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RFID in the Construction of Single Family Dwellings

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Abstract

*Radio Frequency Identification (RFID) has gained momentum within logistics, supply, medical, and asset management, manufacturing, security, military and numerous fields. At the same time, the construction industry has been slow to embrace the technology,despite the fact that the literature indicates several proposals to implement RFID in commercial/industrial construction. The purpose of this paper is to discuss the feasibility of using RFID technology in the construction process of single family dwellings. The state-of-the-art of the RFID technology is discussed, focusing on the limitations and advantages of RFID tags and readers, along with the benefits of using RFID technology in residential projects. We provide a general estimation for thenumber of tags required for the purposes of inventory management and control in a typical residential dwelling project***.**

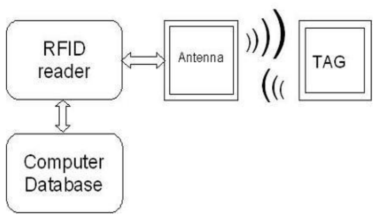
1. Introduction

Radio Frequency Identification (RFID) and barcodescanning are both in the family of automatic identification technologies. However,RFID has the advantage of using radio frequency for the purposes of reading and writing data to and from inexpensive electronic tagsat a distance and without requiring batteries to be installed on tags [1]. Moreover, RFID is considered to be the next-generation of barcode technology [2]. It reads and writes data contactless without requiring a direct line-of–site to identify the target object, which is required when barcode technology is used. A reader can recognize and access multiple identifiers at high update rates at the same time; it has a high throughput capacity in terms of total number of tags; it can encrypt data to limit data access rights and privacy concerns. Once linked to a database (though middleware that stores even more information than it is available on tags) readers can cross link item availability data with specific article/item information for the purposes of various applications [3].

The main components of a RFID system are tags (also known as transponders), antenna, reader and a computer base, as shown in Figure 1. Wireless communication is enabled by an antenna that is attached to the tag and is in the range of an RFID reader.

A typical RFID system comprises of RFID tags and a RFID reader. A RFID tag is often formulated by a microchip which stores data and an integrated antenna serving as transmitter. There are two types of RFID tags: passive and active, where the former has no internal power source but relies on the reader to supply power for wireless communication, and the latter has an internal power source(e.g. batteries)[3].

Figure 1-Components of a RFID System



Current standards include drafts by: the International Organization for Standardization (ISO) [33], the International Electrotechnical Commission (IEC) [33], ASTM International [34], the DASH7 Alliance [35] and EPCglobal [36]. NXP Semiconductors and Impinj Inc. have released low cost (volume sales at about 5 US cents) RFID chips that offer an Inter-Integrated Circuit (I2C) interface [37] for accessing the tags EEPROM memory space in addition to the Gen2 RFID interface [36]. NXP's UCODE I2C (3.3Kbit in size) passive tag's EEPROM memory andImpinj's Monza-X(2.1 to 8.2Kbit) tag EEPROM memory can be accessed without the need for internal to the tag batteries by a standard UHF Gen2 RFID reader. The availability of inexpensive passive tags with on-chip EEPROM memory has opened new avenues for application of RFID, as after reading and identifying a set of tags, a reader can keep track or various possible article/item states.

The prospect of the RFID technology in providing a wireless communication between tags attached to an object and a reader distant from the object,helps researchers envision new applications for the RFID technology around the concept that RFID has a potential to be used on "everything that needs to be controlled." Under this perspective several industries:transportation [4], supply chain [5], inventory control [6], healthcare [7], and construction [8] are taking advantage of RFID technology at different levels of usage.

The construction industry is showing interest in RFID technology with the aim to improve control in its production process. The literature indicates that there are several researchers that are proposing possible applications of the RFID technology forthe construction industry, mainly in the areas of: material controls [6],[9],[10], construction supply chain [11], [12], control of Personal Protective Equipment (PPE)[13], quality inspection [14], tracing structural steel members [15] and project management [3].However these applications are more suitable for large commercial and industrial projects.

The purpose of this paper is to discuss the feasibility of using RFID technology in the construction of single family house dwellings.

Table 1–Use of RFID by Industry (Adopted from ERA Build final report [16])

