Portugal, September 2010.

[2] J. Cleland-Huang, R. Settimi, E. Romanova, R. Berenbach, and S. Clark, "Best practices for automated traceability," *Computer*, vol. 40, no. 6, pp. 27–35, 2007.

[3] D. Yue, X. Wu, and J. Bai, "RFID application framework for pharmaceutical supply chain," in *Proceedings of IEEE International Conference on Service Operations and Logistics, and Informatics (IEEE/SOLI '08)*, pp. 1125–1130, Beijing, China, October 2008.

[4] T. Kelepouris, K. Pramatari, and G. Doukidis, "RFID-enabled traceability in the food supply chain," *Industrial Management & Data Systems*, vol. 107, no. 2, pp. 183–200, 2007.

[5] G. Liu, W. Yu, and Y. Liu, "Resource management with RFID technology in automatic warehouse system," in *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS '06)*, pp. 3706–3711, Beijing, China, October 2006.

[6] A. Moreno, I. Angulo, A. Perallos et al., "Intelligent van for the distribution of pharmaceutical drugs," *Sensors*, vol. 12, no. 5, pp. 6587–6609, 2012.

[7] S. F. Wamba and A. Wicks, "RFID deployment and use in the dairy value chain: applications, current issues and future research directions," in *Proceedings of the IEEE Internationl Symposium on Technology and Society (ISTAS'10)*, pp. 172–179, Wollongong, Australia, June 2010.

[8] Indicod-Ecr: C.F. 80140330152, "Storia di successo-DHL, Mediamarket, Samsung, Sony," http://www.tendenzeonline.info/news/dir/4/view/950/storia-di-successo-dhl-mediamarket-samsung-sony-95000.html.

[9] J. A. Nazábal, P. López Iturri, L. Azpilicueta, F. Falcone, and C. Fernández-Valdivielso, "Analysis of IEEE 802.15.4 compliant wireless devices for heterogeneous indoor home automation environments," *International Journal of Antennas and Propagation*, vol. 2012, Article ID 176383, 14 pages, 2012.

[10] L. Azpilicueta, F. Falcone, J. J. Astráin et al., "Measurement and modeling of a UHF-RFID system in a metallic closed vehicle," *Microwave and Optical Technology Letters*, vol. 54, no. 9, pp. 2126–2130, 2012.

[11] E. Aguirre, J. Arpón, L. Azpilicueta, S. de Miguel, V. Ramos, and F. Falcone, "Evaluation of electromagnetic dosimetry of wireless systems in complex indoor scenarios with human body interaction," *Progress in Electromagnetics Research B*, vol. 43, pp. 189–209, 2012.

[12] P. L. Iturri, J. A. Nazábal, L. Azpilicueta et al., "Impact of high power interference sources in planning and deployment of wireless sensor networks and devices in the 2.4 GHz frequency band in heterogeneous environments," *Sensors*, vol. 12, no. 11, pp. 15489–15708, 2012.

[13] EPCglobal, *EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz-960 MHz Version 1.0.9*.

[14] K. Chiew, Y. Li, T. Li, and R. H. Deng, "On false authentications for C1G2 passive RFID tags," in *Radio Frequency Identification System Security*, pp. 50–65.

[15] H. Landaluce, A. Perallos, I. J. G. Zuazola, and Y. I. Angulo, "Performance analysis of the Slot Counter algorithm in comparison with the real performance of a commercial RFID reader supporting the EPC class 1 generation 2 protocol," in *Proceedings of the 20th International Conference on Software, Telecommunications and Computer Networks (SoftCOM '12)*, pp. 1–5, Split, Croacia, 2012.

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 531364, 15 pages
http://dx.doi.org/10.1155/2013/531364

Research Article

An RFID-Based Tracing and Tracking System for the Fresh Vegetables Supply Chain

Luca Mainetti, Francesca Mele, Luigi Patrono, Francesco Simone, Maria Laura Stefanizzi, and Roberto Vergallo

Department of Innovation Engineering, University of Salento, 73100 Lecce, Italy

Correspondence should be addressed to Luigi Patrono; luigi.patrono@unisalento.it

Received 3 April 2013; Revised 21 May 2013; Accepted 22 May 2013

Academic Editor: Iñigo Cuiñas

The paper presents an innovative gapless traceability system able to improve the main business processes of the fresh vegetables supply chain. The performed analysis highlighted some critical aspects in the management of the whole supply chain, from the land to the table of the end consumer, and allowed us to reengineer the most important processes. In particular, the first steps of the supply chain, which include cultivation in greenhouses and manufacturing of packaged vegetables, were analyzed. The re-engineered model was designed by exploiting the potentialities derived from the combined use of innovative Radio Frequency technologies, such as RFID and NFC, and important international standards, such as EPCglobal. The proposed tracing and tracking system allows the end consumer to know the complete history of the purchased product. Furthermore, in order to evaluate the potential benefits of the reengineered processes in a real supply chain, a pilot project was implemented in an Italian food company, which produces ready-to-eat vegetables, known as *IV gamma* products. Finally, some important metrics have been chosen to carry out the analysis of the potential benefits derived from the use of the re-engineered model.

1. Introduction

The ability to track and trace complete information at item level in an efficient and trustworthy manner is becoming more and more important for companies, mainly due to the increased consumer concern over the safety and the quality of the purchased products. This is even more true for companies involved in the fresh vegetables supply chain, because the delicacy of fresh-cut products requires all stakeholders to organize their business processes as efficiently as possible to guarantee the end customers the highest quality products. The shift from quantity-oriented agriculture to new emphasis on products quality and people's safety has placed new demands for the development and adoption of traceable supply chains. Traceability represents the ability to capture, collect, and store information related to all processes in the supply chain in a manner that provides guarantee to the consumer and other stakeholders on the origin, location and life history of a product. In particular, the adoption of an effective gapless traceability system, in the fresh vegetables supply chain, could enable companies to (i) detect warnings associated with product contaminations quickly and accurately, and (ii) optimize their main production processes in order to reduce cultivation costs and to ensure, at the same time, production optimization. Furthermore, an efficient traceability system represents a fundamental tool for people with special needs, such as patients affected by multiple intolerances [1], who struggle every day to perform elementary actions, such as the choice of food, because of the adverse reactions that particular components could cause if taken.

The development of an efficient traceability system requires the introduction in the supply chain of the technological innovations needed for product identification, process characterization, information capture, analysis, storage, and transmission, as well as the overall systems integration. These technologies include hardware (such as identification tags and labels) and software (computer programs and information systems) solutions. In particular, two of the most important auto-identification technologies able to optimize the critical processes in a supply chain are Radio Frequency IDentification (RFID) [2] and Near Field Communication

(NFC) [3]. They promise to replace the traditional optical auto-identification solutions in near future. Among the different types (i.e., passive, semipassive, and active) of RFID transponders, often called "tags", the passive ones are used in most tracing systems, because they are characterized by a very low cost and small dimensions, since they do not require battery to operate. Passive RFID tags can also be classified according to the frequency band used (e.g., LF, HF, UHF, etc.) and the type of coupling (i.e., magnetic or electromagnetic) between tag antenna and reader antenna. The UHF tags could occasionally encounter problems, causing performance degradation, in the presence of materials, such as liquids and metals, which absorb Radio Frequency (RF) energy. However, some recent works [4–7] have demonstrated that the design of particular UHF tags is able to resolve such issues, thus demonstrating that they represent the best solution for item-level tracing systems in the whole supply chain. NFC is a short-range wireless (HF 13.56 MHz) technology derived from the RFID family. NFC entities can share power and data over a distance of a few centimeters (less than 5 cm). They inherit the basic features of RFID technology (i.e., working in reader/writer mode with passive tags) but they are also characterized by the possibility to share data across active (powered) devices [8]. The diffusion of these RF technologies has been significantly increased by the asserting of international standards such as EPCglobal [9–12] and Global Standard 1 (GS1). In particular, the EPCglobal standard provides a promising open architecture for tracking and tracing objects over the Internet. It defines a full protocol stack able to guarantee item-level data sharing related to products that move in the whole supply chain.

The combined use of different RF technologies and standards in order to improve the supply chain management has been strongly investigated in literature [13, 14]. They were also successfully applied to the agro-food sector [15, 16]. However, the development of a complete gapless traceability system, from the land to the table of the end consumer, is still at the early stages and many issues are still open. Most works propose solutions too invasive and, therefore, not accepted by the operators. A typical example concerns the use of Wireless Sensor Networks (WSN) in greenhouses in order to achieve a precision agriculture [17–19]. Although the use of this technology promises many benefits, its adoption is very limited, since expert agronomists, that argue no sensor node can ever replace their skills, do not accept its use. Therefore, a very critical aspect in a reengineering procedure is that the proposed solution must be thoroughly understood by the operators, before to be accepted, and applied. Furthermore, costs related to the introduction of new technologies are relevant and block their wide adoption. Indeed, although most of the solutions presented in literature are exclusively based on the use of RFID tags, the cost of a tag is still too high to justify its adoption in the packaging of low cost products, such as fresh-cut products, whose price in Italy is about 1-2 euro per pack. Particular attention must be also paid to the choice of the type of tag to be used, since such tags must be used in critical conditions and, in particular, in humid environments, which absorb RF energy. Another important issue still open in the design of an effective traceability system in the fresh vegetables supply chain is related to the integration of management systems of all involved actors. Vegetables producers are generally small local farms without a proper information system, and therefore, actors interact through traditional channels (i.e., phone, fax). However, since the manufacturer can be considered the main actor of the fresh vegetables supply chain, a complete integration of the production company systems could represent an important starting point.

This work proposes an EPC-based gapless traceability system for the fresh vegetables supply chain able to exploit the combined use of different auto-identification technologies, such as RFID, NFC, and the less expensive DataMatrix. Particular attention was focused on the producer, and, therefore, on the early stages of the supply chain, which include farming in greenhouses and manufacturing of packaged vegetables. The proposed item-level tracking and tracing system is characterized by a perfect integration among the adopted hardware and software subsystems in both the greenhouses and the transformation factory, preserving the role of agronomists and reducing the costs for the adoption of new technologies. Specifically, an innovative and low-cost hybrid system, in which the gapless traceability is ensured by the combined use of EPCglobal, passive UHF RFID solution, Android NFC smartphones, NFC tags (i.e., passive HF tags), and the less expensive DataMatrix technologies, is proposed. Furthermore, an Enterprise Service Bus (ESB) [20] is adopted to deploy both traditional and innovative management services in the greenhouses. A clear separation between the logical EPC-based traceability architecture, and the physical infrastructure is a key factor in the proposed system, as it ensures a smooth, gapless, and flexible product traceability both in the greenhouse and in the transformation factory. To validate the proposed reengineered model, a pilot project was implemented in a big Italian producer company. Measurements of the main Key Performance Indicators (KPIs) [13] demonstrated the benefits derived by the use of implemented traceability system in a real scenario.

The rest of the paper is organized as follows. Section 2 introduces the reference scenario, highlighting main problems. The proposed reengineered model and its implementation in a real pilot project are reported in Section 3. Main details related to the software system architecture are summarized in Section 4. In Section 5, a description of the hardware adopted in our work is reported. A system validation is discussed in Section 6. Finally, Section 7 summarizes the conclusions and sketches future works.

2. Main Requirements and Open Issues in the Fresh Vegetables Supply Chain

The quick perishability of the *IV gamma* products, typically characterized by a shelf life of few days, makes the fresh vegetables supply chain, shown in Figure 1, a very interesting scenario.

Figure 1: The fresh food supply chain.

The three main actors involved in this supply chain are as follows.

(1) The *farm*, which produces in farmland and greenhouses the raw materials (e.g., salad, lettuce, rocket, etc.).

(2) The *transformation company*, which purchases and handles large amounts of raw materials in order to produce packaged vegetables.

(3) The *retailer*, which, in general, sells finished products to the end consumer.

In order to study the main open issues of the analyzed scenario, one of the biggest fresh vegetables producers in the South of Italy, Jentu S. Agr. r. l. [21], was investigated. It includes two production centers located in different sites but is characterized by the same product flows.

In the following, the two phases of vegetables cultivation and products transformation are separately analyzed in order to better identify the main points where the use of innovative technologies, such as RFID, NFC, and EPCglobal, could improve the production capacity of the company. Let us observe that the conducted analysis did not involve the transportation process of the harvested vegetables, from greenhouses to the transformation factory, because it is not interesting from a reengineering point of view, since it does not affect on the products quality. In the considered company, in fact, greenhouses are located very close to the transformation factory.

2.1. Vegetables Cultivation. The cultivation phase affects the whole life cycle of vegetables, and it includes the activities of seeding, growing, harvesting, and so forth. All these activities are usually coordinated by an agronomist.

In particular, the Jentu company has several greenhouses, where a portion of the raw materials used in the transformation phase is cultivated. The agronomist, during her/his usual check visit, manually performs the activities of ground sensing and vegetables evaluation. In this step, she/he stores on paper notes all qualitative information detected.

The agronomist uses the captured parameters to decide actions to apply on plants and grounds and she/he annotates all performed operations (i.e., irrigation, sowing, treatments with plant protection products) on a paper form. Periodically, these data are saved into a digital system called "Field Log". It is a management software tool that allows the farm to carefully store very important information about the operations carried out on plants, the adopted cultivation methods, and the use of approved cleaning products. Some activities, such as irrigation and temperature control, are executed in automated manner through remote terminal units and an advanced computerized control system.

Pallets, composed of bins, are used to move crops from the greenhouses to the transformation factory. The partition of a crop in different bins is needed in order to allow its partial use during the production steps, depending on retailers' orders. Before being processed, the crop is weighted, classified and made identifiable by the attached form.

Let us observe that the activities performed by the agronomists are highly exposed to human errors and imprecision, mainly due to the manual execution of the operations and the asynchronous storing of the gathered data.

2.2. Products Transformation. The products transformation phase starts when one or more pallets of raw materials, coming from the greenhouses, are moved into the transformation cycle. A first check of the incoming products is performed. In particular, the quality control manager identifies the correct greenhouse of origin, by reading manually (i.e., without the use of an electronic device) the lot number placed on each pallet, and carries out the weighing process. The obtained data are compared and checked with the information reported on the delivery note. Furthermore, before being accepted, the incoming raw materials must pass a rigorous quality control process. In this case, the operator stores all data about the received products in the company Information System (IS), and prints the "raw materials identification tag" associated with the accepted pallet. This label contains, in addition to information about the quality of the accepted materials, the incoming date and a lot number associated with the particular bin of received products. This correlation is maintained in the "goods weights registry entry" document. Moreover, the identification label includes a linear barcode encoded in Code-128 format.

The accepted pallets are temporarily stocked in a storage warehouse, where they are arranged according to the arrival order, so as to be picked up more easily. Here, the temperature is always maintained between 0°C and +4°C to avoid the deterioration of the fresh products. The pallets are moved into the transformation process according to the First In First Out (FIFO) discipline. More in detail, the operators, by reading the information written on the label associated with each pallet, choose those with the earliest incoming date. Let us observe that this process can easily lead to the selection of wrong pallets, thus increasing the amount of product to be discarded in the next steps (e.g., husking).

The transformation process is essentially composed of different activities, such as husking, cutting, sorting, washing, and drying, which transform the raw materials in finished ready-to-eat (RTE) products. It starts when the operators pick up the pallets from the storage warehouse and move them into the husking area. In this step, the operator has to fill the "line loading register", which contains important data for the product traceability, such as the lot number and the number of bins involved in the transformation process, the signature of the operator carrying out the registration, and the start and end times of the transformation process. The semifinished products are stored in a cold room where they remain waiting to be picked up for the next phase of packaging.

The finished product is packaged and labeled manually or automatically. The packaging is done in a controlled atmosphere. The label on each package reports the ingredients of the product itself, information about the producer company (name and address), the method of conservation (in the refrigerator from +2°C to +8°C), the expiration date (calculated summing 7 days to the production date), a linear bar code encoded by EAN 13, and an alphanumeric string, which identifies the lot.

Finally, the packaged products are placed in plastic boxes and arranged on pallets, according to the orders received from customers. It is important to observe that, in this step, the labels attached on some packages, chosen in a random way, are checked. If a not compliant label is identified, the product is discarded and the entire pallet is checked. The prepared pallets are then moved into the outgoing warehouse, where they remain waiting to be shipped to the point of sale.

Unfortunately, most of the activities of the transformation cycle are performed in manual mode and, therefore, they can represent critical issues of the considered supply chain, especially in terms of timeliness (time spent on the activity) and correctness.

2.3. Requirements for an Efficient Traceability System. The conducted analysis allowed us to identify the main requirements that an efficient gapless traceability system, from the land to the table of the end consumer, should satisfy as follows.

(i) Minimize the error probability in the procedure of data gathering and transcribing into the information system of the company.

(ii) Allow the company to collect automatically a high amount of data, which can be used to provide to the end consumer a complete pedigree of the purchased products, from the land to the table of the consumer.

(iii) Allow a correct and efficient flow of critical information through the whole supply chain, as the product is cultivated, transformed, transported, stored, and sold.

(iv) Allow the company to improve recall procedures, reduce contaminations, and minimize risk in the supply chain.

(v) Optimize the logistic process in terms of human resources and time.

3. Reengineered Model

The analysis of the open issues in the fresh vegetables supply chain allowed us to propose an efficient re-engineering of the main critical processes, exploiting the combined use of innovative RF technologies and the EPCglobal standard. In particular, the reengineered model was defined considering the adoption of passive RFID technologies in UHF band, such as transponders, readers, and antennas. Furthermore, a software infrastructure on top of the Fosstrak framework [22] was developed. In order to better appreciate the main benefits that the proposed model is able to provide, a pilot project was implemented and validated in the Jentu company.

3.1. Vegetables Cultivation. In the cultivation phase, the use of NFC tags is proposed to identify both the operators and the fields where vegetables are cultivated. In particular, greenhouses and fields are partitioned into small portions, where only one type of product is cultivated. Each of these plots of land is uniquely identified by a NFC tag placed on a wooden pole. In such NFC tag an EPC code, encoded with the SGLN (Global Location Number) schema, is stored. The agronomist is provided with a badge containing an NFC tag, and she/he uses an Android smartphone equipped with NFC technology to store all information about activities performed on crops into the Field Log, avoiding the use of paper notes. More in detail, at the end of a treatment on a specific plot of land, the agronomist identifies herself/himself and the treated plot of land, bringing the NFC reader integrated in her/his smartphone to the tag placed on the badge and on the pole, respectively, and automatically stores all data about the performed operations in the mobile Field Log application. These data are immediately sent to the information system of the producer company, thanks to a wireless connection (i.e., 3G). It is noteworthy that the use of small plots of land allows a considerable reduction of the amount of resources used, such as fertilizers and water (i.e., these are used only where needed), while ensuring the production optimization (i.e., it can be slowed or accelerated on the base of the requests of the company). Furthermore, during the harvesting phase, the use of bins and pallets tagged with passive UHF RFID tags is suggested. In this step, the agronomist, after identifying herself/himself as previously described, uses a portable UHF RFID reader, connected via Bluetooth with the smartphone, to scan the EPC code applied on each bin of raw materials. Finally, this association is sent to EPCglobal-based traceability system and stored in the EPC Information Service (EPCIS) repository. This solution aims at enabling a complete traceability, which started from field.

