RFID-based traceability system for architectural concrete

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Abstract

The main objective of the project described on this paper is to develop a traceability system for architectural concrete panels. The system should enable the traceability, both downstream, allowing to know the origin of the panels and which processes were followed for any panel installed in a building, and upstream, so it is possible to further analyze the processes followed by the panel to be installed. Therefore, the planning can be performed for optimizing processes and resources, and achieving an appropriate distribution of the timing, costs, etc.
Techniques based on Radio Frequency Identification (RFID) are used for the tracking, we will develop a system customized for the product, so that, radiofrequency tags can be attached or embedded in concrete. The system has been implemented by means of using passive RFID tags in UHF band, specifically developed to work on architectural concrete. Besides, the design for a portable RFID reader with storage capacity and communication of the information obtained from the panels is proposed, as well as the integration of sensors for their geographic location, essential for the storing tasks in the factory.

Keywords: traceability, life cycle, RFID.

1 Introduction

This project involves a close collaboration between the Universidad de Castilla-La Mancha (UCLM) and the company DRACE PREFABRICADOS DE EDIFICACIÓN S.L., which currently is integrated in the group ACS.
The project aims to study and develop a reliable prototype traceability system in a hostile environment such as the manufacturing of prefabricated concrete and cement mixed up with glass fiber (GRC), which will be able to monitor the life cycle evolution of the architectural concrete panels individually: manufacturing process, factory storage depot, transportation to building work, site assembly, and environmental conditions during its first years, once installed in the building.
In the preceding research projects, our previous work led to the installation of a factory of architectural concrete panels, semi-automated in its first phase, in Guadalajara (Spain) and another one of GRC in Madrid (Spain). Although, at present the second factory has been relocated to the premises of the former one.
Company's efforts are now directed to the improvement and optimization of their production processes, with special emphasis on logistics, see [1] and [2], where a reliable traceability system is fundamental due to its relevance. Therefore, this company has promoted the development of this system prototype.
As RFID technology has numerous advantages over the barcode, many companies are considering either upgrading or incorporating traceability systems based on this technology. The unavoidable advance of the RFID technology will bring enormous benefits and will lead to the emergence of applications that today seem unthinkable.

2 Prefabricated architectural concrete panels

2.1 The factory of prefabricated elements for building

The factory consists of a set of facilities for the production of prefabricated elements for building. The factory distribution is as follows:

- 2.000 m^2 for a concrete plant.
- 7.000 m^2 for a prefabricated concrete building.
- 19.700 m^2 for an open-air storage depot.
- 2.000 m^2 of road areas of circulation and others.

The diagram of the manufacturing system of the architectural concrete panels is shown in Figure 1.