RFID Frequency Chart

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Frequency RFID Technology	Low Frequency 125 - 135 kHz	High Frequency 13,56 MHz	Ultra High Frequency 400 - 960 MHz	Microwave 2,45 - 5,8 GHz
Availability	> 30 years	> 10 years	US > 3 years, EU relatively new	> 10 years
Standardisation	ISO 11784/5 ISO 14223, ISO 18000-2	ISO 14443 ISO 15693, ISO 18000-3	ISO 18000-6, EPCGen1 and2	ISO 18000-4
Subsurface (except metal)	No impact	Low impact	Depends on material	No impact
Fluids	No impact	Low impact	High impact	High impact
Readability on metal	Limited	Bad, special tags available	Limited	Good
Bulk reading	Limited	Up to 50 tags/sec	Up to 150 tags/sec	??
Reading distance	~ 0 - 100 cm	~ 0 - 50 cm	US ~ 0 - 500 cm, EU ~ 0 - 300 cm	~ 0 - 500 meters, active tags
Data transmission rate	Low	Medium	Fast	Very fast
Interference resistance	High	High Frequency	Depends on environment	Susceptible to electronic noise
Typical application	Animal ID, Beer kegs, Car anti theft, Access control, Personal ID	Track and tracing, Cooling chain control, Person ID, Item level tagging	Supply chain management (SCM), Pallet and container tracking, Trailer tracking in shipyards, Pallet and case tagging	Toll collection, Real time location systems, Long range access control vehicles, Aircraft part maintenance
Industrial sectors	Farming, Slaughterhouse, Brewery	Airport, Slaughterhouse, Pharmaceutical, Healthcare, Production, SCM product level	Production, SCM on pallet and colli level	Army, Shipping, Airlines and Government
Other	Oct. 2004 FDA approved a 134 kHz from VeryChip that can be implanted in humans			
Market developers			EPCglobal, US: Wal-Mart, DOD, FDA, EU: Metro, Tesco, Carrefour	Governments, Boeing, Security and safety companies

2. RFID Read Range

According to Kelmet all [13] there are two ways of transmitting information between a transponder and a reader: a magnetic coupling (LF/HF) or electromagnetic wave (RF/MW). The LF/HF works in a frequency ranges between 135 kHz and 13.56 MHz's. This type of RFID offers low read ranges using normal size antenna and transponders. Typical read ranges for LF are up to 2 cm and for HF up to 1m. The electric magnetic wave uses frequency bands of 868MHz (UHF) and 2.4GHz (MW). The read range extends up several meters.

The frequency that an RFID tag operates affects its capabilities and the applications which it is appropriated for. Passive tags operate at low, high and ultra-high frequency spectrums. Low frequency tags operate in the 125-135 kHz range, and they use less power and are better at penetrating non-metallic materials including items with high moisture content. They are ideal for applications where the tags need to read through materials or water at close range [16]. Low frequency tags are not very effective at inventory management applications, such as in a warehouse setting, due to their limited effective range. Most tags operating at this range are limited to approximately 30cm [17].

Tags operating in the 13.56MHz high frequency range can work around metals and objects with high water content. They have a greater effective range than the low frequency tags, but are still limited to an effective range of approximately 1 m [17].

The ultra-frequency range is from 400-960 MHz. They offer greater range, up to 8 m and are able to transfer data at higher rates. They also require more power and have a greater difficulty passing though material. They require a direct path between the tag and the reader [17]. The UHF is regulated differently among nations; in the USA the UHF range is 902-928. Another constraint of the use of UHF waves is that waves can bounce off surfaces and could potentially read tags that are not intended to be read. As can be seen from Table 1, the RFID frequency from the ERA Build final report displays a number of applications and industries that are using different frequencies [16].

3. RFID Tag Anti-Collision Protocols

RFID systems use radio frequency to send energy to a RFID tag, while the tag emits a unique identification code (ID) back to the RFID reader. Since readers and tags communicate through the air interface or wireless channel, simultaneous transmissions in RFID systems leads to collisions as the readers and tags typically operate on the same channel. If multiple tags are to be identified simultaneously, collision would be occurred. For this reason, anti-collision protocols need to be devised between the tags and the reader to minimize collisions [18].

RFID tag anti-collision protocols proposed to solve tag collisions can be grouped into deterministic and probabilistic methods. The deterministic methods are developed on the basis of tree-based protocols such as: query-tree protocol (QT), binary search protocols (BS), dynamic binary search protocol (DBS), and new enhanced anti-collision algorithmic (NEAA). The probabilistic methods are based on the ALOHA protocol such as Basic Framed Slotted ALOHA protocol (BFSA) and Dynamic Frame Slotted ALOHA protocol (DFSA) [19].