3.2. Products Transformation. As previously described, bins and pallets of raw materials, which are moved into the transformation cycle, are tagged with passive UHF RFID tags. This type of tag is considered mainly because it is able to guarantee high performance in presence of multiple readings. Furthermore, thanks to a native feature of the EPCglobal standard, a traceability system in the whole supply chain can easily trace information at different layers (i.e., pallet, bin and product). In particular, EPC Global Returnable Asset Identifier (GRAI) [23] encoding scheme is used to tag pallets; EPC Global Individual Asset Identifier (GIAI) [23] encoding scheme is used to tag bins. According to the reengineered model, the incoming warehouse of the company is equipped with a RFID gate composed of one UHF RFID reader and four Far Field antennas in UHF band. This configuration, in fact, is able to guarantee high performance in terms of successful reading rate of bins. A worker, after performing the weighing process, moves the pallets through the gate, enabling the automatic identification and validation of all incoming bins. The retrieved data are immediately compared with the information contained in an electronic version of the delivery note and saved in the information system of the producer. In such a way, the quality control manager has only to store data about the weigh and the quality control check executed on the accepted materials. All information not necessary for products traceability, but important for the company, are stored in an Enterprise Resource Planning (ERP) database. For this purpose, an ad hoc Web service has been developed. This solution aims at removing efficiency problems, due to the manual execution of control and registration operations, currently performed as described in Section 2.2.

In the reengineered model, pallets and bins of raw materials stocked in the storage warehouse are tagged with passive UHF RFID tags and, therefore, an operator, by using a portable UHF RFID reader, can easily identify the appropriate pallets or bins to move into the manufacturing process. Two snapshots of the application used by the operator in this phase are shown in Figure 2. Let us observe that, also in this case, the combined use of RFID and EPC is able to overcome the efficiency limits previously described.

An UHF RFID gate, placed at the entrance of the husking area, detects the bins of raw materials moved into the transformation process and automatically updates the information system of the producer. Let us observe that the use of RFID technology allows to substantially mitigate correctness and timeliness problems, since all the information previously recorded manually by the workers are now detected by the gate and managed by the information system. The low cost of fresh ready-to-eat products does not justify the use of RFID tags to identify each item; therefore, the adoption of the DataMatrix technology is proposed to implement an efficient item-level traceability system. Each finished RTE product is labeled using a two-dimensional barcode containing the Serialized Global Trade Number (SGTIN) EPC code in ECC 200 encoding scheme. By this way, a 2D code reader can be used to trace data on each finished product.

Finished products, before being placed in reclosable boxes equipped with UHF RFID tags, are read by a DataMatrix reader. Furthermore, the use of an UHF RFID reader enables the association between the packaged products and the boxes that contain them. By this way the system can easily trace all products included in a well-defined box. Subsequently, the boxes are arranged on pallets tagged with UHF RFID tags and moved to the outgoing warehouse, equipped with a UHF RFID gate able to automatically detect this transfer and store the associated information in the information system of the company. The combined use of RFID and EPC technologies substantially improves these activities, removing efficiency problems, due to the manual execution of the control operations described.

Finally, the use of an item-level tracing system based on the EPCglobal standard optimizes the main activities related to the return flow management process. For example, it enables the automatic identification and tracking of all

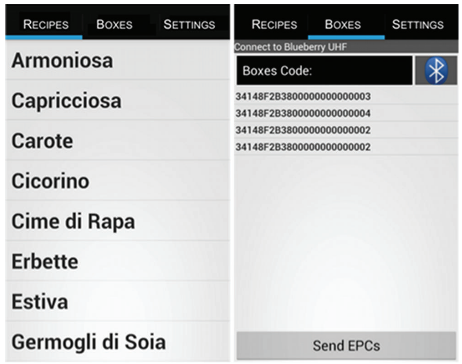


Figure 2: Snapshots of the application used by the operator in the storage warehouse.

products returned from a retailer. Furthermore, by using a complete traceability system, the producer company can exactly know which other products were sold to the same retailer, substantially improving the recall procedure of noncompliant products.

3.3. Overview of the Pilot Project. In order to better clarify the reengineered model previously described, a graphical summary of the pilot project implemented in the Jentu company is presented in this section. In particular, Figure 3 and Table 1 summarize the main RF devices introduced in both greenhouses and transformation factory.

4. Hardware Description

In this section, the main features of the auto-identification systems selected to realize the pilot project are presented. In particular, a summary of the main devices provided by the reengineered model in each area of the considered company is reported in Table 2, while more details are described in the following.

As noted in the previous table, in the cultivation phase, the following devices are used.

(i) *NFC tags*: identification of farmers and field areas in the greenhouse is crucial in the gapless traceability system; we used two different types of NFC tags for farmers and plots of land. In particular, for the farmer identification, we used a Mifare Ultralight NFC card by NXP Semiconductors (Figure 4(a)(1)). For the plots of land we used a Mifare Classic NFC tag by NXP Semiconductors (Figure 4(a)(2)).

(ii) *Portable NFC/RFID scanner*: a smartphone Samsung i9023 Nexus S (Figure 4(b)(1)) connected to the UHF RFID reader BlueBerry of TERTIUM Technology (Figure 4(b)(2)) was used as portable scanner. In particular, the Samsung Nexus S is an Android smartphone equipped with NFC technology, while the BlueBerry reader is a small and easy-to-use device able to transmit the data to a mobile phone or a smartphone through the Bluetooth interface. All high-level operations, such as processing of the readings,

Table 1: Mapping between RF devices and working areas in the Jentu company.

	Greenhouses	Incoming warehouse	Storage warehouse	Production	Labeling area	Order composition area
NFC tags	√					
UHF RFID tags	√	√	√	√		
NFC Smartphone	√					
Portable RFID reader	√					
UHF RFID gate		√		√		
DataMatrix printer					√	√
Portable DataMatrix/RFID reader			√			

Table 2: Devices used in the pilot project.

	Vegetables cultivation	Products transformation				
	Greenhouses	Incoming warehouse	Storage warehouse	Production	Labeling area	Order composition area
NFC Tags	(i) NXP Semiconductors Mifare Ultralight NFC card (ii) NXP Semiconductors Mifare Classic NFC tag					
UHF RFID Tags	LABID INSKYL3 wet inlay	LABID INSKYL3 wet inlay	LABID INSKYL3 wet inlay	LABID INSKYL3 wet inlay		LABID INSKYL3 wet inlay
Portable DataMatrix/RFID Reader	SAMSUNG i9023 Nexus S smartphone + TERTIUM Technology BlueBerry UHF		METEOR BIP-6000 Industrial PDA			METEOR BIP-6000 Industrial PDA
RFID UHF Gate		IMPINJ Speedway Revolution R420 + 4 KATHREIN wide range antennas		IMPINJ Speedway Revolution R420 + 4 KATHREIN wide range antennas		IMPINJ Speedway Revolution R420 + 4 KATHREIN wide range antennas
DataMatrix/RFID Printer					Zebra RZ400 RFID Desktop Printer	

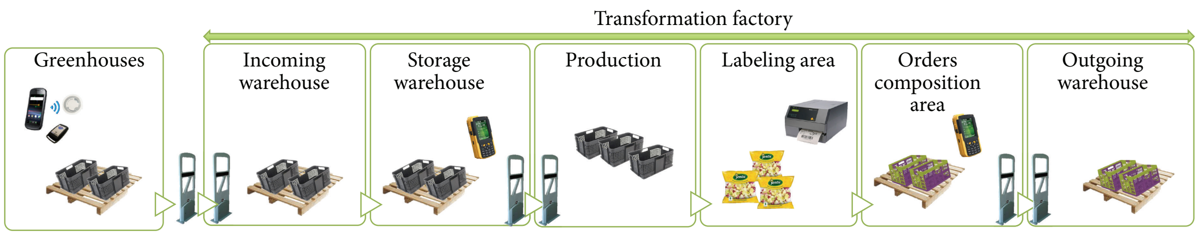


Figure 3: Main RF devices introduced by the reengineered model.

Figure 4: Main devices used in the pilot Project: (a) NFC tags: (1) Mifare Ultralight and (2) Mifare Classic; (b) portable NFC/RFID scanner composed of a (1) Samsung i9023 Nexus S and a (2) BlueBerry reader; (c) INSKYL3 passive UHF RFID tag; (d) RFID UHF gate composed of (1) Impinj Speedway Revolution R420 reader and (2) Wide Range UHF Kathrein antenna; (e) BIP-6000 of Meteor scanner; (f) Zebra RZ400 printer.

forwarding them via text message, e-mail, or GPRS, are delegated to the device the BlueBerry reader is interfaced with. Ultimately, it represents an easy way to integrate the RFID communication system to any device equipped with a Bluetooth interface (PDA, Netbook, Notebook, PC, etc.).

(iii) *Passive UHF RFID tags*: in order to choose the most suitable passive UHF tags to be used for our business scenario, a preliminary technological scouting has been performed. It is important to observe that the choice of the type of RFID tag is affected by different requirements as size of the tag itself, compatibility with EPCglobal standard, high scanning speed, high performance in presence of liquids and metals, low cost, and high stress of tag label during product life cycle. Therefore, after preliminary tests carried out in laboratory, we chose the passive UHF RFID tag wet inlay INSKYL3 of LABID (Figure 4(c)), whose size is 54 mm × 18 mm, equipped with the Impinj Monza 4 chip.

Multiple and heterogeneous devices have been chosen for the implementation of the reengineered manufacturing phase. More in detail, as shown in Table 2, the devices used in the pilot project are as follows.

(i) *RFID UHF Gate*: An RFID UHF gate, composed of a reader Impinj Speedway Revolution R420 (Figure 4(d)(1)) connected to 4 antennas Wide Range UHF Kathrein (Figure 4(d)(2)) though coaxial cables LMR-195 with weight attenuation in the range 25–35 dB per 100 m, was used in the pilot. The reader supports EPCglobal UHF Gen 2 and ISO 18000-6C protocols. It is characterized by a maximum receive sensitivity and maximum return loss equal to −82 dBm and 10 dB, respectively. The Wide Range antennas provide frequency range of 865–870 MHz and they are characterized by a circular polarization.

(ii) *Portable DataMatrix/RFID scanner*: in this case, the choice has been the handheld BIP-6000 of Meteor (Figure 4(e)). It is an industrial PDA designed to withstand the harshest working environments, certificate IP65 and equipped with 2D barcode reader and RFID reader. It also has integrated GPS, GSM, HSDPA, and WLAN, and a 3.0 megapixel camera with flash. In particular, this reader is equipped with the Android OS, which enables a simple integration with the connected system.

(iii) *DataMatrix/RFID printer*: the printer Zebra RZ400 (Figure 4(f)) was selected to print 2D code and write information in the RFID tag. It is equipped with a USB 2.0 interface and supports currently available protocols, including EPC Gen 2/ISO 18000-6C.

5. Overall System Architecture

The need to preserve and adapt the functionalities offered by the existing traceability and management systems leads us to give special attention to the technologies integration procedure in the Jentu company. The main services of the greenhouse management, such as the Field Log, must continue to be provided, beside the newer ones. Moreover, the Field Log application must become part of the new traceability system; that is, the data logged through it must be shared or reused in an EPCIS style. Furthermore, the innovative hardware and software systems, introduced in the transformation factory, must work on top of the existing architecture.

In order to satisfy the systems integration requirements, a software architecture based on the Enterprise Service Bus (ESB) [17] was defined. An ESB is an architecture model used for designing and implementing the interaction and communication among mutually interacting software applications in Service Oriented Architecture (SOA). It promotes agility and flexibility with regards to communication and interaction among applications.

In the next sections, more details about the different subsystems composing the whole architecture are given.

5.1. Greenhouse Management System. The combined use of Android smartphone, NFC, and RFID technologies is fundamental for the integration between the data producer (the agronomist working in the greenhouse) and the data consumer (the traceability system). Moreover, the use of smartphone enables an easily integration of the traceability system with any external device equipped with a Bluetooth interface (e.g., handheld UHF RFID communication system). The latter aspect is strongly important, as it allowed us to integrate the UHF RFID technology in a device that is not natively provided of it.

An agronomist Android app has been designed and prototyped; it can be seen as a write-only interface towards the traceability system. The agronomist uses the app for tracing the following main activities typical of a crop lifecycle:

(1) LAND activity: instantiate a new cultivation in a specific area of the greenhouse;

(2) FIELD_LOG activity: record a new crop observation event or intervention;

(3) HARVESTING activity: mark the cultivation as cropped when it reaches the maturation date.

Each activity involves the recording of the gathered information both in the EPCIS and in the Field Log system, so that the new and the legacy systems are bridged.

The UML sequence diagram, shown in Figure 5, is used to model the full interaction between the agronomist and the traceability system architecture for the FIELD_LOG activity.

The agronomist identifies herself/himself and the plot of land in the greenhouse; after filling the requested fields, she/he clicks the "Save" button and a request is built and forwarded to the ESB. Notice that a single click is needed to register the event both in the Field Log application and in the EPCIS, exploiting the high configurability of the ESB. The event is stored in the EPCIS as an ObjectEvent with the EPCIS property "ACTION" set to "OBSERVE".

In Figure 6, a screenshot of the agronomist mobile application for the FIELD_LOG activity is shown.

The agronomist fills the following fields.

(i) *Agronomist*. It is the full name of farmer that is encoded by the unique 7 hex digits ID stored in the farmer's Mifare NFC badge. Every NFC tag contains a read-only factory-assigned worldwide-unique serial number that can be used as a key into a database. The agronomist is needed because every detection is mapped with the responsible farmer in the EPCIS; the farmer app automatically fills this field when a farmer NFC card is in range.

(ii) *Greenhouse*. When the farmer wants to operate on a portion of land, she/he identifies it through the assigned NFC tag; so the field in the application is auto-filled.

(iii) *Date and Start/End Time*. The farmer stores the treatment duration by filling the fields representing the beginning and the end of the treatment.

(iv) *Agricultural Phase*. Each agricultural phase identifies one of the possible statuses of the considered portion of land. The farmer selects from a list the current status of the land (i.e., sowing, growing, etc.).

(v) *Treatment*. It represents the particular operation performed by the farmer on the considered portion of land. This value is selected from a preloaded list.

(vi) *Commercial Product*. In this field the farmer inserts the commercial product that she/he uses to facilitate and improve the achievement of specific effects on the ground and/or the plants.

(vii) *Machine*. The farmer selects from a list the equipment she/he uses during the treatment.

Let us observe that, in order to ensure a gapless traceability, only information about the date and the time related to the execution of a treatment must be stored. It is automatically saved in the EPCIS repository when the ObjectEvent is generated. However, the Field Log system requires also the storage of the duration of each performed treatment. To meet this requirement, in an efficient but simple way, the "Date and Start/End Time" fields have been introduced in the mobile application.

5.2. Hybrid Tracing System. The proposed tracing system is an innovative and low-cost hybrid system, in which the gapless traceability is ensured by using an EPC-style tracing and tracking system in the greenhouses, performed by the agronomist using Android NFC smartphones and NFC tags,

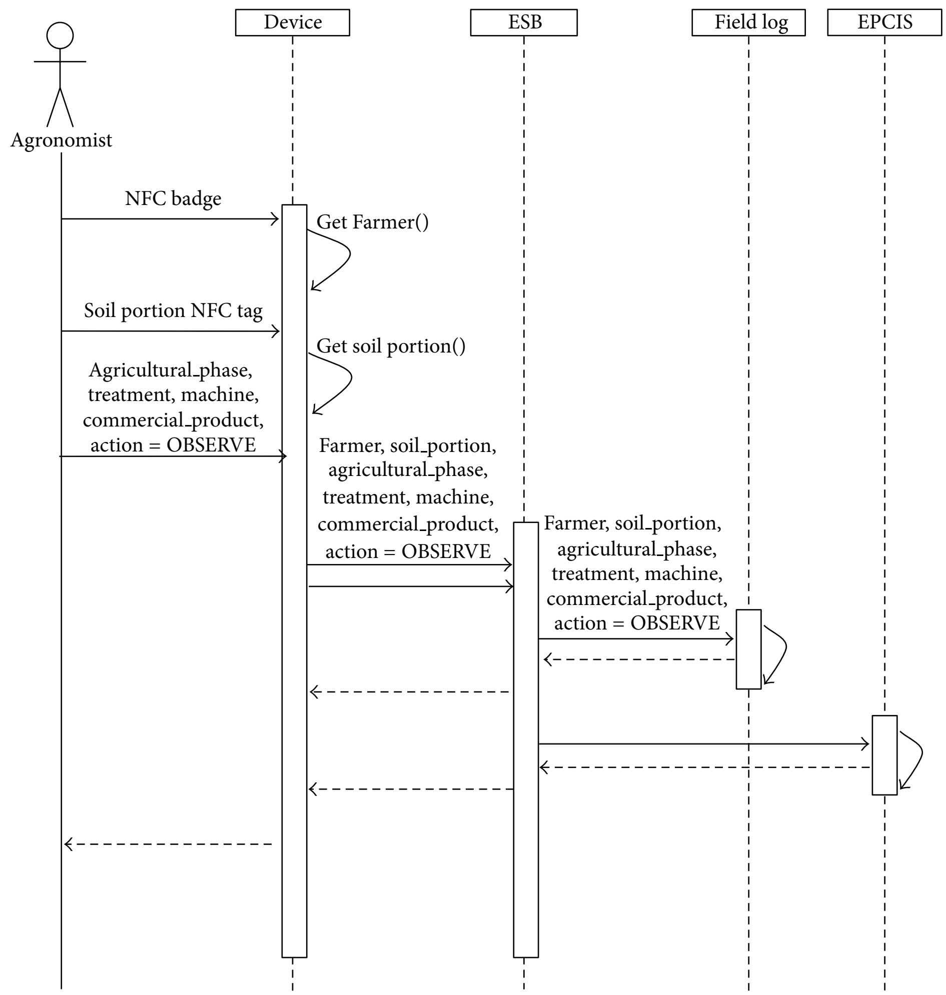


Figure 5: Sequence of interactions between the agronomist and the traceability system when a new observation or treatment is performed in the greenhouse.

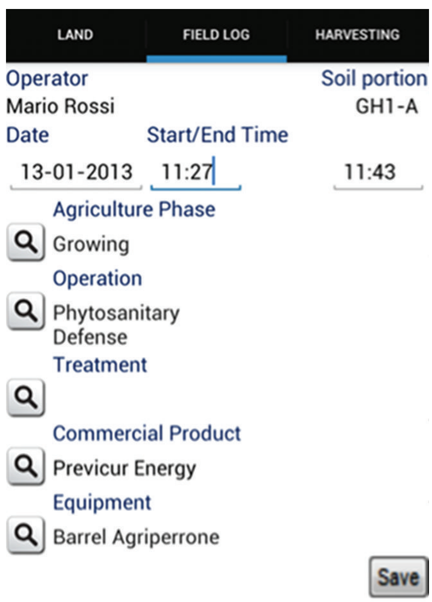


Figure 6: The agronomist's Android app interface.

and a classic EPCglobal architecture in the transformation factory, implemented using both UHF RFID and the less expensive DataMatrix technologies.