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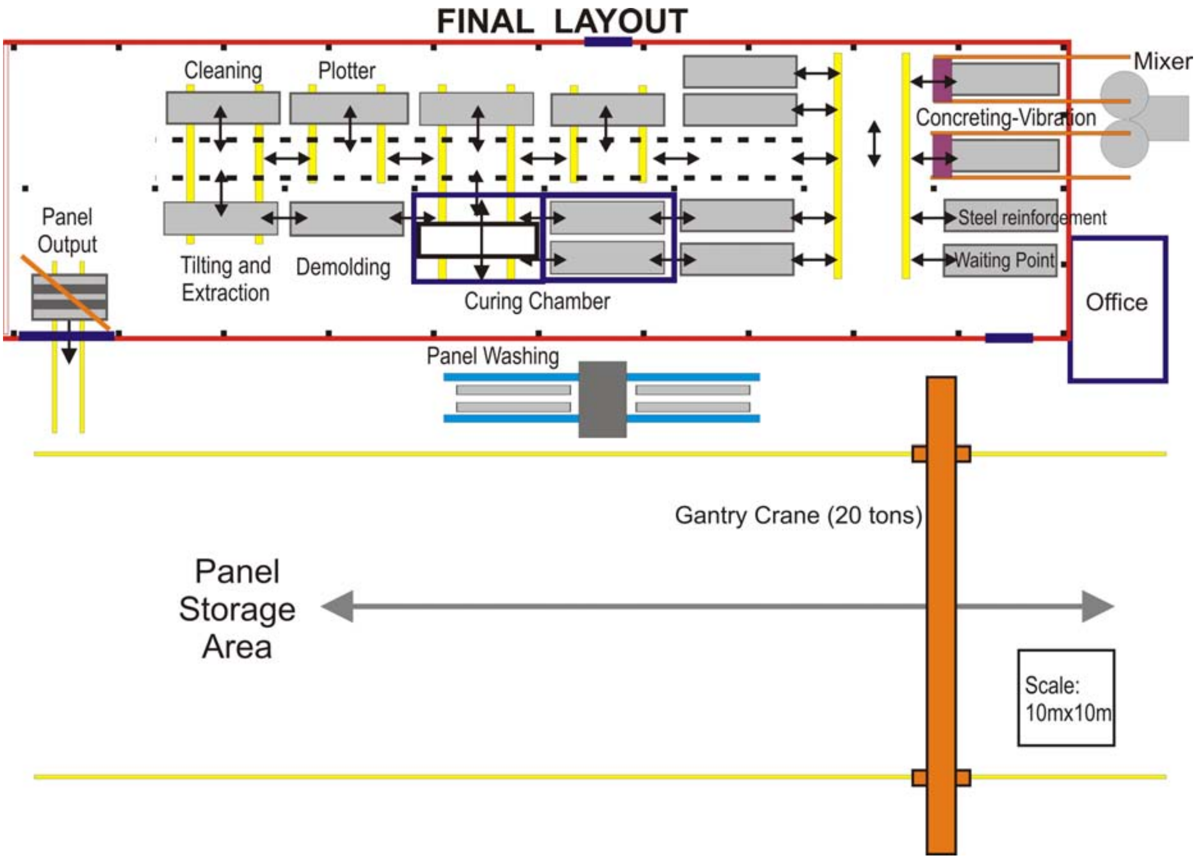

Figure 1 Diagram of the architectural concrete panels factory

A carousel system using large mobile tables (12 m x 3.5 m and 5000 kg) has been implanted instead of a conventional one made of fixed tables, where all the materials must be transported and the workers moved around the whole factory.

This carousel system automates the movement of the tables that are shifted through several tasks: cleaning, implementation of casts, frame setting, concreting, final operations, unmolding and extraction. In this way, the optimization of the productive process is achieved and it looks more like a mounting line.

2.2 Type of product and manufacturing process

The manufactured type of product is panels for facades of buildings with three-dimensional shapes with an elevation of up to 50 centimeters on the base level. Several types of panels can be manufactured by means of different options depending on the type of isolation, surface finish and three-dimensional shape.

The tracking process of a panel since it is manufactured till its final installation in the building work is as follows:

1. Technical Office:
    - Division of the facade.
    - Generation of schematics for panels and molds.
    - Factory planning according to the installation working plan.
2. Manufacturing:
    - Cleaning of the table and mold elements.
    - Use of uncasing liquid.
    - Planning of panel or panels to manufacture in a table.
    - Construction of the table panels mold.
    - Placing of the reinforcing frame panels.
    - Concreting and concrete distribution.
    - Vibration to improve the finish by removing the air bubbles.
    - Waiting for the panels hardening until they can be unmolded.
    - Withdrawal of the elements that are part of the mold once hardening.
    - Flip and vertical extraction to minimize the effort.
    - Setting the elements to fit the structure.
    - Final review.
3. Manipulations:
    - Storage in the factory depot.
    - Truck loading.
    - Transportation to the building work.
    - Storage at installation site (if necessary).
    - Assembly work.
    - Gasket sealing.

2.3 Objectives of the project

As a general objective, we aim to study and develop a traceability system for the lifecycle of an architectural concrete prefabricated panel in the factory. Finally, this system is intended to make an easier management and

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achieve an improvement and optimization of the productive processes.