A clear separation between the logical EPC-based traceability architecture, and the physical infrastructure, based on UHF RFID, NFC, and DataMatrix technologies, is a key factor in the proposed system, as it ensures a smooth, gapless and flexible product traceability both in the greenhouse and in the transformation factory.

We used the Fosstrak platform [22] as open-source EPCglobal implementation. It is Java-based and provides supporting components for the development and integration of tracking and tracing applications. The Fosstrak EPCIS component runs on Apache Tomcat servlet container and exposes two SOAP services: the Capture interface, for storing EPC events into the EPCIS repository, and Query interface, for extracting EPC event data.

The Fosstrak ALE Middleware implements EPCglobal's ALE 1.1 specification [24]. To communicate with readers, the Fosstrak ALE Middleware uses the Low Level Reader Protocol (LLRP). For readers that do not support LLRP, the ALE Middleware uses the Fosstrak Hardware Abstraction Layer (HAL). The HAL Adaptor is a Java class interface, which we implemented in three classes:

(i) the LLRPAdaptor class, already implemented in the Fosstrak framework, in order to get readings from the EPC UHF RFID readers;

(ii) the NFCAdaptor class, which is synchronously called by a Java servlet listening on a specific URL for POST requests incoming from NFC smartphones;

(iii) the DataMatrixAdaptor class, implementing the communication with a DataMatrix IP Camera connected to the company's network.

In Figure 7, a high level UML class diagram showing how the different technologies are cabled inside the Fosstrak ALE Middleware is reported.

The LogicalReader class is a logical representation of different physical sensors, for each of these an Adaptor was implemented. Being the NFC reading performed manually (volunteered) by the agronomist, the only way to model the interaction with the LogicalReader class is to expose a Java Servlet running in Fosstrak. When the servlet is called, the EPCBuffer is filled with EPCs; so the NFCHTTPController can asynchronously get the EPC list from the buffer.

In the next section, a deep look on how to publish the servlet URL onto the Enterprise Service Bus will be given.

5.3. Information Systems Integration. Many ESB vendors, also open source, exist. In this work, the WSO2 (Oxygenating the Web Service platform) [25] vendor was used, since it was identified as one of the most robust solution by Gartner and Forrester [26]. The WSO2 ESB engine is Apache Synapse [27], which plays a role of broker in the software architecture and supports many open standards (e.g., XML, XSLT, XPath, SOAP, JMS, WS-Security, WS-ReliableMessaging, WS-Addressing, SMTP).

In Figure 8, the overall system architecture is shown.

The architecture is split into four macro-areas.

(i) *Delivery Channel Architecture*. It includes all the services' interfaces, both legacy and innovative. The information generated and requested by the clients flow within a unique logical link toward the information system and it is conveyed by using a mapping configured in the WSO2 ESB.

(ii) *Shared Service Infrastructure*. It is the core WSO2 ESB implementation, as it allows delivering the services requested by the applications by totally hiding the service implementation details. The different subsystems comprised in this layer was properly configured to map the requests incoming from the delivery channel architecture layer; we configured different protocols at different ISO/OSI levels, for example, REST for mobile application, SOAP for the traceability interfaces, TCP/IP sockets for UHF RFID readers, and connections with the DBMS instantiated by legacy applications.

(iii) *Service Enabled Applications*. This layer includes the SOA-ready services. Communication flow is depicted as bidirectional also for delivering service composition and for talking with nonservice-enabled assets. The EPCIS resides here. A Field Log adaptor has been introduced, in order to let the agronomist mobile app also save data into the field log as well as into the EPCIS (service composition).

(iv) *Nonservice-Enabled Assets*. Non-SOA-ready services such as legacy systems and ISO/OSI transport layer services (e.g., socket based) find place in this layer. Existing bundled systems (i.e., Irrigation Control System, Enterprise Resource Planning, Outsourcing Inventory Management) fall into the Packaged software category. Fosstrak's Application Level Event (ALE) middleware is deployed on an Apache Tomcat servlet container. It establishes LLRP protocol links with the UHF RFID reader placed in the Delivery Channel Architecture, and a classical TCP/IP socket with the Capturing Application, which push event to the Fosstrak EPCIS subsystem. Database Management Systems are also included in this layer.

In the WSO2 proxy configuration file, Fosstrak's EPCIS repository query endpoint and the web services needed by the agronomist Android app are mapped by specific proxy services. A proxy services define virtual services hosted on the ESB that can accept requests, mediate them, and deliver them to an actual service. Proxy services could perform transport or interface switching and expose different semantics than the actual service, that is, WSDL, policies, and QoS aspects like WS-RM, WS-Security, and so forth. Through the use of endpoints, it is possible to define a specific destination for a message. Once the endpoints are defined, it is possible to call the configured Web services by invoking a URL following this schema: http://<esb_ip>:<esb_port>/services/<proxy_name>/
<service> where:

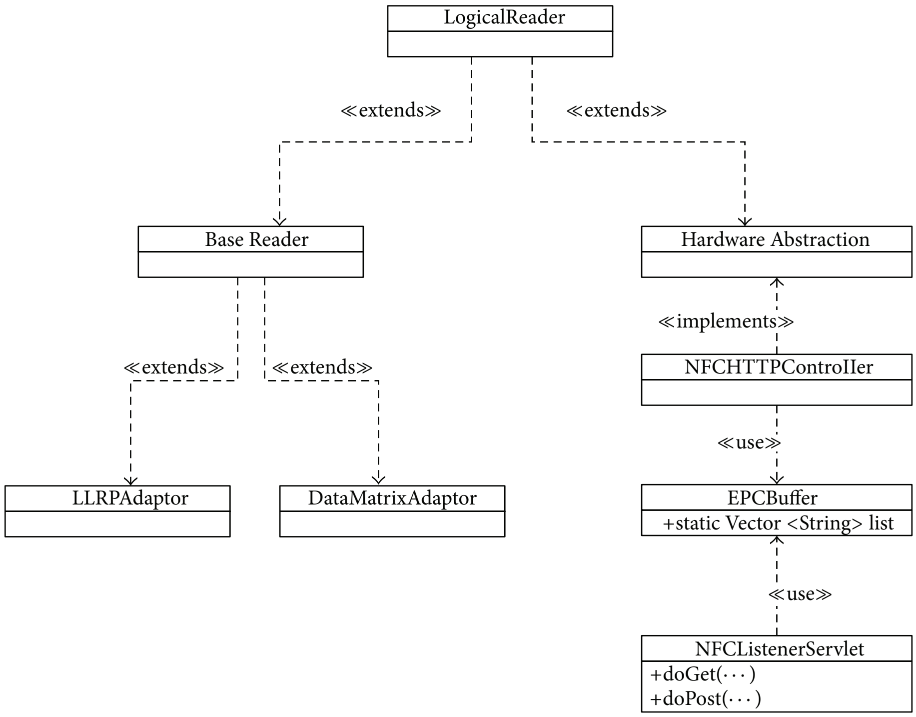


Figure 7: The integration of different physical sensing technologies in Fosstrak.

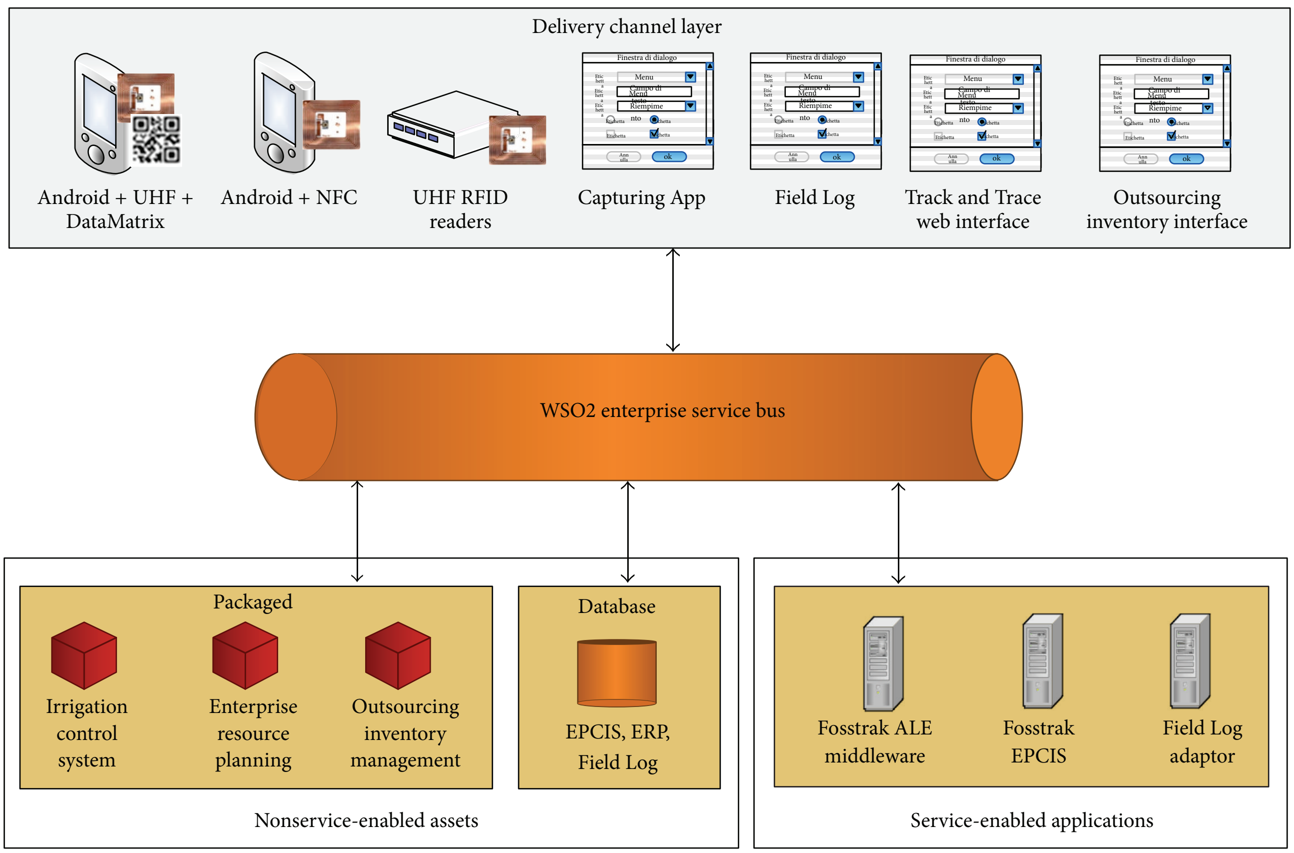


Figure 8: The overall system architecture.

(i) the <esb_ip> is the IP address of the server on which WSO2 runs; notice that this IP address is unique for each service;

(ii) the <esb_port> is the TCP port on which WSO2 is listening;

(iii) the <proxy_name> is the name of the proxy service configure into the ESB configuration file;

(iv) the <service> identifies a precise service retrievable from the specified proxy.

Using proxy services, the implementation of existing and innovative Web services onto the company architecture is almost immediate and requires few lines of codes. We deployed both SOAP and REST Web services. In particular, we deployed some REST Web services involved in the communication between the Android app of the agronomist and the tracing system. For instance, two Web services CultivationPhases and Formulation are used by the Android app to populate the static field views in the app interface by retrieving these from a well-defined vocabulary of terms. A FieldLog service is used to save the gathered information to the legacy Field Log application.

6. System Validation

The system validation phase was carried out by using both a Living Laboratory approach and a pilot project. In particular, the first method allowed us to obtain initial experimental results, in a controlled test environment, demonstrating that an accurate choice of passive UHF RFID solutions is fundamental to guarantee high performance of the proposed tracing system in each step of the supply chain. On the other hand, the development of the pilot project enabled us to validate the complete traceability system (i.e., hardware and software), and to appreciate the potential benefits derived by the use of RF technologies and EPCglobal standard in a real scenario. In particular, measurements of the main Key Performance Indicators (KPIs) demonstrated how the proposed reengineered process is able to mitigate the timeliness and correctness problems previously described.

Therefore, different preliminary tests, carried out in our laboratory environment, allowed us to identify the most suitable RFID tag to be used in the considered scenario. The experimental campaigns were designed to measure the successful reading rate of different tags during two of the most critical steps of the supply chain: (i) the movement of a pallet composed of tagged bins of raw materials, and (ii) the identification of tagged bins during the harvesting procedure, through the use of a portable RFID reader connected, via Bluetooth, to an Android smartphone.

Seven different types of commercial passive UHF RFID tags, equipped with an Impinj chip, were used.

(i) DOGBONE, whose size is 86 mm × 24 mm, equipped with the Impinj Monza 4 chip;

(ii) WEB, whose size is 30 mm × 49 mm, equipped with the Impinj Monza 4 chip;

(iii) UH423, whose size is 30 mm × 50 mm, equipped with the Impinj Monza 5 chip;

(iv) UH3D40, whose size is 40 mm × 40 mm, equipped with the Impinj Monza 4 chip;

(v) INSKYL3, whose size is 54 mm × 18 mm, equipped with the Impinj Monza 4 chip;

(vi) SKL4020, whose size is 40 mm × 20 mm, equipped with the Impinj Monza 5 chip;

(vii) XC-TF8024-C06, whose size is 50 mm × 30 mm, equipped with the Impinj MonzaTM 4 QT chip.

More in detail, in the first experimental campaign (Figure 9), a pallet with 28 plastic boxes containing finished products, organized on seven layers and tagged on their short side, able to cross the UHF RFID gate, was used. In order to simulate realistic conditions, several pallet compositions were analyzed.

(i) *Configuration I*: the pallet was prepared placing the boxes with their tag antenna oriented toward the outside and avoiding the overlapping of tag antennas.

(ii) *Configuration II*: the pallet was prepared placing the boxes with their tag antenna oriented toward the center of pallet itself and trying to obtain the overlapping of tag antennas.

(iii) *Configuration III*: the pallet was prepared placing the 50% of the boxes with their tag antenna oriented toward the outside and the remaining boxes oriented toward the center of pallet.

Each of the previous configurations were evaluated according to two different movement modes of the pallet as follows.

(i) *Translation*: it simulates the crossing of the pallet through the gate in direct direction; in such a case the tags on the boxes are parallel to the antennas of the gate during the movement.

(ii) *Rotation*: it simulates a rotation of the pallet when it crosses the gate; in such a case the tags on the boxes are perpendicular to the antennas of the gate for much of the time.

With regard to the first experimental campaign, 100% of successful reading rate has been measured in all tests confirming that the physical, chemical, and biological properties of the vegetable products do not affect the performance of the RFID tags.

The second test campaign aims to evaluate the tags performance when the portable RFID reader is used considering different reading distances (e.g., 5, 10, 15, 20, 25, up to 90 cm) and different reading angles (e.g., -30°, 0°, $+30^{\circ}$) between reader and tag antenna. In this test, a single box was used, and, for each tag, from 20 to 60 reading attempts were performed. This test demonstrated that all preselected UHF tags show optimal (i.e., 100% of successful reading) performance for distances in the range from 5 cm to 25 cm. Furthermore, the INSKYL3 tag obtained the 100% of reading rate also for

Figure 9: Pallet configuration during the first experimental campaign.

longer reading distances, up to 80 cm. The performed tests demonstrated that tags performances are not substantially affected by the reading angles (angles in the range from +30° to −30° did not show substantial changes).

This preliminary analysis led us to identify the INSKYL3 RFID tag as the tag to be used in the pilot test.

As previously declared, the pilot project allowed us to validate the proposed reengineered model. To demonstrate the proper operation of the proposed system, a screenshot of the traceability interface, evidencing the history (ePedigree) of the product from the sowing up its entry in the plant as raw material, is shown in Figure 10. In the "GRAI general information" table, all read events related to pallet used to carry the raw materials from greenhouse to company are reported. The box "EPCs children list" shows the aggregation among pallet and raw material bins. The supplier information is shown in the box called "Detailed information". Finally, in the "Field log" table, all treatments performed on the soil portion by operators are listed.

Furthermore, a KPI comparison between the current model and the reengineered model was performed considering the two main analyzed phases separately: (i) vegetables cultivation and (ii) products transformation. This analysis is summarized in Table 3.

Considering the first phase, the reengineered model substantially reduces the timeliness metric of "average time to write a report", which passes from a value of 90 seconds, in the current model, to a value of 25 seconds, thus ensuring a reduction of about 70 percent. Similar results can be appreciated for metrics related to the correctness, such as "percentage of reports with errors," "percentage of lost reports," and "percentage of error in the data entry activity," whose values, which are equal to 17, 10, and 15 in the current model, are reduced to zero in the reengineered model.

The combined use of RF technologies has highlighted similar benefits also in the transformation phase. As example, the timeliness KPIs regarding the processes of incoming and storage of raw materials are substantially improved. In particular, the "average time to receive a pallet" is reduced from a value of 195 seconds, in the current model, to a value of 55 seconds, in the reengineered model; the "average time to store information about raw materials and print the identification tag" is reduced from a value of 90 seconds to a value of 0 second; the "average time to identify an accepted pallet" passes from 120 seconds to 15 seconds. Similarly, the "percentage of error in the data entry procedure" and the "percentage of wrong pallets moved into the transformation process," which are equal to 15 and 30 in the current model, are reduced to zero in the reengineered model.

7. Discussion and Conclusions

In this paper, a gapless traceability system, based on the use of innovative RF technologies and EPCglobal standard both in the company's greenhouses and in the transformation factory, was proposed. According to the reengineered model, the agronomist uses an NFC Android smartphone to map the performed interventions and the sensed variables to a specific plot of land. This technique leads to overcome the paper-based classification of crops in the greenhouses, and to improve the efficiency of the subsequent phases of the transformation process. In such a way, each phase of the cultivation and transformation processes is traced and it becomes available for the traceability service. The use of DataMatrix instead of RFID tags to tag the final products ensures low costs and easy access to the traceability service for the end consumer. Furthermore, an ESB-based architecture has been introduced in order to integrate the company's legacy systems with the innovative technologies. It guarantees low impact in relation with the processes currently held both in the cultivation and transformation processes, and, at the same time, great flexibility and scalability towards future extensions.

In order to evaluate the benefits of the proposed reengineered model, a pilot project was implemented in an important company of the South of Italy. The conducted analysis allowed us to demonstrate the potential benefits introduced by the combined use of the innovative RF technologies in the fresh vegetables supply chain.

Nevertheless, business benefits are not the only ones obtainable by using the innovative traceability system presented in this work. It enables also important advantages for the consumers, as it copes with the consumers' concerns over the safety and the quality of the purchased food. This is an important aspect for (at least) two reasons: (i) the spread of a "public consciousness" among people about the need for a more valuable diet is leading the consumers to prefer products whose origins can be clearly stated and certified; (ii) people suffering of food intolerances need to avoid adverse reactions derived by the assumption of some kinds of food [1]. Such people must fight every day also in performing regular human activities, as having meals; in this case, the drastic solution of removing a particular food (e.g., tomatoes) from a patient's diet is not the right choice, as the same product would not lead to any adverse reactions if cropped in different soils (e.g., far from industrial plants) or with different treatments (e.g., excluding chemical products). Also the opposite is true: a product definitely stated as safe for the patient's health status may not be secure if the same vegetable is produced by a different company with different treatments in a different geographical area.

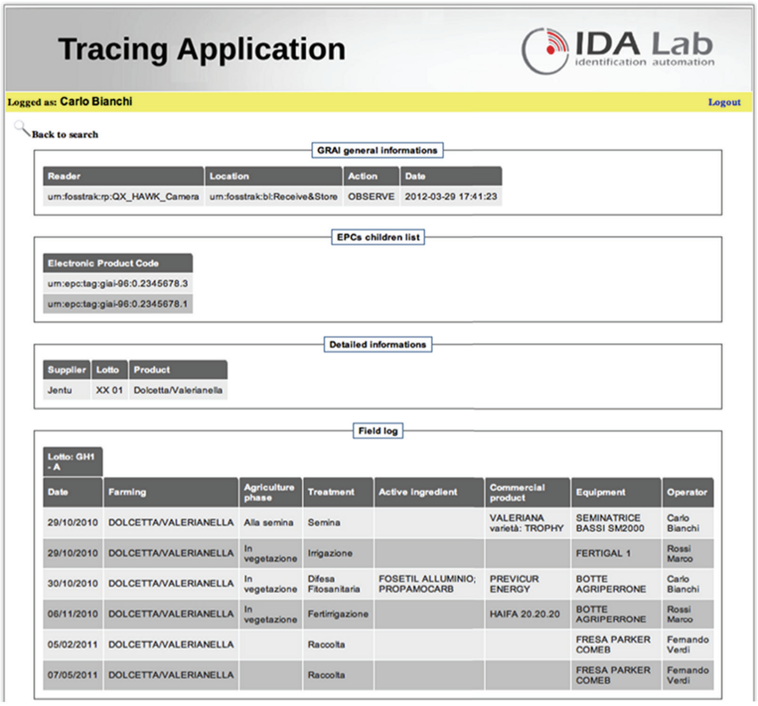


Figure 10: The ePedigree for a specific product.

Table 3: Main KPI used to compare current and re-engineered models.

Phase	KPI	Current model	Reengineered model
(i) Cultivation	Average time to write a report	90 sec per report	25 sec
	Percentage of reports with errors	17%	0%
	Percentage of lost reports	10%	0%
	Percentage of error in the data entry activity	15%	0%
(ii) Transformation	Average time to receive a pallet	195 sec	55 sec
	Average time to store information about raw materials and print the identification tag	90 sec	0 sec
	Percentage of error in the data entry procedure	15%	0%
	Average time to identify an accepted pallet	120 sec	15 sec
	Percentage of wrong pallets moved into the transformation process	30%	0%

However, several problems have been encountered during the design and development of the presented traceability solution. First of all, the implementation of the ESB has highlighted some difficulties mainly related with the integration of packaged legacy systems like the Field Log. The application in use in Jentu did not provide any sort of software interfaces like Web services; that is, it was not SOA-ready. Anyway the ESB engine WSO2 was flexible enough to forward and inward data directly dealing with the application's database. Obviously this led us to carefully check the integrity of the information in the Field Log application. Secondly, the need of making the Android app suitable for agronomists contrasted with the high complexity of the EPCglobal industrial standard. For example, RFID readers usually transmit strict event data like the EPC code and few other technical parameters. Business data like the information on the crops and the performed operations shall be added later in the capturing application, running on a separate PC. We eased this step by leveraging the concept of the EPC ECreport custom fields, by which the Android app can generate rich events including custom business information as well as the EPC IDs, sending them to the traceability server in a single tap onto the smartphone screen.

Finally, let us observe that the improvement of the proposed traceability system, considering, as an example, the tagging of machines and boxes of products used during the treatments in the greenhouses to further automate the introduction of their associated data in the system, will characterize future works.

Acknowledgments

The authors wish to thank Eng. Giampietro Boschiroli and Dr. Sergio Serra of the company Jentu S. Agr. r. l. for their practical advice, which has been fundamental for obtaining the experimental results shown. Furthermore, the authors thank Dr. Daniele D'Aprile who has collaborated with the IDA Lab group of the University of Salento, Lecce, Italy, for his support in the architecture implementation.

References

[1] L. Mainetti, L. Patrono, and R. Vergallo, "Combining EPCglobal and HL7 to deploy innovative e-health services for patients affected by multiple intolerances," in *Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL '11)*, article 86, pp. 1–6, ACM, Barcelona, Spain, October 2011.

[2] K. Finkenzeller, *RFID Handbook, Fundamentals and Applications in Contact-Less Smart Cards and Identification*, John Wiley & Sons, New York, NY, USA, 2003.

[3] NFC Forum, The Near Field Communication (NFC) Forum, 2004, http://www.nfc-forum.org/home/.

[4] L. Catarinucci, R. Colella, M. De Blasi, L. Patrono, and L. Tarricone, "Experimental performance evaluation of passive UHF RFID tags in electromagnetically critical supply chains," *Journal of Communications Software and Systems*, vol. 7, no. 2, pp. 59–70, 2011.

[5] L. Catarinucci, R. Colella, M. De Blasi, L. Patrono, and L. Tarricone, "Enhanced UHF RFID tags for drug tracing," *Journal of Medical Systems*, vol. 36, no. 6, pp. 3451–3462, 2012.

[6] K. V. S. Rao, P. V. Nikitin, and S. F. Lam, "Antenna design for UHF RFID tags: a review and a practical application," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 12, pp. 3870–3876, 2005.

[7] M. E. de Cos and F. Las-Heras, "Dual-band antenna/AMC combination for RFID," *International Journal of Antennas and Propagation*, vol. 2012, Article ID 804536, 7 pages, 2012.

[8] L. Mainetti, L. Patrono, and R. Vergallo, "IDA-Pay: a secure and efficient micro-payment system based on Peer-to-Peer NFC technology for Android mobile devices," *Journal of Communication Software and Systems*, vol. 8, no. 4, 2012.

[9] U. Barchetti, A. Bucciero, M. De Blasi, L. Mainetti, and L. Patrono, "Implementation and testing of an EPCglobal-aware discovery service for item-level traceability," in *Proceedings of the International Conference on Ultra Modern Telecommunications and Workshops*, IEEE, Ed., pp. 1–8, Institute of Electrical and Electronics Engineers (IEEE), St. Petersburg, Russia, October 2009.

[10] EPCGlobal, The EPCglobal NetworkTM: overview of design, benefits and security, 2004, http://www.epcglobalinc.org/.

[11] F. Thiesse, C. Floerkemeier, M. Harrison, F. Michahelles, and C. Roduner, "Technology, standards, and real-world deployments of the EPC network," *IEEE Internet Computing*, vol. 13, no. 2, pp. 36–43, 2009.

[12] F. Paganelli and D. A. Parlanti, "DHT-based discovery service for the internet of things," *Journal of Computer Networks and Communications*, vol. 2012, Article ID 107041, 11 pages, 2012.

[13] A. Guido, L. Mainetti, and P. Patrono, "Evaluating potential benefits of the use of RFID, EPCglobal, and ebXML in the pharmaceutical supply chain," *International Journal of Healthcare Technology and Management*, vol. 13, no. 4, pp. 198–222, 2012.

[14] E. Bottani, R. Montanari, and A. Rizzi, "The impact of RFID technology and EPC system on stock-out of promotional items," *International Journal of RF Technologies*, vol. 1, no. 1, pp. 6–22, 2009.

[15] M. Trebar, A. Grah, Á. Melcón, and A. Parreno, "Towards RFID traceability systems of farmed fish supply chain software," in *Proceedings of the 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM '11)*, pp. 6–11, September 2011.

[16] L. Catarinucci, I. Cuiñas, I. Expósito, R. Colella, J. A. G. Fernández, and L. Tarricone, "RFID and WSNs for traceability of agricultural goods from Farm to Fork: electromagnetic and deployment aspects on wine test-cases," in *Proceedings of the 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM '11)*, pp. 12–15, September 2011.

[17] M. Keshtgari and A. Deljoo, "A wireless sensor network solution for precision agriculture based on zigbee technology," *Wireless Sensor Network*, vol. 4, pp. 25–30, 2012.

[18] A. D. Siuli Roy and S. Bandyopadhyay, "Agro-sense: precision agriculture using sensor-based wireless mesh networks," in *Proceedings of the 1st ITU-T Kaleidoscope Academic Conference, Innovations in NGN: Future Network and Services (K-INGN '08)*, pp. 383–388, May 2008.

[19] L. Xiao and L. Guo, "The realization of precision agriculture monitoring system based on wireless sensor network," in *Proceedings of the International Conference on Computer and Communication Technologies in Agriculture Engineering (CCTAE '10)*, vol. 3, pp. 89–92, June 2010.

[20] D. A. Chappell, *Enterprise Service Bus*, O'Really Media, 2009.

[21] Jentu S. Agr. r. l., http://www.jentu.biz/home.html.

[22] Fosstrak, Open source RFID platform, https://code.google.com/p/fosstrak/.

[23] EPC Tag Data Standard (TDS), EPCglobal Standards and Technology, 2007, http://www.gs1.org/gsmp/kc/epcglobal/tds/tds_1_3_1-standard-20070928.pdf.

[24] The Application Level Events (ALE) Specification, Version 1.1.1, http://www.gs1.org/gsmp/kc/epcglobal/ale/ale_1_1_1-standard-core-20090313.pdf.

[25] WSO2 lean, enterprise, middleware, http://www.wso2.com/.

[26] L. Fulton, J. R. Rymer, M. An, and M. Czarnecki, *The Forrester Wave: Enterprise Service Buses*, Forrester Research, 2011.

[27] Apache Synapse, http://synapse.apache.org/.

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 916526, 9 pages
http://dx.doi.org/10.1155/2013/916526

Research Article

Exploring the Limitations on RFID Technology in Traceability Systems at Beverage Factories

Isabel Expósito and Iñigo Cuiñas

Departamento de Teoría do Sinal e Comunicacións, Universidade de Vigo, 36310 Vigo, Spain

Correspondence should be addressed to Iñigo Cuiñas; inhigo@uvigo.es

Received 27 March 2013; Revised 1 June 2013; Accepted 5 June 2013

Academic Editor: Luca Catarinucci

The application of RFID in traceability of products in beverage factories is analyzed in terms of the electromagnetic conditions defined by the massive presence of metallic elements and liquids. Various experiments are reported to determine the maximum reading range from RFID tags installed on tanks or to read RFID information around bottles, both empty and full of wine, trying to put in context the possible problems that could appear when installing an RFID-based traceability system within a winery, a brewery, or any other beverage factory.

1. Introduction

During last years, the development of radio frequency identification (RFID) technologies has been fast and their applications grow in parallel to the reduction of costs [1]. A lot of companies and even some European projects proposed the use of RFID technology to build full traceability systems, substituting barcodes in some applications but extending the functionalities to the complete production chain [2–4]. The development of international standards, such as EPC global [5], has given an additional impulse to further spread this technology. Reading some reports, it would seem that the RFID is the solution for all traceability problems. The reason to propose the use of this technology for traceability purposes is that it allows the unequivocal identification of each agent along a production chain (machines, containers, products, and even operators) and a fast and accurate registration of all of them when being involved at each step of the process. Thus, the reconstruction of a product history becomes no more than a query at the database storing all the data previously collected in the factory.

The wide diversity of tags available in the market allows the use of RFID in a large range of applications. Tags could even be printed directly to the final product by means of inkjet-printing technology [6]. Passive RFID tags are the most used tracing systems due to their lower cost, especially at item level. Several frequencies are also available. The choice of the frequency will depend on the requirements of the applications (required reading range, environmental conditions, multitag reading, etc.).

The development of an RFID-based traceability system in a beverage factory (wine, liquors, sodas, etc.) presents some technical challenges due to the special considered environments: large metallic tanks, liquids, glass bottles, and so forth, all of them electromagnetic unfriendly elements. But the developments of such system could lead to improved benefits associated with reduction of time expenses, reduction of errors, and accuracy of the information. The objective of this paper is not only to present an implementation of an RFID-based traceability and its advantages but also to isolate and evaluate the possible limitations due to the presence of liquid and metallic elements.

The paper is organized as follows. After this introduction, a brief description of related works occupies Section 2. Section 3 is centered on the guidelines of a complete traceability system based on RFID technology. Then, the detection and analysis of limitations for RFID operation due to the environment characteristics are the focus of Section 4, which is followed by the Conclusions section.

2. Related Works

Previous examples of the implementation of RFID tracing systems in food supply chains can be found in the literature, even in scenarios with adverse propagation conditions [7–9].

When certain reading distance or multiple readings are required, UHF technology is commonly used. Previous studies have been performed to evaluate the theoretical limitations in the performance of UHF RFID tags [10], not only for tags working in far filed conditions but also for the ones designed to operate in near field [11], as they are less affected by the presence of liquids and metals. However comparative test shows that UHF far field tags can provide good performance also in critical environments. That is one of the reasons to use FF UHF tags in our research and also to allow the developed system to be in compliance with the EPCglobal standard. The benefits of the combined use of both RFID technology and EPCIS standards in supply chains have been also analyzed [12].

Some authors propose specific tag designs to highly overcome the limitations of UHF RFID tags in critical environments [13, 14] although our study was performed with commercial available RFID tags as it aims to test if their use is feasible in the nonelectromagnetic friendly environment of a winery, in order to minimize the costs of initial investment.

3. RFID-Based Traceability System

There are several reasons for a factory manager to implement a traceability system, both voluntary and compulsory. The mandatory reasons came from the legislation that controls quality or origin guarantee of the products. The voluntary ones arise from the conviction of a better organized and improved work along the production chain. Both reasons could be applied to many beverage factories: several wineries or whisky companies are involved in denominations of origin that force the adoption of traceability systems. Others are not forced to do that, but they produce added value liquors and need to guarantee consumers their quality.

Anyway, all the involved factories have something in common: the quality of the processes applied to the liquids (wines, liquors, and sodas) has to be certified, and all the related data are stored, to assure complete product traceability. The handled data include information regarding liquid analysis, treatments applied, equipment used in processing, and so forth. Previous to the RFID-based system implementation, the usual procedure was to store the data in register books and then manually copy the most important in digital registers (i.e., spreadsheets). The RFID-based approach aims to automatically collect all these information in digital supports and to develop applications to easily recover the data related to a specific product.

The processing stage is, by far, the most important one in beverage factories supply chain. It is the largest and most complex one, and the different processes performed in it will define the different characteristics and qualities of the products. That is, the processing phase of wine starts when the grapes collected arrive to the winery and it ends when the wine is bottled and stored, through a succession of actions: grapes classification, pressing, decantation, fermentation, blending, product treatments, conservation, and so forth. All the locations where the grapes and wine pass trough have to be identified in order to assure the traceability of wine. In each step of the processing phase, a lot of meaningful information is generated and has to be collected and stored in a database, especially those regarding chemical analysis and treatments performed. And something like this occurs at factories producing other beverages.

The RFID system designed in the presented research for a beverage company will allow easy data collection and digital storage of them, partly removing the current system of paper based registers and manual loading of data in spreadsheets. Along the whole processing stage Events will be generated and stored, so that the state of the product can be precisely controlled at each moment, and all the information related to the processes is easily accessible. Some assets are reused in different phases, so that a precise and unequivocal identification of them is required to ensure traceability. RFID tags will be attached to the different equipment used.

Two issues are solved with the RFID-based system: the automation of traceability data collection and their storage in digital supports and the quick access to traceability information at any point of the supply chain.

3.1. Automation of Traceability Data Collection and Their Storage in Digital Supports. At wine or liquor processing stage the amount of data handled is very large, and a precise control on them is needed, to assure a good quality and its traceability. As stated above, the registration of traceability data is typically done manually and then transferred to computer format using spreadsheets.

The first step, when developing a traceability system, is to perform a study of the business processes in the factory to identify the different steps in its supply chain and the information flow between them. Once the mandatory/optional information to be collected was defined, the points in the chain to do the capture are set.

The business processes are defined in terms of Events according to the EPCglobal standard [15]. We have used the Fosstrak EPCIS repository to store the Events, and we have run its access interfaces in a GlassFish application server [16]. The assets and locations involved and their relation to intermediate and final products are also identified. After collecting all the necessary requirements, the system design centered (HW and SW definitions) around two main points (Figure 1).

(i) *Data Capturing.* As all the locations and assets involved in raw and final products processing have to be identified in order to perform product traceability, they have been assigned an EPC code by tagging them with RFID labels. Some assets are reused in different phases, so that a precise and unequivocal identification of them is required to ensure traceability.

Then, a capture application for an RFID reader must be programmed to read those RFID tags and to introduce any other relevant data related to the production

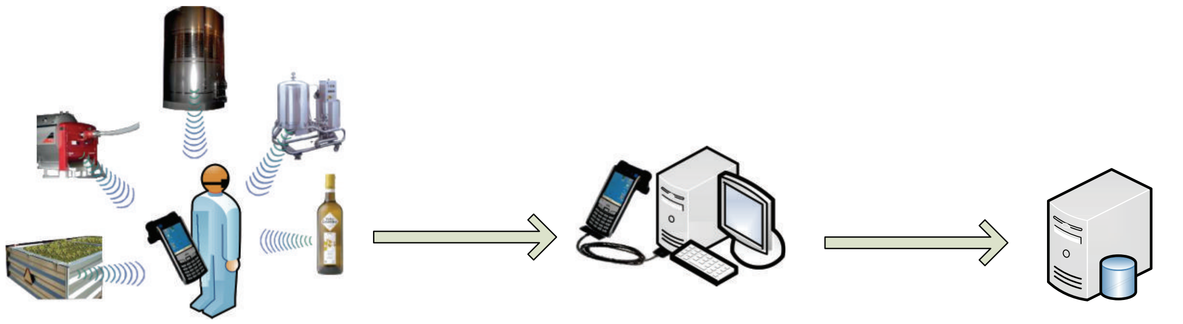


Figure 1: Schema of the data capturing process.

at each step of the supply chain. For each action performed one or several XMLs containing the generated EPCIS Events are built with all the collected information and stored in the handheld memory.

(ii) *Database Data Storage*. A PC desktop application is programmed to manage the communications with the EPCIS repository for information storage and recovery functions. The XMLs generated during data collection have to be copied from the handheld reader's memory to a PC. Then, by using one of the desktop application features, the data in the XMLs are sent to the EPCIS capture interface and stored in the repository. In this way we have all the pertinent data available in digital support (an MySQL database in a computer) available for consultation.

The RFID system designed will allow easy and fast data collection directly in digital support, removing paper based registers. At the same time the number of errors (and their associated costs) is reduced, and a better use of employees' time is achieved.

3.2. Quick Access to Traceability Information at Any Point of the Supply Chain. Currently, a high amount of spreadsheets should be checked for recovering traceability data, for example, in case they have been required by the competent authority or if there has been a recall.

The solution must be a desktop traceability application to track the wine at the winery. On the one hand it allows obtaining the complete traceability information of a bottle, through its batch number. On the other hand there is the possibility of querying for liquid information at any point of the supply chain, by using the tank number. Thus, the system makes the information sharing easier and also improves the visibility throughout the supply chain.

In addition, the RFID system allows linking unequivocally the liquid product with the data related to its production: performed processes, locations, environmental and chemical parameters, and so forth giving the producer a better control of product quality. So quality control and traceability are performed at the same time.