As specific objectives managed through the development of this traceability system for the DRACE PREDIF factory of prefabricated panels, we can mention the following:

- Analysis of different systems and radiofrequency tracking technologies for identifying those which best fit the product, concrete panels. It will include testing the actual panels.
- Identify the precise specifications to be met by the tracking and location system more appropriate for this factory.
- Propose the hardware architecture of the traceability system, and selection of the equipment to be used as a prototype.
- Propose the software architecture to make easy the integration with the databases and applications used by the company. It will include the selection of the software for the development, the design of a database for the traceability system, and the design of the interfaces with the company's systems.
- Develop a prototype for the traceability system.
- Validation of the prototype for the real manufacturing system.
- Integration of sensors to measure the panel features using RF equipments to manage the information provided by the traceability system.

2.4 Development of the work

To manage the objectives proposed in this project it has been estimated that it will be necessary to perform at least the following tasks:

1. Definition of the problem and adjustments of the partial objectives.
2. Construction of the concept model.
3. Identify the precise specifications to be met by the tracking and location system more appropriate for this factory.
4. Analysis of different systems and radiofrequency tracking technologies for identifying those which best fit the product.
5. Design, assemble and testing of the panels tracking system.
6. Study and design of the hardware architecture of the traceability system, and selection of the equipment to be used as a prototype.
7. Study and design of the software architecture for the integration with the databases and applications used by the company. It will include the design of a database for the traceability system, and the design of the interfaces with the company's systems.
8. Design and development of the prototype for the traceability system.
9. Design of experiments and perform the tests on the prototype for the traceability system.