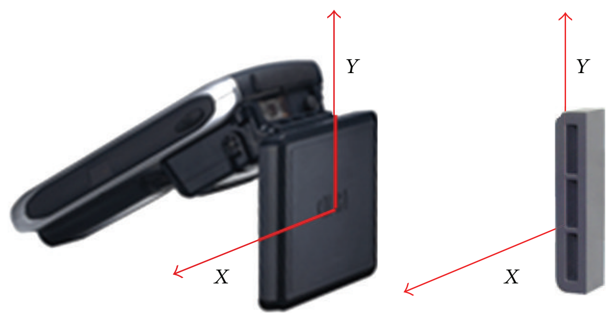


Figure 2: Coordinate system to establish a reference for the tag orientation.

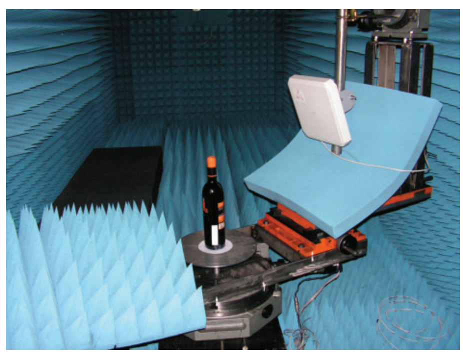
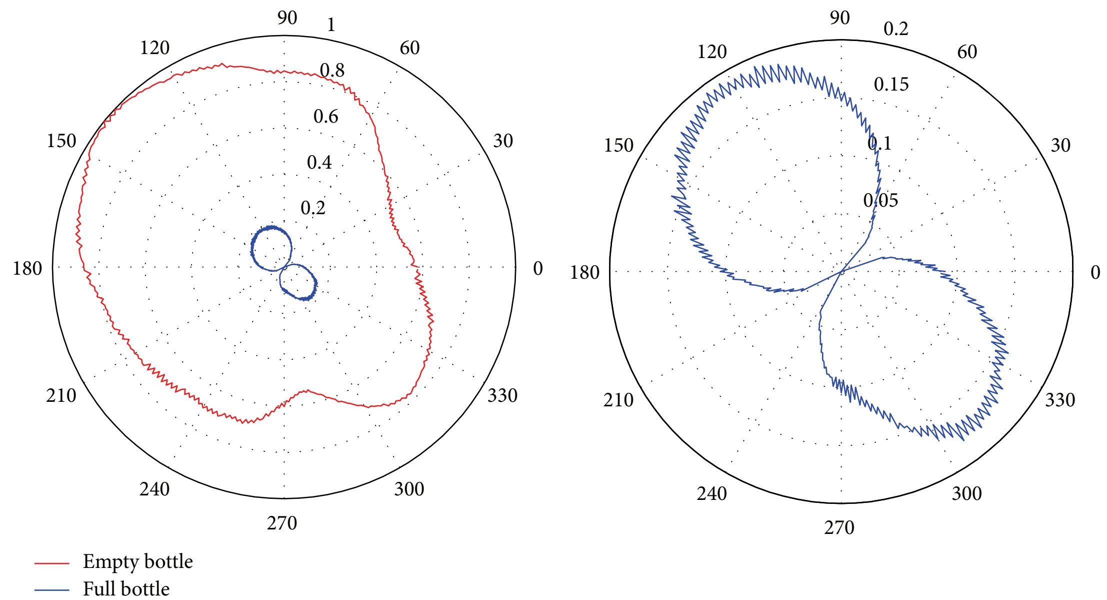


Figure 3: Setup for the measurements of received signal and reading arc around bottles.

4. Identification and Analysis of RFID Limitations within a Beverage Factory

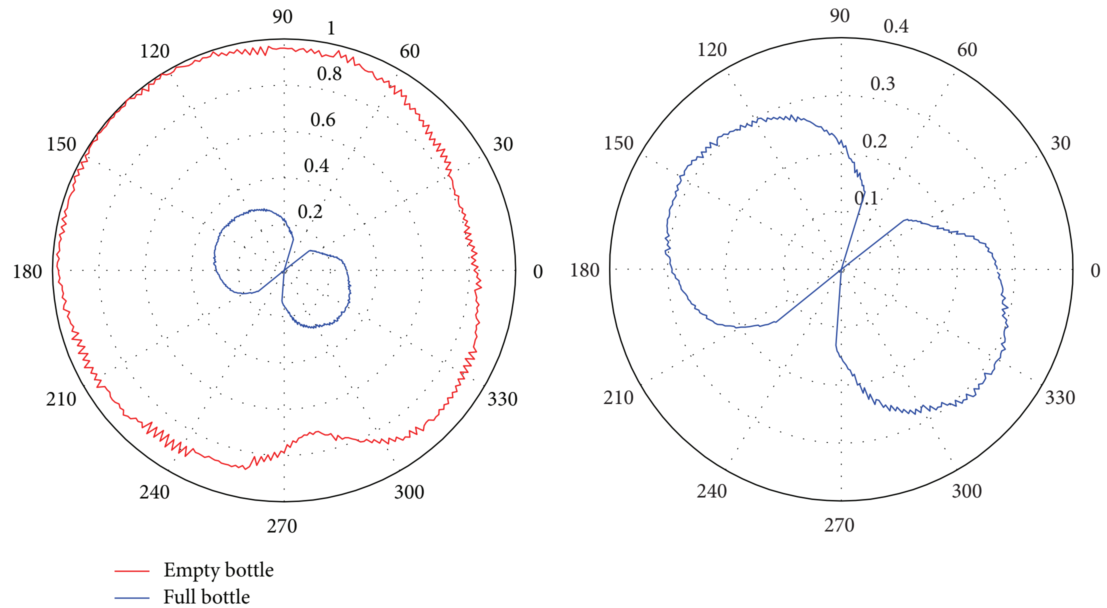
The first step to identify the possible limitations when operating an RFID-based traceability system within a beverage factory is the reflection on the materials that (i) make especially the propagation of radio waves difficult and (ii) are also present in such factories.

It is well known that conductive materials generate isolation with respect to their shadowed areas and also induce strongly reflections of radio waves that beat the metallic



(a) (b)

Figure 4: Percentage of received power, using tag 1, around bottle 2.



(a) (b)

Figure 5: Percentage of received power, using tag 2, around bottle 2.

surface [17]. Radio wave propagation in factory buildings presents large multipath phenomena, directly related to building age, inventory, wall locations, and ceiling height [18]. Beverage factories are full of large metallic tanks, so it is expected to find a complicated electromagnetic ambience: important multipath phenomena and vast areas with no radio coverage. This absence of radio coverage could be solved by applying imaginative techniques as taking advantage of HVAC ducts [19].

Liquids are other unfriendly materials for electromagnetic activities, as propagation conditions could change or even disappear within such materials. Obviously, there are lots of liquids in beverage factories, and the air and surfaces humidities are also elevated. Besides that, most of the liquid products of such factories are commercialized in glass bottles, which depending on their conductivities could be complicated materials: scattering or attenuation phenomena could be induced around each individual bottle [20]. So, a set of

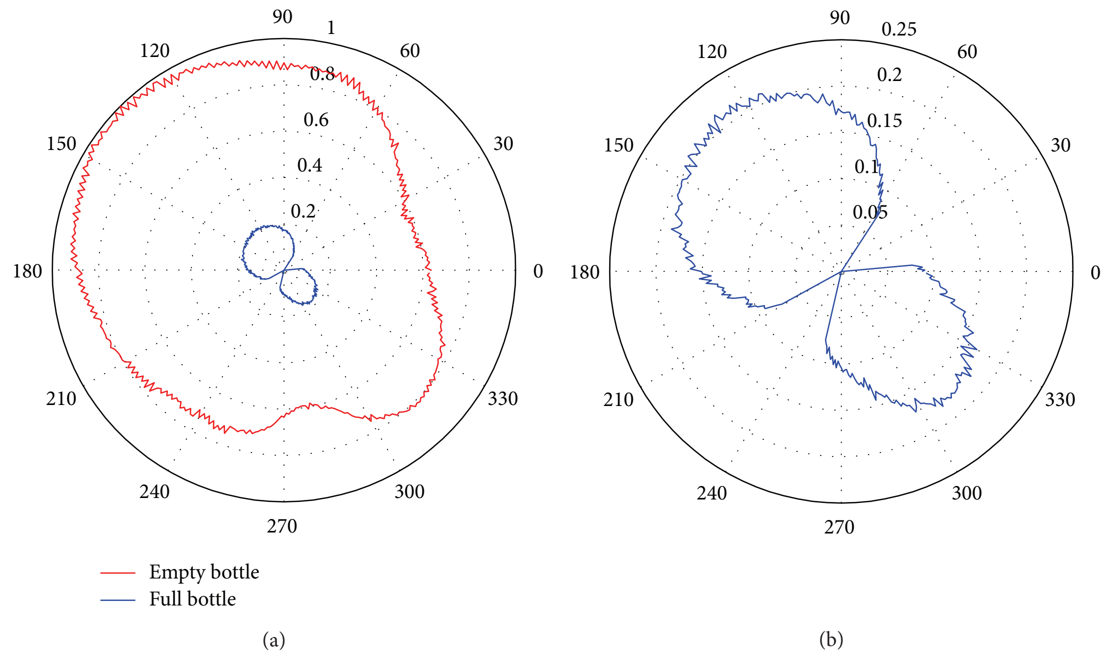


FIGURE 6: Percentage of received power, using tag 5, around bottle 2.

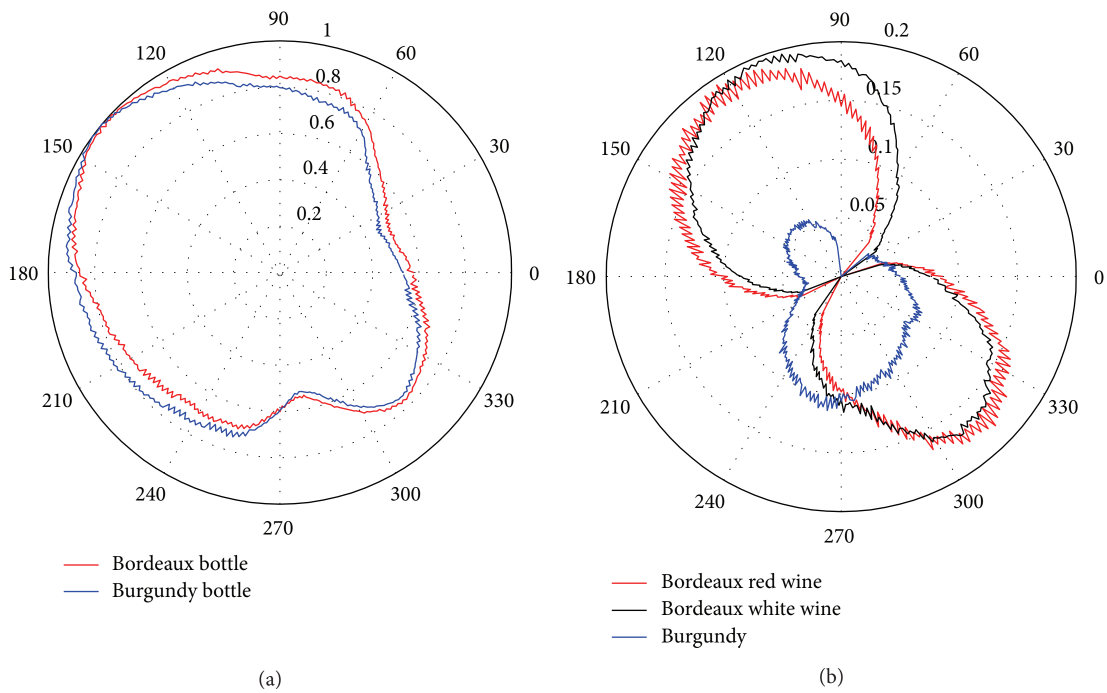


FIGURE 7: Comparison of the percentage of received power, using tag 1, around three bottles.

bottles would be a very difficult environment to be electromagnetically modeled.

4.1. Metallic Tanks. Several tests were performed to measure the maximum reading range of a tag attached to a wine tank. The tag used was the Confidex Halo [21], and its reading range attached to the tank was measured by using the ATID AT-570 handheld reader [22]. Although the antenna design for RFID tags is rapidly expanded [23] and there are special tag designs that would improve the radio performance isolating the tag from the surface where it is glued [24], this work is focused on commercial inexpensive tags, as they are the most accessible ones for RFID integrators.

Table 1: Maximum reading distance of a tag glued on a metallic tank depending on its orientation.

Position to the vertical axis	Maximum reading range
0°/90° on nonmetal surface	162 cm/160 cm
0° on metal surface	81 cm
30° on metal surface	78 cm
60° on metal surface	73 cm
90° on metal surface	53 cm
120° on metal surface	53 cm
150° on metal surface	73 cm

The measures were performed in such a way that the reader antenna and the tag were parallel to each other, according to the coordinate system indicated in Figure 2. Besides, the maximum reading distance was measured for several positions of the tag on the tank, indicated as an angle with respect to vertical direction (Y), assuming cylindrical metallic tanks oriented with its axis along Y.

Table 1 shows the maximum reading range for each orientation of the tag in the tank and a measure of the reading range with the tag in a nonmetal surface (a wall) for comparison.

0° to the vertical axis (i.e., the tag is vertically installed) seems to be the best position for the tag (it can be read at up to 81 cm). The difference in reading distance between this case and 90° to the vertical axis, that is, horizontal installation (53 cm of reading range), may be due to the curvature of the tank, because the metal contact underneath tag is not uniform in its entire surface. This difference is minimal in the reference case maybe because the tag is attached to a flat surface.

It is interesting to observe that the presence of the metallic surface divides by two the maximum reading distance; that is, it degrades the performance of the RFID link.

4.2. Bottles. A radio electric measurement campaign involving different models of bottles, different kind of wines, various RFID tag designs, and several locations of the RFID tags has been performed within an anechoic chamber. As a difference with previous experiences, where researchers used tailor made setups [25], this measurement campaign has been developed with standard RFID reader. Figure 3 shows instant snapshot of the measurement campaign.

Measurements were made using the Alien ALR-9900 reader [26] and an Alien ALR-8611-AC antenna [27]. As the tests have been performed within an anechoic chamber, the use of only one type of RFID reader has no impact on the obtained results. Up to eight different tag models (Table 2) were tested looking for situations which would be common to most of them, depending on their adaptation to the electromagnetic conditions of the bottle. To assess whether the type of wine contained in the bottle and the shape of the bottle influence the measure, measurements have been made attaching tags in four bottles of different wines. To evaluate how much the signal is attenuated in the presence of liquid, the same measurements were made in two empty bottles in order to establish a reference.

We considered that, using individual bottles during the experiment, we could isolate the effects of the bottle and wine on the propagation conditions. When using various bottles at a time, it could be difficult to explain which effects are due to the wine and individual bottle and which are a consequence of multipath among the set of bottles.

Table 3 shows detailed information about the shape of the bottles. The distance between the center of the antenna and the center of the platform where the bottle is placed is 60 cm, and the antenna is pointing to the bottle with an angle of 19° with respect to the vertical axis.

The first results of the campaign show that the received power is reduced in all cases, due to the presence of the liquid, which also modifies the radiation pattern, as can be observed in Figures 4, 5, and 6. The maximum received power is reduced between 31% and 89% depending on the type of tag used, with a mean value of 63%. In the same way the arc around the bottle where the reading of the tag is possible is also reduced, from 9% to 73%, with a mean value of 28% (in only one of the combinations considered no reduction is observed).

Table 4 shows the percentage of reduction of received power when the wine is inside the bottle. As expected the tags on the filled bottles are not able to guarantee optimal performance, due to the attenuation of radio waves in the presence of liquids. Analyzing the results, it seems that the reduction in the power received from the tag due to the presence of liquid is more related to the type of tag used than to the shape of the bottle and the chemical characteristics of the liquid inside it, as the percentage values are quite similar, in most of the cases, for a given tag model. Only slight differences can be attributed to the specific chemical characteristics of wine, as happens with bottles 2 and 4, which, despite containing the two red wines, do not have the same percentage. The wines are under different denominations of origin.

When considering the arc around the bottle where the tag can be read, as indicated in Table 5, the model of tag used has a great influence on arc reduction, but, in some situations, for a given tag, the reduction is different, and this could come from the shape of the bottle or from the content inside it.

(i) For tag 2 and tag 4 the arc at which the reading is possible is smaller for the bottle with Burgundy shape.

(ii) In the case of tag 3 the differences in reading arc appear to be caused by the type of wine (better results for white wine).

When choosing the best model to be used, the results showed in both tables should be considered together. For example, although tag 7 was the one with less reduction in the receiving power, the reading arc is reduced to a half; tag 8 allows less receiving power than tag 7 but the reading arc is the best. So, for an application where the relative position between the tag and the reader cannot be controlled with precision, tag 8 would be a better solution.

Figure 7 shows a comparison of the radiation pattern for a specific tag and the two bottle shapes analyzed. If the bottle is empty, the radiation pattern for the two shapes is very similar, but we can appreciate a great difference when the bottle is full

Table 2: Characteristics of the RFID tags used in the tests.

Tag	1	2	3	4	5	6	7	8
Chip	Impinj Monza 3	NXP U-Code G2XL	NXP U-Code G2XL	Impinj Monza 3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3
Size (mm)	97 × 27	97 × 15	80 × 25	54 × 34	98 × 12	73.5 × 21	47 × 50	97.5 × 23
Inlay	Paper							
Prot.	EPC Class 1 Gen 2							
Freq.	860–960 MHz							

Table 3: Characteristics of the bottles of wine used in the tests.

	Bottle 1	Bottle 2	Bottle 3	Bottle 4	Reference bottle 1	Reference bottles 2, 3, and 4
Shape	Burgundy	Bordeaux	Bordeaux	Bordeaux	Burgundy	Bordeaux
Height	30 cm	30 cm	32 cm	31.5 cm	30 cm	31.5 cm
Neck length	10.5 cm	8.5 cm	8.5 cm	8.5 cm	10.5 cm	8.5 cm
Base diameter	7.5 cm	6.8 cm	6.8 cm	7 cm	7.5 cm	7 cm
Type of wine	White	Red	White	Red	—	—

Table 4: Percentage of reduction in the maximum received power due to the influence of wine.

	Tag 1	Tag 2	Tag 3	Tag 4	Tag 5	Tag 6	Tag 7	Tag 8
Bottle 1—white wine—Burgundy shape	89%	78%	59%	82%	86%	83%	38%	62%
Bottle 2—red wine—Bordeaux shape	81%	68%	80%	76%	78%	81%	31%	62%
Bottle 3—white wine—Bordeaux shape	80%	70%	68%	78%	80%	80%	42%	62%
Bottle 4—red wine—Bordeaux shape	83%	70%	75%	79%	81%	82%	41%	62%

Table 5: Percentage of reduction in the reading arc around the bottle due to the influence of wine.

	Tag 1	Tag 2	Tag 3	Tag 4	Tag 5	Tag 6	Tag 7	Tag 8
Bottle 1—white wine—Burgundy shape	16%	67%	45%	65%	28%	13%	40%	16%
Bottle 2—red wine—Bordeaux shape	18%	22%	73%	36%	27%	23%	49%	0%
Bottle 3—white wine—Bordeaux shape	14%	26%	45%	30%	25%	17%	41%	9%
Bottle 4—red wine—Bordeaux shape	19%	26%	71%	44%	24%	15%	54%	9%

Table 6: Maximum received signal and reading arc values at different tag heights.