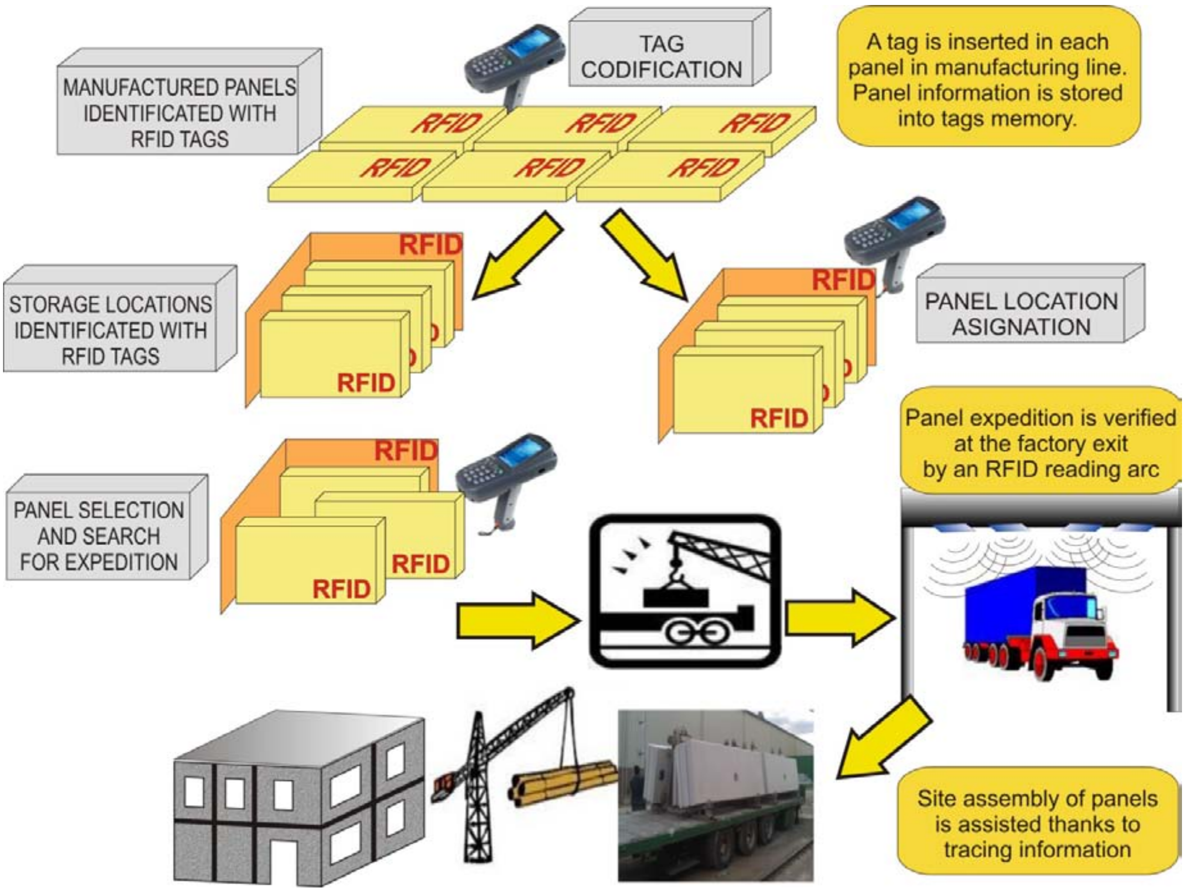

Figure 2 Outline of the RFID-based traceability system

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3 State of the art of RFID-traceability

The RFID technology is based on the use of radiofrequency tags and antennas or RF sensors for reading and/or writings (as needed). Tags are usually flat elements, joined to the pieces to detect and consist of a transmitting and receiving antenna together with a chip. The chip can contain large amount of information, depending on its type. Some of them only can store a 96 or 128-bit code, whereas others, are able to save additional information plus the encoding part, because they have got up to 512 bits.
The RF sensors are devices able to create electromagnetic fields at different frequencies and in different areas depending on its power. They are responsible for getting the information stored on the labels and write them with the relevant data in each moment.
The operation is rather simple. When a tag is within the range of an RF sensor, it induces an electric current in the antenna through electromagnetic radiation. The current feeds the chip and causes it to transmit the information to be obtained. In high-capacity labels different sections of the chip memory can be accessed as a function of the excitation electromagnetic signal.
New databases management systems are used for the management of the information related to the tags, allowing the traceability of products. In this way, information can be managed using a computer and a local server to host the database when the information users are local. When it is possible to have global customers, a global server should be used (i.e. Internet) and in the user locations a local server connected to the global is required, besides the computer. This is the case of Auto-ID/EPC technology, see [3] and [4]. An important issue is that the database sheets can be allocated in the server itself or may be in the RF tags of each one of the elements, if they are able to. In this last case, the server only manages the sheet codes and the transfers of their associated information.

4 Incorporation of the RFID system for tracking panels

The traceability system will cover the whole process above described; technical office will generate all information to be included in radiofrequency tags, to track the panels in the subsequent stages.
Figure 2 shows the outline of the management system for panels.

4.1 Labelling

Prior to labelling all the information concerning the production works will be already created and stored into the database.
Once at the factory, the tag will be embedded into the panel on the labelling place. Then panel serialization is made, so that they have been individually tracked, using an RFID reader as shown in Figure 3.

Figure 3 Label serialization place

Tag placement has been chosen in order that the tag suffers as little damage as possible contributing in as much information as possible. Different possibilities were tested: placing the tag side by side with the panel frame during the deposition of concrete, embedding the tag into the concrete, pasting the tag inside the panel once the concrete is hardened, etc.
It is convenient to take into account that many of the RFID implementation attempts see [5], have been shown problematic from a technical view considering the RFID technology limits. The different frequencies that can be used in RFID systems provide different benefits and drawbacks, for example, ultra high frequency (UHF, typically 868 MHz) provides high reading ranges (up to 6 m, typically 2 or 3 m), but it has penetration problems in certain material (metals).
Due to the presence of steel reinforcement to strengthen the panels during handling, it is convenient to analyze all possibilities, since low frequency (LF, typically 125 KHz) offers improved performance in the presence of metals or liquids, but has a limit range and needs a larger antenna. An intermediate solution is usually high frequency (HF, typically 13.56 MHz) offering shorter range than UHF, but other advantages such as better penetration in different materials.
It is also necessary to take reading speed and anti-collision system benefits into account for reading multiple tags at once. In general, the higher the frequency the higher the speed of data exchange, so that anti-collision system have a chance to make more time slots.
For all these reasons, we have chosen to use UHF band (868 MHz in Europe) and fix the tags inside the panel using a special adhesive after concrete is hardened, as shown in Figure 4.