Position of tag's center	Arc width	Maximum (a.u.)
7 cm	177°	1534.3
7.8 cm	174°	1547.6
8 cm	175°	1549.3
8.5 cm	166°	1513.0
9 cm	133°	1345.5
9.5 cm	111°	1190.4
10 cm	47°	930.1
10.5 cm	96°	920.5
11 cm	124°	1141.1
11.5 cm	196°	1298.5
12 cm	172°	1321.7
12.5 cm	114°	1244.4
13 cm	99°	1141.7
13.5 cm	92°	1091.3

of liquid. Such a difference does not exist when the bottles have the same shape but different content (red or white wine).

Besides, another test has been performed to choose the best height to place the tag along the bottle. During the tests, the tag is attached to the bottle with its center situated between 7 and 13.5 cm with respect to the bottom of the bottle, and this last one is placed at a fixed location in the center of the chamber (as already shown in Figure 3). For each position of the tag, the RFID antenna is moving along a 360-degree arc around the bottle location, centered at the bottle axis. The antenna stops at each degree, where 25 readings of the tag are performed.

Measurements have been performed with the same four bottles used in the previous experiment and two models of tags. Table 6 shows the width of the arc at which the reading is possible and the maximum value of received signal (RSSI measured by the RFID reader arbitrary units) in each position of the tag for one of the bottles (Bordeaux shape and white wine). The maximum distance between the tag and the reader antenna is reached when the tag lies on the rear side of the bottle. Table 7 presents this distance for the Bordeaux

Table 7: Distance between the antenna and the center of the RFID tag.

Position of tag's center	Maximum distance	Minimum distance
7 cm	57.32 cm	52.50 cm
7.8 cm	56.99 cm	52.13 cm
8 cm	56.65 cm	51.77 cm
8.5 cm	56.32 cm	51.40 cm
9 cm	55.99 cm	51.04 cm
9.5 cm	55.67 cm	50.69 cm
10 cm	55.34 cm	50.33 cm
10.5 cm	55.02 cm	49.98 cm
11 cm	54.70 cm	49.63 cm
11.5 cm	54.39 cm	49.28 cm
12 cm	54.08 cm	48.94 cm
12.5 cm	53.77 cm	48.59 cm
13 cm	53.46 cm	48.25 cm
13.5 cm	53.16 cm	47.92 cm

shaped bottle with white wine. Such distance depends on the distance between the antenna and the bottle, the diameter of the bottom of the bottle, and the height at which the tag is glued. Minimum distance (tag on the front side) is also presented for comparison.

Results show that, in this case, the best position to put the tag is with its center between 7 cm and 8 cm away from the bottom of the bottle. For these distances the receiving signal reaches its maximum values, with a good reading arc compared with other positions. Only the width of reading arc is larger at 11.5 cm, but the values of receiving signal are smaller. This bottle was chosen to represent the experiment as the results for the previous combinations of tags and bottles clearly center the best position in the same place, both in terms of reading arc and power received. So, the results for the mentioned bottle were more interesting to remark because the best position was not the same for the two factors to be considered.

5. Conclusions

In this paper, the use of RFID technology is analyzed for implementing traceability at beverage factories, where the ambience is not electromagnetically friendly. The main concepts of such systems are introduced.

Then, different problems related to radio wave propagation are analyzed and evaluated by means of measurement campaigns performed around metallic tanks and wine bottles. An especial care is taken in comparing the performance of the RFID tags when the material under discussion is not present (the metallic tanks or the wine inside the bottle), as it reinforces the idea of the degradation observed by comparing both situations.

Acknowledgments

This work has been supported by the European Commission (CIP-Pilot Actions), under the project "RFID from Farm to Fork," Grant agreement no. 250444. Research is supported by the European Regional Development Fund (ERDF) and the Galician Regional Government under Project CN 2012/260 "Consolidation of Research Units: AtlantTIC."

References

[1] J. Landt, "The history of RFID," *IEEE Potentials*, vol. 24, no. 4, pp. 8–11, 2005.

[2] RFID-F2F (RFID From Farm to Fork), http://www.rfid-f2f.eu/.

[3] ASPIRE, "Advanced Sensors and light weight Programmable Middleware for Innovative RFID Enterprise applications," http://www.fp7-aspire.eu/rfid/sme/.

[4] eTrace, http://www.tracefood.org/index.php/International:SAFEFOODERA_eTrace.

[5] EPCglobal standard for the Electronic Product Code, http://www.gs1.org/epcglobal.

[6] J. Virtanen, J. Virkki, A. Z. Elsherbeni, L. Sydänheimo, and L. Ukkonen, "A selective ink deposition method for the cost-performance optimization of inkjet-printed uhf rfid tag antennas," *International Journal of Antennas and Propagation*, vol. 2012, Article ID 801014, 9 pages, 2012.

[7] N. Mai, S. G. Bogason, S. Arason, S. V. Árnason, and T. G. Matthíasson, "Benefits of traceability in fish supply chains—case studies," *British Food Journal*, vol. 112, no. 9, pp. 976–1002, 2010.

[8] M. Trebar, A. Grah, A. A. Melcon, and A. Parreno, "Towards RFID traceability systems of farmed fish supply chain," in *Proceedings of the 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM '11)*, pp. 6–11, Hvar, Croatia, September 2011.

[9] J. Yan, Z. Feng, and D. Jian-Gang, "Research on vegetable traceability system based on internet of things and its application," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 5, no. 8, pp. 2520–2526, 2013.

[10] P. V. Nikitin and K. V. S. Rao, "Performance limitations of passive UHF RFID systems," in *Proceedings of the IEEE Antennas and Propagation Society International Symposium (APS '06)*, pp. 1011–1014, Albuquerque, NM, USA, July 2006.

[11] F. Fuschini, C. Piersanti, L. Sydanheimo, L. Ukkonen, and G. Falciasecca, "Electromagnetic analyses of near field UHF RFID systems," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 5, pp. 1759–1770, 2010.

[12] A. L. Guido, L. Mainetti, and L. Patrono, "Evaluating potential benefits on the use of RFID, EPCglobal, and ebXML in the pharmaceutical supply chain," *International Journal of Healthcare Technology and Management*, vol. 13, no. 4, pp. 198–222, 2012.

[13] L. Catarinucci, R. Colella, M. de Blasi, L. Patrono, and L. Tarricone, "Enhanced UHF RFID tags for drug tracing," *Journal of Medical Systems*, vol. 36, no. 6, pp. 3451–3462, 2012.

[14] L. Catarinucci, R. Colella, M. de Blasi, L. Patrono, and L. Tarricone, "Experimental performance evaluation of passive UHF RFID tags in electromagnetically critical supply chains," *Journal of Communications Software and Systems*, vol. 7, no. 2, pp. 59–70, 2011.

[15] *EPC Information Services (EPCIS) Version 1.0.1 Specification*, 2007, http://www.gs1.org/gsmp/kc/epcglobal/epcis/epcis_1_0_1-standard-20070921.pdf.

[16] Fosstrak, Open source RFID platform, https://code.google.com/p/fosstrak/.

[17] M. Alonso and E. Finn, *Fundamental University Physics. Vol II: Fields and Waves*, Addison-Wesley Publishing Company, Reading, Mass, USA, 1967.

[18] T. S. Rappaport, "Characterization of UHF multipath radio channels in factory buildings," *IEEE Transactions on Antennas and Propagation*, vol. 37, no. 8, pp. 1058–1069, 1989.

[19] P. V. Nikitin, D. D. Arumugam, M. J. Chabalko, B. E. Henty, and D. D. Stancil, "Long range passive UHF RFID system using HVAC ducts," *Proceedings of the IEEE*, vol. 98, no. 9, pp. 1629–1635, 2010.

[20] Y. Zhang, K. Yemelyanov, X. Li, and M. G. Amin, "Effect of metallic objects and liquid supplies on RFID links," in *Proceedings of the IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting (APSURSI '09)*, Charleston, SC, USA, June 2009.

[21] Confidex Halo Product Datasheet, Confidex Limited, January 2010.

[22] AT570 Reference Guide, version 1.1, ATID Company Limited.

[23] K. V. S. Rao, P. V. Nikitin, and S. F. Lam, "Antenna design for UHF RFID tags: a review and a practical application," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 12, pp. 3870–3876, 2005.

[24] M. E. de Cos and F. Las-Heras, "Dual-band antenna/AMC combination for RFID," *International Journal of Antennas and Propagation*, vol. 2012, Article ID 804536, 7 pages, 2012.

[25] P. V. Nikitin and K. V. S. Rao, "LabVIEW-based UHF RFID tag test and measurement system," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 7, pp. 2374–2381, 2009.

[26] ALR-9900+EMA, Enterprise RFID Reader, Alien Technology, 2012.

[27] ALR-8611-C, High Performance RFID Antenna, Alien Technology, 2009.

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 713943, 10 pages
http://dx.doi.org/10.1155/2013/713943

Research Article

Near Field UHF RFID Antenna System Enabling the Tracking of Small Laboratory Animals

Luca Catarinucci, Riccardo Colella, Luca Mainetti, Vincenzo Mighali, Luigi Patrono, Ilaria Sergi, and Luciano Tarricone

Department of Innovation Engineering, Salento University, 73100 Lecce, Italy

Correspondence should be addressed to Luigi Patrono; luigi.patrono@unisalento.it

Received 12 April 2013; Revised 31 May 2013; Accepted 1 June 2013

Academic Editor: Iñigo Cuiñas

Radio frequency identification (RFID) technology is more and more adopted in a wide range of applicative scenarios. In many cases, such as the tracking of small-size living animals for behaviour analysis purposes, the straightforward use of commercial solutions does not ensure adequate performance. Consequently, both RFID hardware and the control software should be tailored for the particular application. In this work, a novel RFID-based approach enabling an effective localization and tracking of small-sized laboratory animals is proposed. It is mainly based on a UHF Near Field RFID multiantenna system, to be placed under the animals' cage, and able to rigorously identify the NF RFID tags implanted in laboratory animals (e.g., mice). Once the requirements of the reader antenna have been individuated, the antenna system has been designed and realized. Moreover, an algorithm based on the measured Received Signal Strength Indication (RSSI) aiming at removing potential ambiguities in data captured by the multiantenna system has been developed and integrated. The animal tracking system has been largely tested on phantom mice in order to verify its ability to precisely localize each subject and to reconstruct its path. The achieved and discussed results demonstrate the effectiveness of the proposed tracking system.

1. Introduction

The cost-effectiveness and ease of use of passive radio frequency identification (RFID) systems in the Ultra High Frequency (UHF) band are promoting a huge diffusion of such technology in a wide range of scenarios, even quite far from the canonical ones related to logistics. Identification of goods containing liquids or metal [1–3], traceability of sensitive goods, such as pharmaceutical products [4–7], RFID-based sensor data transmission [8–10], RFID-assisted navigation of robots [11], and augmented RFID scenarios [12–15], which are only a few of the many possible examples. A peculiar case study, not yet exhaustively explored [16], consists of the tracking of small-size animals carrying a small-enough RFID tag. Indeed, animal tracking and animal behavior analysis have always had a crucial impact both in dedicated disciplines and in biomedical contexts [17], and different technologies are typically adopted depending on the application context. For instance, in most cases medium/large size animals (e.g., cows, pigs, etc.) in outdoor environment are monitored, and GPS-based or radar-based tracking solutions are adopted [18, 19]. But when groups of small laboratory animals in indoor environments are considered, a different solution is necessary. This is the most important challenge, because the behavior analysis of small laboratory animals is crucial when, for instance, the effects of new drugs or vaccines for humans must be preliminary evaluated. The literature in this field proposes solutions primarily based on Low Frequency (LF) [16] or High Frequency (HF) [10] RFID systems and, consequently, not exploiting the powerful of the EPC Class-1 Generation-2 standard, which provides, for instance, anticollision mechanisms for the concurrent identification of multiple tags. Other reported solutions, not based on RFID technology, make use of sophisticated and rather expensive vision systems [20], which, though avoiding the animal to carry or having implanted any kind of device, can be strongly inaccurate, especially when colonies of animals very similar to each other must be simultaneously localized and tracked.

In such a context, it is worth highlighting that a first attempt that tries to exploit the passive RFID technology in UHF band in order to implement and validate localization and tracking systems is summarized in [21]. Moreover, a feasibility study on the use of UHF solutions for small animal tracking is reported in [22]. Both works demonstrate the appropriateness of the use of RFID technology in the addressed problem.

In this work, a novel system suitable for the tracking, in indoor environments, of laboratory animals free to move within the cage has been tackled. It relies on the use of passive Near Field (NF) UHF RFID technology. More specifically, the ground of the animal cage is virtually split into partially overlapping cells whose size is comparable with that of the animal. As the system is mainly thought for laboratory mice tracking, squared cells, with side equals to 12 cm, are considered. Under the fundamental working assumption that a passive NF UHF RFID tag is implanted in every animal, customized NF reader antennas covering the cells with a confined and uniform magnetic field are positioned right below the cage and in correspondence with each elementary cell. The individuation of the requirements of such NF antennas and their realization and characterization are the main scientific aspects of this work, as the more uniform and confined is the magnetic field of each antenna, the easier and more effective is the processing procedure of the captured data from antenna system. These requirements are satisfied by means of segmented loop techniques in order to introduce a distributed capacitance along the loop that help to lead in-phase the current distribution. In this way, a rather uniform magnetic field even for loop lengths comparable with the wavelength (λ) can be obtained.

Once the antennas have been realized and singularly characterized, the optimum distance between each couple of antennas has been experimentally estimated, and a matrix of 32 RFID antennas has been assembled. Moreover, in order to minimize both the number of RFID readers and the power radiation, the antennas have been connected to the four ports of a single RFID reader by means of a multiplexing device. In this way, the antennas are fed in time division and, consequently, at any instant, only one of them radiates. Finally, once Far Field (FF) measurements have been performed in order to verify the absence of electromagnetic compatibility problems, a software subsystem driving the hardware components and including an effective algorithm, able to extract reliable information about the animals' position on the basis of the Received Signal Strength Indication (RSSI), has been implemented. Finally, the whole tracking system has been validated successfully.

The paper is structured as follows. In Section 2, the description of the system architecture is given and its requirements individuated. In Section 3, the design of the NF antenna system is presented, whilst the whole system is described and characterized in Section 4. Finally, results are given in Section 5, and conclusions are drawn in Section 6.

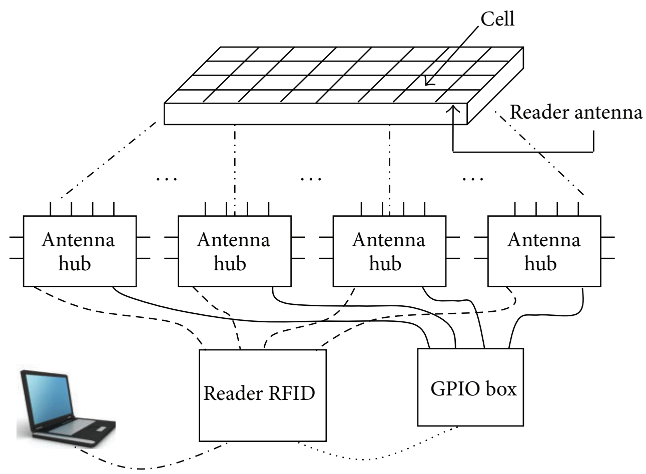


Figure 1: Hardware scheme of the proposed tracking system.

2. System Architecture and Main Requirements

The main goal of this work is to design and realize an RFID-based tracking system suitable for the behavior analysis of groups of animals and even of each single animal belonging to a group. In particular, the system is thought for small-sized laboratory animals, usually mice, free to move within a cage. Consequently, a resolution of the order of the animal size is considered satisfactory. As for the enabling technology, passive UHF RFID typology has been chosen because, compared with other solutions usually based on vision systems, it is cheaper and guarantees better performance even in case of strong similitude among the animals and in absence of illumination. The basic idea is to firstly design and realize a particular NF antenna system suitable for UHF RFID readers to be placed below the animal cage and, then, to validate the integration with software modules developed for management, controlling, storing, and reporting. Each reader antenna should be able to generate a rather uniform magnetic field in a well-defined and confined region representing the generic elementary cell of the system. In such a way, when only one of the antennas reads an RFID tag, the animal position is promptly individuated. Vice versa, if more than one antenna read the same RFID tag, the potential ambiguity can be solved through an algorithm based on RSSI analysis. The general scheme is represented in Figure 1, where a case with 32 elementary cells is considered. As can be observed, a PC is used to control the RFID reader and to elaborate the collected data. In order to minimize the number of readers, the system cost, and the emitted power, a single 4-port RFID reader is used which powers up all the 32 antennas in time division by means of a multiplexer composed of the GPIO box and four antenna hubs. Differently from [22], in which only a preliminary and very simplified hardware system was presented (e.g., the Antenna Hubs were not used) and the focus was only on the software architecture design and implementation, in this work a more complex hardware system is presented. By using such a hardware, it is possible to monitor a larger environment and therefore a greater number of animals, reducing the costs.

It is fundamental to identify the main requirements to be satisfied by the hardware components (e.g., antenna, multiplexer, etc.) as well as by the software infrastructure in order to design an efficient animal tracking system.

As for the antenna system in the RFID UHF bandwidth (860–960 MHz), the main goal is to realize a single antenna able to generate a magnetic field as uniform as possible in a region as large as the elementary cell, which in the mice case is smaller than 12 cm × 12 cm. It is worth observing that conventional loop antennas cannot be adopted, as they would guarantee a uniform magnetic field only for loop length significantly smaller than $\lambda/2$ [23], that is, for squared antennas with edges significantly smaller than 4 cm at the interested working frequency.

Based on such an antenna system, the software infrastructure should be able to pilot the system, to collect data, to resolve potential ambiguities when more antennas read the same tag, and finally to produce a report for each animal showing paths, interactions with other animals, and potential anomalous behaviors. For such goals, the proposed software architecture should be subdivided into three modules:

(i) the data acquisition module, that should be able to guarantee an efficient management by exploiting the Low Level Reader Protocol (LLRP) [24] and should provide reading reports of each reader antenna to be stored in a relational database;

(ii) the processing module, that should be able to transform the intercepted raw data into fine location data;

(iii) the plotting module, that should be able to provide the end-user (i.e., animals behavioral researcher) with both a synthetic vision and a detailed vision.

3. Antenna Design

In order to obtain an effective localization, each antenna composing the animal tracking system has to be specifically designed in order to (1) irradiate a magnetic field as confined as possible in a cell, (2) ensure an inductive coupling with the RFID tag when the animal is on the cell associated to the reader antenna, and (3) guarantee a uniform magnetic field within the cell in order to minimize the localization uncertainty. Actually, even though NF UHF RFID reader antennas exhibiting good electromagnetic performance are on the market, antennas that contemporaneously cover all the mentioned requirements are not present yet and, consequently, have to be specifically designed. According to the first specification, among all the possible antenna structures [23, 25–27], the loop structure seems to be a good solution to implement NF reader antennas. Nevertheless, in the conventional loop [23, 25], when the antenna perimeter is comparable with the wavelength (λ) at the operating frequency (f), the antenna does not produce a uniform magnetic field because currents are not in phase along the circumference. This aspect does not satisfy the other desired properties. The problem can be overcome by modeling the structure as a segmented loop antenna.

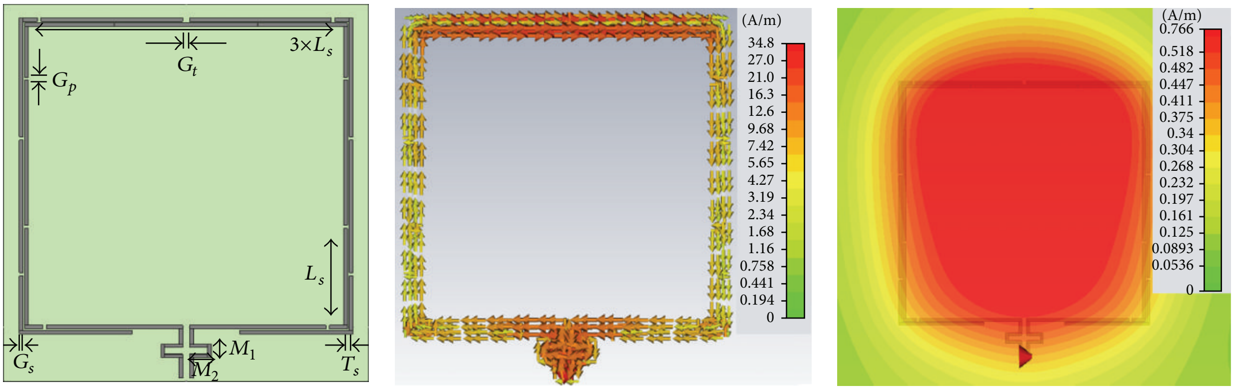
Although segmented loop antennas for RFID applications are in the literature [26], excessive dimensions of such antennas, of about 16 cm × 18 cm, are not compatible with the size of the cells at the desired frequency. For such reason, in order to reduce the segmented loop antenna size and, at the same time, preserve the radiative properties of this type of antennas, some modifications have been introduced. In Figure 2(a), the layout of the proposed segmented loop antenna is shown. The parameters L_s and G_p indicate the segment length and the gap distance between each segment respectively, whilst the parameter T_s is the width of the segment and G_s is the distance among inner and outer segments. As can be observed, differently from the segmented loop antennas presented in [26], the proposed structure exhibits two technical improvements which guarantee, on the one hand, a considerable size reduction (even up to 50%) and, on the other hand, fine regulation and a balancing of the current flow along the loop. The former improvement consists of introducing an inner segment at the top of the antenna having size $3 \times L_s$. The effect of this relatively "long" segment is to balance the current distribution, which typically tends to concentrate itself at the bottom of the antenna (near to the feed) when the overall loop dimension is reduced. Actually, the size of this segment is sufficiently small if compared with the wavelength, thus avoiding the current phase inversion, and at the same time it is long enough to favor the current flow along the top side of the antenna. The latter improvement consists of properly modifying the gap G_t at the top of the antenna, which allows a fine tuning of the current distribution in the whole antenna.

On such basis, the antenna in Figure 2(a) has been preliminarily designed on an FR-4 board having dielectric constant $\varepsilon_r = 3.7$, substrate thickness $h_s = 1.6$ mm, and copper thickness $h_c = 0,035$ mm and then optimized to work in the European dedicated UHF RFID band. Moreover, a matching network, consisting of a small loop in proximity of the feed (see Figure 2(a)), has been introduced to match the antenna impedance to the reader port impedance of 50 Ω. Table 1 summarizes the antenna parameters obtained after the simulation phase carried out by using CST Microwave Studio software [28].

More in detail, such parameters have been evaluated through a parametric optimization by using a gradient-based interpolated Quasi-Newton optimizer of CST and by setting a resonance frequency of 866 MHz as fitness function.

After such phase, size of the antenna is of 89.0 mm × 93.0 mm (becoming 100.0 mm × 115.0 mm including the support board) with a reduction in terms of occupied area of 51% with respect to the segmented loop presented in [26]. In spite of such a considerable size reduction, the current flow along the antenna is uniform as can be observed in Figure 2(b), and consequently the expected radiated magnetic field is uniform as well, and rather confined in a region slightly larger than the total area of the antenna. For a better clarification, in Figure 2(c) a slice of the simulated distribution of the radiated magnetic field at 2.5 cm of distance from the antenna is shown, confirming the actual magnetic field uniformity and the proper antenna operation.

Finally, in order to prove also the faultless impedance matching between the antenna and the reader port, in Figure 3, graphs of both simulated and measured |S11| scattering parameters related to the reference impedance of 50 Ω in the frequency band 700–1100 MHz are reported. Graphs highlight the very good agreement between the two curves with a resonance peak of −29 dB in the first case and −23 dB



(a) (b) (c)

FIGURE 2: (a) Segmented loop antenna for animal tracking system. (b) Current distribution of the segmented loop antenna. (c) Magnetic field distribution of the segmented loop antenna for animal tacking system at 2.5 centimeters of distance.

TABLE 1: Segmented loop antenna parameters.

Parameter	Value (mm)	Description	Type
L_s	30.0	Segment length	Fixed
G_p	1.1	Gap between segments	Fixed
T_s	1.0	Segment width	Fixed
G_s	0.35	Distance inner-outer segment	Fixed
G_t	1.9	Gap at the top of the loop	Tunable
M_1	4.0	Matching element height	Tunable
M_2	5.0	Matching element width	Tunable

in the second one at 866 MHz. The $|S_{11}|$ measure has been carried out by using the Vector Network Analyzer (VNA) model R&S ZVL 6.

4. System Design

The system, as a whole, is designed and implemented so as to provide accurate data on the mice movements during the desired observation period. Macroscopically, the system consists of the blocks represented in Figure 4, in which it is possible to distinguish the hardware subsystem, shown in Figure 1, and the software subsystem, responsible for configuring/controlling the hardware and for processing raw data coming from the antennas.

As already stated, the area of the cage is divided into a matrix of cells and, in correspondence to each cell, one of the antennas designed in Section 3 is positioned. Each antenna sends a readings report at a very high frequency (about 250 ms), so as to detect even very fast mice movements. The hardware subsystem mainly consists of an Impinj Speedway Revolution R420 reader [29] with four antenna ports, an Impinj GPIO adapter [30], and one HD15 cable. The GPIO adapter allows to connect up to four Impinj Antenna Hubs [30], each of which accepts up to 8 reader antennas. In this way, up to 32 different antennas can be powered in time division through a single 4-port RFID reader, but no more than one of them is powered at a certain time, thus reducing potential array effects and preserving energy wasting.

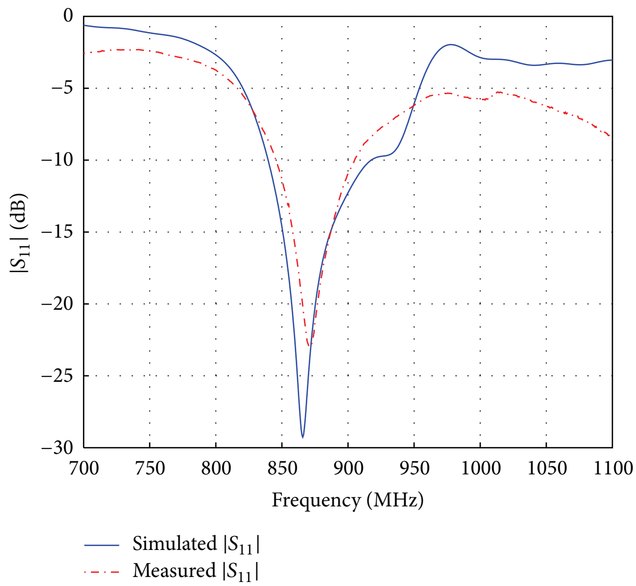


FIGURE 3: Simulated and measured $|S_{11}|$ of the segmented loop antenna.

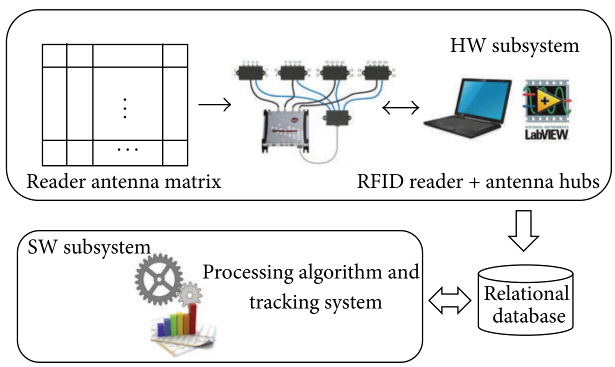


FIGURE 4: Overall schema of the proposed tracking system.

Each Antenna Hub is connected to the GPIO adapter by using a straight Ethernet cable and to the reader by using an SMA-male to R-TNC-female coaxial cable, whereas each reader antenna is connected to its Antenna Hub by using an SMA-male to SMA-male coaxial cable. Finally, the reader is connected to the computer via a cross Ethernet cable. In this way the application will acquire all reader antennas reports and will store them in a relational database. However, it is worth pointing out that, apart from the research activity costs for both software and antenna design, the whole hardware costs do not exceed the amount of 3.000,00 euros. Such costs are considerably lower than costs of other and more adopted solutions based, for instance, on vision systems.

The software subsystem, instead, consists of an application that acquires the data coming from the antennas, a processing algorithm that processes these raw data, and a software module responsible for the plotting of tracking graphs. These three software modules interact with each other by means of a relational database, in which both raw readings and final positional data are stored. One of the main tasks of the acquisition application is to preliminarily configure the RFID reader by specifying some operating parameters such as the transmission power of the antennas. The interaction between this software module and the hardware subsystem is made possible by exploiting the LLRP, according to which packets are formatted. The acquisition application also allows the end-user (i.e., researcher) to preliminarily acquire the identifiers to be traced. In such a way, only the data of interest are collected and processed. The core of the software subsystem is represented by the algorithm that processes raw data. In case of ambiguities due, for instance, to potential simultaneous readings of the same tag by more than one antenna, the algorithm evaluates the RSSI value associated with each reading and, on the basis of specific considerations regarding the succession of cells in the detected path (concept of adjacency between cells based on the Chebyshev distance calculation [31]), resolves the ambiguities. Finally, the data processed and stored in the database are extracted by the plotting module and presented as space and time graphs showing the movement of mice during the observation period. Moreover, many other data, such as the average residence time in each cell, are summarized.

In order to validate the proposed tracking system several tests have been carried out by using plastic test tubes filled with saline solution and on each tube a passive RFID tag has been applied. The saline solution is able to simulate with a good approximation the attenuation caused by the animal tissue during the reading of the tag.

The tag type used in the tests is a commercial passive NF UHF RFID transponder characterized by a memory of 32 bits, whose antenna size is 15 mm × 10 mm and the mounted chip is the ImpinjMonza4D [32]. Finally, this tag has an inlay composition characterized by aluminum on the top and polyester PET as substrate.

5. Results

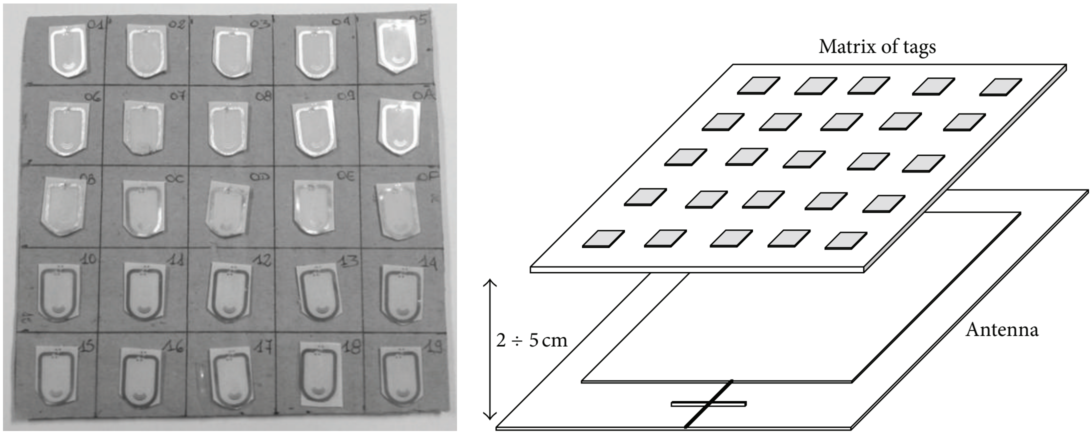
In this section, validation results related to both the designed antenna system as well as the whole tracking system are given.

5.1. Antenna System Results. Once a first prototype on the segmented loop antenna proposed in Section 3 has been realized, a characterization aimed at verifying the capability to effectively read a tag within a cell has been performed through the RSSI measurement of each read tag. In order to verify the proper functioning even when multiple tags are read simultaneously, the test has been performed by using a matrix of 25 NF RFID tags arranged on a 12 cm × 12 cm (the same size of a cell) paperboard substrate as illustrated in Figure 5(a). More in detail, the antenna under test has been firstly connected to the Impinj Speedway Revolution RFID reader, then the tag matrix has been placed in front of the antenna at different distances in a range from 2 cm to 5 cm, in steps of 1 cm, as shown in Figure 5(b). For each step, the average RSSI of each of the 25 tags has been evaluated through the reader by varying the reader output power between 24 dBm and 30 dBm in steps of 3 dBm for a test time of 20 seconds per point.

The goal of such study is the experimental evaluation of suitable combination of antenna distance and emitted power guaranteeing a rather uniform RSSI within a cell. Consequently, gathered RSSI values have been elaborated by using MATLAB [33], and graphs reporting a map of the RSSI distribution at different distances and different power levels have been obtained and reported in Table 2. In particular, for each RSSI map, a single cell represents in gray-scale the average RSSI value in dBm measured for each tag of the matrix. It can be observed that null values of RSSI are present in some cases, whilst in most cases a quite uniform RSSI distribution is appreciated. In particular, the best result is obtained at a distance of 5 cm and power of 27 dBm. In such case, RSSI values vary in a rather narrow range between −55.0 dBm and −65.68 dBm, and the distribution is quite uniform.

Once the proper functioning of a single antenna has been demonstrated, a second test aimed at estimating the optimum distance between two adjacent antennas has been performed in order to validate also the whole animal tracking platform. Such a test has been carried out by placing the antennas (opportunely connected to an Impinj Speedway reader) with two sides adjacent between them and by locating an NF tag along the separation line at a distance of 5 cm above the antennas surface (Antenna_I and Antenna_II in Figure 6(a)). Consequently, the distance between the two antennas has been gradually increased from 0 cm to 2 cm, in step of 1 cm, in order to evaluate the minimum distance guaranteeing the continuity in the tag identification during a transition between two different antennas. More specifically, for each step the NF tag has been unbalanced towards the Antenna_I and the ratio between the readings performed by the Antenna_I and the overall number of readings of the two antennas has been evaluated. In Table 3, results are reported. As can be observed, optimum values have been obtained for gaps of 1 cm and 2 cm, with a percentage of readings of the Antenna_I greater than 95%.

On such basis an average gap of 1.5 cm has been then set. Finally, in order to verify the proper tag localization even during diagonal transitions along two different antennas, a system of four antennas (Antenna_I, Antenna_II, Antenna_III,



(a) (b)

FIGURE 5: (a) A 5 × 5 matrix of RFID NF tags. (b) Schema used for both antenna/tag distance and reader power output evaluation.

TABLE 2: Graphs of the RSSI distribution of the tag matrix.

Output reader power

Distance

2 cm, 24 dBm	A	B	C	D	E
A	0.00	−63.92	−63.81	−64.17	0.00
B	−60.39	−46.66	−44.71	−46.01	−57.09
C	−61.23	−50.16	−49.01	−49.42	−55.99
D	0.00	−55.50	−53.44	−54.00	−59.30
E	0.00	−57.50	−54.64	−63.04	−67.26

2 cm, 27 dBm	A	B	C	D	E
A	−71.47	−62.97	−62.62	−62.86	−68.41
B	−59.53	−45.00	−43.06	−44.78	−56.00
C	−60.06	−48.58	−47.11	−47.71	−55.00
D	−65.69	−54.08	−52.30	−53.02	−58.70
E	−68.06	−56.05	−53.01	−62.02	−65.87

2 cm, 30 dBm	A	B	C	D	E
A	−69.33	−62.04	−61.88	−62.12	−67.35
B	−58.63	−43.30	−42.00	−43.29	−54.83
C	−59.32	−47.03	−45.97	−46.27	−53.82
D	−64.83	−53.27	−51.30	−52.00	−57.70
E	−66.54	−54.87	−51.59	−60.95	−64.77

3 cm, 24 dBm	A	B	C	D	E
A	0.00	−63.25	−62.40	−64.54	0.00
B	−63.89	−49.99	−47.08	−48.05	−55.90
C	−63.14	−51.90	−50.00	−49.99	−55.00
D	0.00	−56.93	−54.12	−54.58	−58.95
E	0.00	−58.95	−55.98	−62.01	−65.86

3 cm, 27 dBm	A	B	C	D	E
A	0.00	−62.10	−61.43	−63.20	−69.84
B	−62.56	−48.77	−45.78	−46.93	−54.27
C	−61.95	−50.58	−48.00	−48.14	−53.93
D	−66.46	−55.95	−53.24	−53.88	−57.70
E	−67.35	−57.95	−54.88	−60.82	−64.58

3 cm, 30 dBm	A	B	C	D	E
A	−73.30	−61.03	−60.50	−62.34	−68.57
B	−61.54	−47.00	−44.11	−45.64	−53.02
C	−60.85	−48.85	−46.81	−46.94	−52.14
D	−65.13	−54.94	−51.92	−52.07	−56.80
E	−65.84	−56.16	−53.05	−59.87	−63.21

4 cm, 24 dBm	A	B	C	D	E
A	−62.82	−56.98	−55.66	−57.82	−67.00
B	−59.35	−52.99	−50.81	−52.98	−60.07
C	−60.99	−54.79	−53.41	−54.09	−59.78
D	−65.02	−58.92	−57.07	−58.46	−62.93
E	−62.87	−58.03	−58.31	−62.25	−65.77

4 cm, 27 dBm	A	B	C	D	E
A	−61.65	−55.78	−54.34	−56.97	−65.26
B	−58.64	−51.49	−49.23	−51.10	−59.11
C	−59.94	−53.92	−52.25	−53.00	−58.95
D	−63.34	−58.08	−56.43	−57.51	−62.20
E	−61.45	−56.94	−57.08	−61.10	−64.30

4 cm, 30 dBm	A	B	C	D	E
A	−60.98	−54.43	−53.08	−55.73	−64.29
B	−57.15	−50.31	−48.05	−50.10	−57.95
C	−58.90	−52.23	−50.95	−51.47	−57.51
D	−62.43	−56.91	−55.02	−56.57	−60.89
E	−60.27	−55.21	−55.94	−59.61	−62.86

5 cm, 24 dBm	A	B	C	D	E
A	−64.10	−60.23	−58.91	−60.90	0.00
B	−61.74	−57.00	−54.96	−56.93	−62.16
C	−62.46	−57.43	−56.29	−56.93	−61.38
D	−64.59	−60.46	−58.94	−59.96	−63.30
E	−64.38	−61.08	−60.23	−62.55	−65.09