4.2 Manufacture tracking

By placing RFID readers at different points within the manufacturing process, the development of each panel can be known at all times and can be written into the database. It also allows collecting useful information for process optimization, cost allocation, etc. This will be considered later in a second phase of the project, when the labelling place is defined and the type of tag chosen, as the company

Figure 4 Tag fixed inside of the panel

Figure 5 Order dispatching arc

does not require a detailed tracking of the manufacturing processes.

4.3 Stocks location

In order to make the tracking and positioning available on the factory storage depot, an RFID reader was developed for outdoor location, with data storage and data transmission capabilities. This information will be used for making easier order dispatching and panel loading on the transport platform.
Due to the reader is an essential element specifically developed for this project, it will be described in more detail in the next section.

4.4 Order dispatching

Another key element of the traceability system is the order dispatching arch, showed in Figure 5. This should ensure the reading of all panels on the transport, and automatically generates the shipping order for the carrier.
In this case we have used two RFID readers, one at each arch pole, connected to four lineal antennas each. We have chosen this type of antenna because of its greater reach and penetration in the concrete after reading tests are performed.

4.5 Transport tracking and on building work location

Traceability system will enable then to carry out tracking the transport to the building work and assembling on the building structure, improving their management. In this case we require the collaboration of the carrier and the construction management.
In the future, adding sensors during concrete hardening will reveal the temperature and humidity to which the panels are exposed, which will give rise to studies on durability upon different weather conditions.

5 RFID reader

As noted in the previous section, in this paper a portable reader is proposed to be used on the factory storage depot where panels are stocked up.
RFID reader can be divided into four functional blocks: microcontroller (MCU), RFID subsystem, GPS subsystem and supply. A simplified block diagram of the complete system is shown in Figure 6.

5.1 Microcontroller

The microcontroller will be responsible for the coordination tasks and will control the rest of the RFID reader subsystems.
The system requirements are not so high, an 8-bit microcontroller has selected: ATMEGA32U4 from Atmel, see [6], equipped with peripherals for serial communication (UART and SPI) with the other subsystems and an USB interface for connection with a computer. Because it is a portable reader, we have paid special attention to energy-efficient issues, but also the development tools: compiler (C language), programmer and debugger (JTAG).

5.2 RFID subsystem

The RFID subsystem, see [7], will be responsible for reading passive tags in the UHF band.
An integrated module has been selected: SkyeModule M9 from SkyeTek, see [8], it works within the UHF band, from 862 to 955 MHz, and it is compatible with most of protocols for passive tags: EPC Gen 1 Class 1, EPC Gen1 Class 2, ISO 18000-6C, ISO 18000-6B e ISO 18000-6A.
Again, system portability has required reaching a compromise between reading distance and power consumption, as well as the availability of low power modes during standby periods.
RFID subsystem require a 5 V power supply capable of provide about 500 mA at 20 dBm for a reading distance of around 1 m.

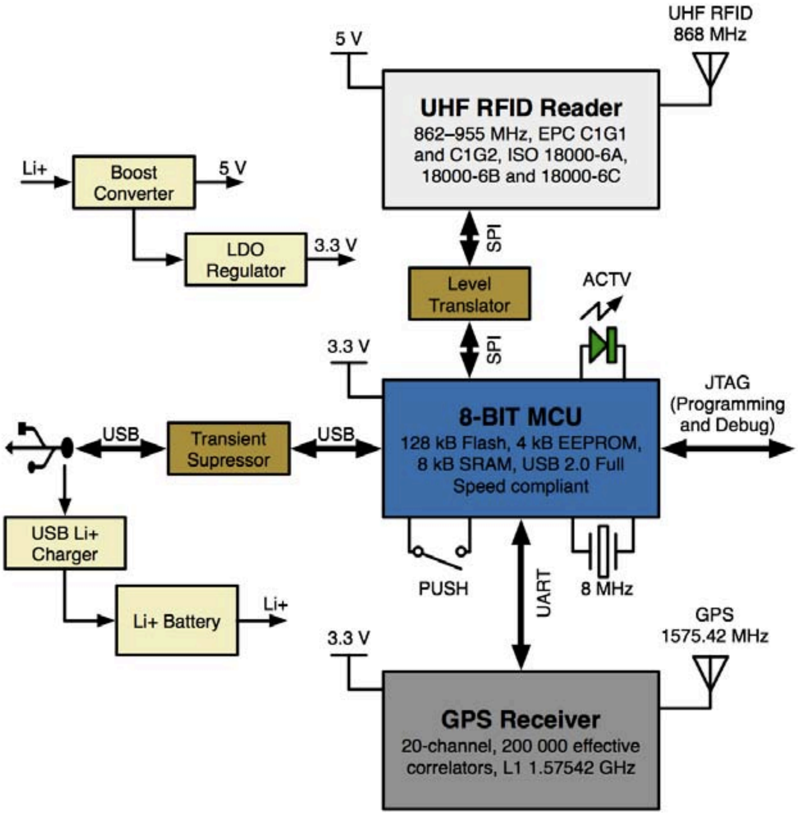

Figure 6 Block diagram of the proposed portable RFID reader

Communication with the module is done via the SPI serial interface, using a SkyeTek proprietary protocol (SkyeTek Protocol v3).

5.3 GPS subsystem

The need to allocate the panels within some accuracy in the factory depot during stock and their subsequent location for loading and transporting has made necessary the addition of a GPS receiver.
The GPS subsystem, see [9], will therefore be responsible for obtaining the location coordinates of the panel, which will be stored into the database along with panel identification.
In this case we have selected Jupiter 32 from Navman, see [10], the main reason for this choice was its swift response on data acquisition, and, of course, the availability of low-power modes.
The GPS subsystem requires a 3.3 V supply capable of providing 60 mA during acquisition periods.
Communication with the module is done via an UART serial interface through NMEA-183 protocol.

5.4 Supply

A lithium-ion battery will power all the system elements, see [11], with a rated voltage of 3.7 V. Charging this battery is made by an USB port. We have chosen a battery capacity around 1400 mAh, balancing its capacity, volume and weight.

This battery will power the two profiles needed for the RFID reader; to achieve this, a first boost (step-up) DC/DC stage rise the nominal battery voltage to 5 V, and later, an LDO voltage regulator gets 3.3 V from the previous stage. This topology was chosen because it has got a good immunity to noise.

5.5 Operation

In an attempt to maximize the battery life, the system is usually in a low power state. This state is regularly left for a short time interval, with the intention of updating GPS ephemerides, so that the acquisition time is minimized when it is carried out. The RFID subsystem, responsible for the highest consumption of the system, and will only be activated on user's demand. This action will initiate a reading of all the tags in the activity field of the reader. That information will be stored into the internal microcontroller memory together with the coordinates obtained by the GPS receiver.
The USB connection of the RFID reader will be twofold; on one hand charging internal battery, and on the other hand downloading stored data against application database.

6 Conclusions

This paper presents a traceability system for architectural concrete panels, covering its lifetime: design, manufacturing, storage, transportation, assembly and tracking.
The major trouble has been finding a suitable RFID tag for reinforced concrete, due to the attenuation introduced by

concrete and its framework. In fact, tag manufacturers are investigating new designs to improve product adaptation. Nowadays, we are testing out the panel-labelling stand and the order dispatching arch. We have finished the design phase of the stock location system by means of the RFID reader and we are going to manufacture the first prototype for testing.

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