5 cm, 27 dBm	A	B	C	D	E
A	−62.81	−59.07	−57.79	−59.90	−65.68
B	−60.64	−55.59	−53.31	−55.51	−61.19
C	−60.98	−56.09	−55.00	−55.49	−60.12
D	−62.81	−59.05	−57.46	−58.85	−62.14
E	−62.83	−59.92	−59.11	−61.17	−63.91

5 cm, 30 dBm	A	B	C	D	E
A	−61.92	−58.01	−56.67	−58.85	−64.44
B	−59.52	−54.68	−52.51	−54.36	−60.11
C	−59.98	−55.11	−53.86	−54.51	−59.18
D	−61.99	−58.29	−56.73	−57.86	−61.21
E	−61.69	−58.48	−58.01	−60.15	−62.60

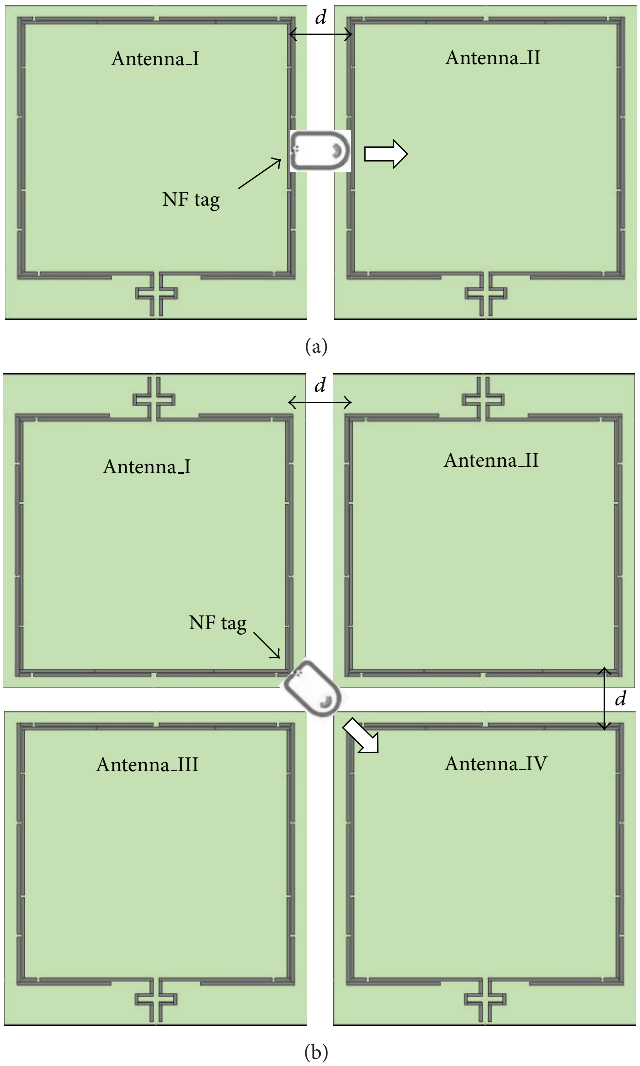


Figure 6: (a) Antenna disposition for horizontal tag transition. (b) Antenna disposition for diagonal tag transition.

Table 3: Antenna distance results.

	Antenna 1 (Read percentage)	Antenna 2 (Read percentage)
0 cm	53%	47%
1 cm	95%	5%
2 cm	97%	3%

and Antenna_IV) placed reciprocally at 1.5 cm of distance has been arranged as shown in Figure 6(b). The previous test has been replicated unbalancing the tag on Antenna I along a diagonal (Antenna_I–Antenna_IV) and calculating the percentage ratio between the number of readings of the Antenna_I and the sum of the readings of all the antennas. The obtained reading percentage of 95% confirms that the distance of 1.5 cm among the antennas is a suitable choice.

On the basis of the obtained results, the hardware setup for the animal tracking system has been composed by adopting 32 segmented loop antennas and by setting a distance between antennas and the cage of 5 cm, the separation gap between each couple of antennas of 1.5 cm, and the output reader power of 27 dBm.

Moreover, in order to verify the absence of any electromagnetic compatibility problem potentially due to the array effect, far field measurements have been performed at different distances from the antenna platform. Thanks to the use of the multiplexer, only one antenna is powered at a certain time slot, so that even at very short measurement distances (30 cm) less than 1 V/m has been measured.

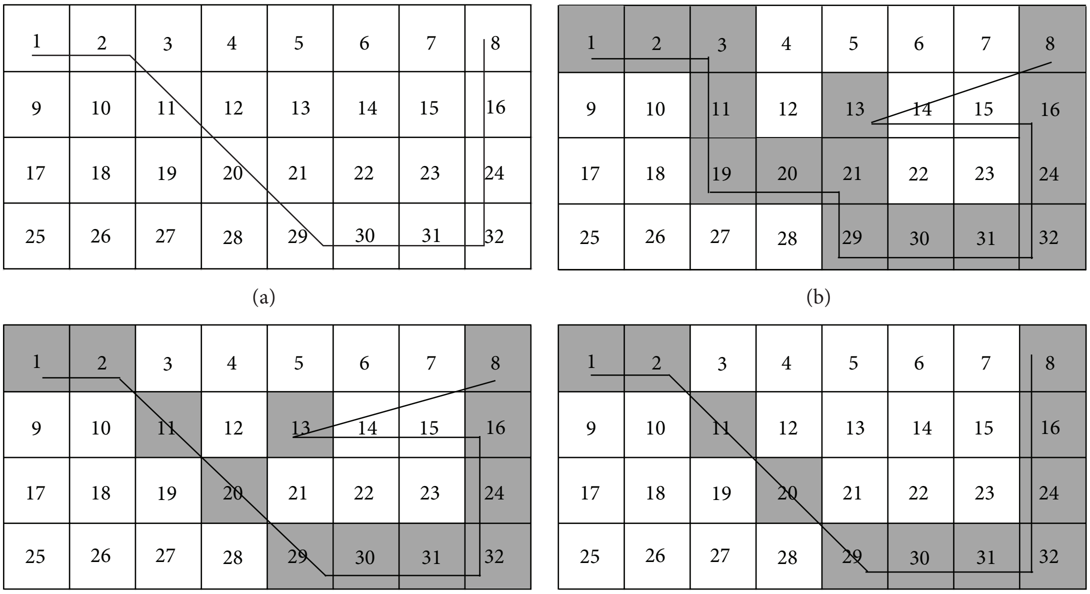
As further validation test, the effect of the tilt of a tag (mouse) with respect to the antenna system plane has been studied, so as to take into account the mice attitude to stand up on their hind legs (e.g., to drink or play). In particular, the tagged phantom mouse has been placed at a distance of 5 cm from the antenna system plane and its tilt has been varied from 0° to 90°. Performed measurements have shown negligible RSSI variations, thus guaranteeing the mice localization even in such a particular case.

5.2. System Validation. In order to demonstrate the effectiveness of the whole realized system, a real scenario has been reproduced by moving a plastic tube filled with saline solution and containing an NF UHF RFID tag in a cage placed over the designed antenna system. In such a way the plastic tube emulates the mouse, and it has been moved on the cage floor in order to reproduce many predefined paths. In the meanwhile, data are acquired, interpreted, filtered, and presented thanks to the joint work of the hardware and software subsystems.

In particular, in Figure 7(a), one of the paths actually performed is shown, whereas in Figure 7(b) the sequence of raw readings detected by the proposed antenna system is given. It can be observed that the path is not perfectly reconstructed. In particular, some cells (3, 19, and 21) very close to the real path and even one cell (the number 13) distant from the path more than 30 cm (almost three cells) are erroneously considered. It is worth recalling that at this step no algorithm corrections have been performed yet. Figures 7(c) and 7(d) show, instead, the result of the data processing performed by the software system after a partial step (Figure 7(c)) and at the end of the elaboration (Figure 7(d)). In particular, after the RSSI analysis, the spurious readings performed by antennas related to cells adjacent to the performed path are corrected, and, finally, also the error associated with the cell that does not comply with specific adjacency requirements between cells is eliminated.

It is worth observing that the movement of the plastic tube is perfectly reconstructed in several different conditions, thus demonstrating the effectiveness of the proposed framework, now ready for a validation through a living animal approach. In Figure 8, a real photo of the whole system in order to clarify the experimental setup is shown.

Finally, a further test has been carried out in order to verify the capability of the proposed system to deal with multiple mice at the same time. In Figure 9, two paths are reported. They have been reproduced moving by hand two phantom mice approximately at the same speed (almost two



(a) (b) (c) (d)

FIGURE 7: Experimental results of the overall tracking system: (a) path actually performed; (b) raw readings detected by antennas; (c) partially processed path; (d) final result of the raw readings processing.

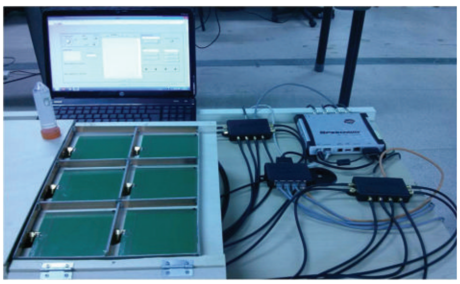


FIGURE 8: A real photo of the experimental setup.

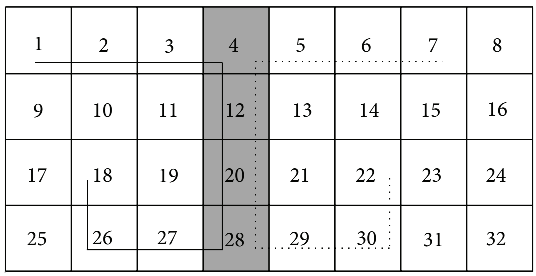


FIGURE 9: Paths used to evaluate the system capability to intercept simultaneously readings of different tags.

cells per second). In such a way, both phantom mice cross simultaneously some of the cells (i.e., cells number 4, 12, 20, and 28). The paths have been reproduced several times and consequently reconstructed by the software platform. Then, the ratio between the number of erroneously detected cells and the total number of interested cells has been evaluated. Errors inferior to 1% have been calculated in both paths, thus confirming the correct working of the system also for more than an animal.

6. Conclusions

In this work, a tracking system enabling the behavior analysis of small living laboratory animals in cages has been proposed and validated. In particular, the system takes advantages from the functionalities of RFID technology in the UHF band, which guarantees reasonable costs and naturally allows the monitoring of colonies of animals—very similar to one another—and even of each single animal both during day and night time.

In particular, an antenna system composed of up to 32 NF antennas in the UHF RFID bandwidth has been realized. Each antenna guarantees a radiated magnetic field almost uniform in a confined and well-defined region as large as a small mouse and representing the generic elementary cell of the system region. The matrix of antennas has been then positioned below the animal cage floor and connected to an UHF RFID reader by means of a multiplexer. The capability of each antenna to read a tag applied on a phantom mouse (a plastic tube filled with a saline solution) in the antenna-related cell has been firstly verified. Finally, a software platform has been realized. It is able to both drive the hardware subsystem and to collect, analyze, and summarize the reading data. Both the antenna system and the whole platform have been then validated, clearly demonstrating the appropriateness of the proposed system to enable an effective animal behavior analysis based on UHF RFID technology.

Acknowledgments

This work has been supported by the University of Salento within "5per1000" project whose title is "An Innovative Small Animals RFId-Based Tracking System (SMART)." The authors thank Dr. Stefano Pieretti of the Italian National Institute of Health, Rome, Italy, for his precious assistance, and Dr. Andrea Secco that collaborates with the IDA Lab group of the University of Salento, Lecce, Italy, for his support in the algorithm implementation.

References

[1] L. Catarinucci, R. Colella, M. De Blasi, V. Mighali, L. Patrono, and L. Tarricone, "High performance RFID tags for item-level tracing systems," in *Proceedings of the 18th International Conference on Software, Telecommunications and Computer Networks (SoftCOM '10)*, pp. 21–26, Zagreb, Croatia, September 2010.

[2] L. Catarinucci, R. Colella, M. De Blasi, L. Patrono, and L. Tarricone, "Enhanced UHF RFID tags for drug tracing," *Journal of Medical Systems*, vol. 35, no. 6, pp. 3451–3462, 2011.

[3] G. Calcagnini, F. Censi, M. Maffia et al., "Evaluation of thermal and non-thermal effects of UHF RFID exposure on biological drugs," *IEEE Transaction on Information Technology in Biomedicine*, vol. 16, no. 6, pp. 1051–1057, 2012.

[4] A. Guido, L. Mainetti, and L. Patrono, "Evaluating potential benefits of the use of RFID, EPCglobal, and ebXML in the pharmaceutical supply chain," *International Journal of Healthcare Technology and Management*, vol. 13, no. 4, pp. 198–222, 2012.

[5] M. Maffia, L. Mainetti, L. Patrono, and E. Urso, "Evaluation of potential effects of RFID-based item-level tracing systems on the integrity of biological pharmaceutical products," *International Journal of RF Technologies: Research and Applications*, vol. 3, no. 2, pp. 101–118, 2012.

[6] L. Catarinucci, R. Colella, M. De Blasi, L. Patrono, and L. Tarricone, "Experimental performance evaluation of passive UHF RFID tags in electromagnetically critical supply chains," *Journal of Communications Software and Systems*, vol. 7, no. 2, pp. 59–70, 2011.

[7] U. Barchetti, A. Bucciero, M. De Blasi, L. Mainetti, and L. Patrono, "RFID, EPC and B2B convergence towards an item-level traceability in the pharmaceutical supply chain," in *Proceedings of the IEEE International Conference on RFID-Technology and Applications (RFID-TA '10)*, pp. 194–199, June 2010.

[8] A. Esposito, L. Tarricone, M. Zappatore, L. Catarinucci, and R. Colella, "A framework for context-aware home-health monitoring," *International Journal of Autonomous and Adaptive Communications Systems*, vol. 3, no. 1, pp. 75–91, 2010.

[9] L. Catarinucci, R. Colella, and L. Tarricone, "Sensor data transmission through passive RFID tags to feed wireless sensor networks," in *Proceedings of the IEEE MTT-S International Microwave Symposium (MTT '10)*, pp. 1772–1775, May 2010.

[10] L. Catarinucci, R. Colella, and L. Tarricone, "Enhanced UHF RFID Sensor-Tag," *IEEE Microwave and Wireless Components Letters*, vol. 23, no. 1, pp. 49–51, 2013.

[11] L. Catarinucci, S. Tedesco, and L. Tarricone, "Customized ultra high frequency radio frequency identification tags and reader antennas enabling reliable mobile robot navigation," *IEEE Sensors Journal*, vol. 13, no. 2, pp. 783–791, 2013.

[12] R. Acierno, M. Maffia, L. Mainetti, L. Patrono, and E. Urso, "RFID-based tracing systems for drugs: Technological aspects and potential exposure risks," in *Proceedings of the IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS '11)*, pp. 87–90, January 2011.

[13] L. Catarinucci, D. De Donno, R. Colella, F. Ricciato, and L. Tarricone, "A cost-effective SDR platform for performance characterization of RFID tags," *IEEE Transactions on Instrumentation and Measurement*, vol. 61, no. 4, pp. 903–911, 2012.

[14] D. De Donno, L. Catarinucci, and L. Tarricone, "Enabling Self-Powered Autonomous Wireless Sensors with New-Generation I2C-RFID Chips," in *Proceedings of the IEEE MTT-S International Microwave Symposium Digest (MTT '13)*, pp. 1–4, Seattle, Wash, USA, June 2013.

[15] U. Barchetti, A. Bucciero, M. De Blasi, L. Mainetti, and L. Patrono, "Implementation and testing of an EPCglobal-aware discovery service for item-level traceability," in *International Conference on Ultra Modern Telecommunications and Workshops*, October 2009.

[16] M. Kritzler, L. Lewejohann, A. Krüger, M. Raubal, and N. Sachser, "An RFID-based tracking system for labortory mice in a semi natural environment," in *Proceedings of the Pervasive Technology Applied Real-World Experiences with RFID and Sensor Networks*, 2006.

[17] J. Aguzzi, V. Sbragaglia, D. Sarriá et al., "A new laboratory radio frequency identification (rfid) system for behavioural tracking of marine organisms," *IEEE Sensors Journal*, vol. 11, no. 10, pp. 9532–9548, 2011.

[18] F. Bonadonna, M.-A. Lea, and C. Guinet, "Foraging routes of Antarctic fur seals (Arctocephalusgazella) investigated by the concurrent use of satellite tracking and time-depth recorders," *Polar Biology Journal*, vol. 23, no. 3, pp. 149–159, 2000.

[19] G. Neisen, *Validation of a local positioning monitoring system (LPM) in relation to dairy cow behavior [Ph.D. thesis]*, Sustainable Agricolture ASPSA, 2005.

[20] SMART video-tracking system. Panlab S.L.U., Barcelona (ES), http://www.panlab.com/.

[21] Y. Zhang, M. G. Amin, and S. Kaushik, "Localization and tracking of passive RFID tags based on direction estimation," *International Journal of Antennas and Propagation*, vol. 2007, Article ID 17426, 9 pages, 2007.

[22] L. Catarinucci, R. Colella, M. De Blasi, V. Mighali, L. Patrono, and L. Tarricone, "An innovative animals tracking system based on passive UHF RFID technology," in *Proceedings of the 20th International Conference on Software, Telecommunications and Computer Networks (SoftCOM '12)*, September 2012.

[23] J. L. Volakis, *Antenna Engineering Handbook*, McGraw-Hill, New York, NY, USA, 4th edition, 2007.

[24] Low Level Reader Protocol (LLRP) Standard, http://www.gs1.org/gsmp/kc/epcglobal/llrp.

[25] C. A. Balanis, *Antenna Theory Analysis and Design*, John Wiley & Sons, New York, NY, USA, 2nd edition, 1997.

[26] X. Qing, C. K. Goh, and Z. N. Chen, "Segmented loop antenna for UHF near-field RFID applications," *Electronics Letters*, vol. 45, no. 17, pp. 872–873, 2009.

[27] Z. Xing, L. Wang, C. Wu, J. Li, and M. Zhang, "Characteristics and application of a novel loop antenna to UHF RFID receivers," *International Journal of Antennas and Propagation*, vol. 2011, Article ID 480717, 7 pages, 2011.

[28] CST Microwave Studio, http://www.cst.com/Content/Products/MWS/Overview.aspx.

[29] Speedway Revolution RX420 UHF RFID Reader, http://www.impinj.com/Speedway_Revolution_UHF_RFID_Reader.aspx.

[30] Speedway Reader Antenna Hub, http://www.impinj.com/searchresults.aspx?searchtext=antenna%20hub.

[31] T. Kløve, T.-T. Lin, S.-C. Tsai, and W.-G. Tzeng, "Permutation arrays under the Chebyshev distance," *IEEE Transactions on Information Theory*, vol. 56, no. 6, pp. 2611–2617, 2010.

[32] Impinj Monza 4 tag chip family, http://www.impinj.com/News_and_Events/Press_Releases/2010/Impinj_Monza_4_Tag_Chip_Family_Raises_Bar_in_RFID_Performance_and_Privacy.aspx.

[33] MATLAB, http://www.mathworks.it/products/matlab/.