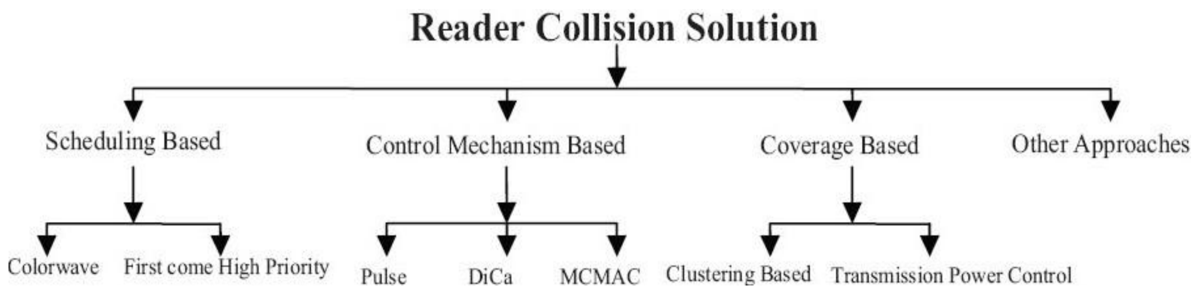
According to Bonuccelli [20] the anti-collision protocols listed above exhibit overall system efficiency smaller than 50%.Jia and Feng [19] are proposing a new anti-collision protocol named Collision Tree protocol (CT) claiming to overcome the performance of existing ones. There are other proposals that are suggesting acombination of tree based protocols with features of the ALOHA protocols[21], and the selection of the protocol based on the environment in which it will be used and not solely on capacity[22]. The best anti-collision protocols are part of patents and are integrated in market solutions. They detect more than 200 tags per second for 13.56 MHz tags in a reader-collision free environment [23].

4. RFID Readers Collision

According to Engels and Sarma [24] all tag readers have a finite space around them within which they can communicate with tags. This space is referred to as the reader's interrogation zone. Readers whose interrogation zones intersect can interfere with one another, to the point where neither reader will be able to communicate with any tags located within their respective interrogation zones. Readers may also interfere with one another's operation even if their interrogation zones do not overlap. This interference is due to the use of radio frequencies used in cellular telephone systems. Interference detected by one reader and caused by another reader is referred to as reader collision.

The literature indicates that there are various reader anti-collision algorithms which perform limitedly and cannot fully satisfy performance requirements, thus leaving room for improvements [25]. According to Gandino [26] the Distributed Color System (DCS) is a state-of-the-art anti-reader collision protocol based on time division; however he is proposing a Probabilistic DCS (PDCS) claiming a theoretical performance improvement of 30% over the DCS protocol.

. **Figure 2-**Classification of existing RFID reader anti-collision algorithms [25]



According to Joshi [25] each reader anti-collision algorithms proposed in the literature has its unique properties and functionalities. Some operate by means. of scheduling, some in a distributed way and some work on the principle of a notification mechanism of broadcasting packets as indicated in Figure2

5. RFID in Construction

Some of the areas that RFID could benefit the construction industry include "materials management, tracking of tools and equipment, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, field operations, and construction safety" [16]. On particularly large construction projects this would seem to be an accurate statement. Projects relying on large lay-down yards (staging areas) could readily see improvements related to inventory management and if combined with GPS, simplify locating inventory items. Tracking personnel, equipment, and tools as well as controlling access to restricted areas could all be accomplished via RFID technology.

Economies of scale in projects measuring in the tens to hundreds of thousands of square feet probably justify large scale investment in RFID technology. The amount of material, number of personnel and equipment, and in general the complexity of a large scale project lends itself to RFID tracking. An added value feature would be the ability to quickly determine if specific materials used in a project are later subject to recalls such as defective siding recalls [27] or the Chinese drywall recall [28] with just a quick scan of an embedded RFID chip.

At the same time, solid business cases for the use of RFID in the construction industry seem to be lacking. This may be due to the very nature of the industry. Every "construction project will be unique to a certain degree, whether it is by size, complexity, life-cycle, geographic location, etc." [29]. Besides complexity and scale of the project, there remains the issue of whether the company is able to accommodate new technology. The lack of standardization across the industry and the high potential cost of implementation [16] may further restrict adoption. Frequently, many projects include multiple contractors/subcontractors jointly working on a project. The lack of standardization across the industry would serve as a roadblock in such a situation because of the added costs that some of the contractors would be forced to endure for each new project.

5.1 Construction of Single Family Residential Dwellings with RFID

Based upon housing sales for the period of 2003 through 2008, we find that the typical house sold in Duval County, FL was 2,461 square feet in size and sat on property of approximately 0.29 acres or roughly 12,600 square feet [30]. This limits the area that an RFID implementation would need to cover and the amount of materials. Whereas in a large construction project, the environment would almost force the utilization of at least some active RFID tags and the amount of metal used would be substantially greater impacting the frequencies that would be needed; the small scale construction project would have fewer obstacles of this sort to deal with. A small scale construction zone is rarely fenced in and the amount of area for placement of supplies is limited and thus easier to track. Mobile readers would generally suffice in this type of environment. The range of the mobile readers is somewhat more limited than fixed readers, but the complexity of deployment of the fixed readers in this type of environment is eliminated.

With the current trend toward lean construction practices, materials are scheduled to arrive just as needed, versus having stock piles of materials. Having limited volumes of items to scan at any given point in time would simplify the reading process and as an added benefit reduce the potential for tag collisions. Excessive read times would also be potentially reduced. A minimal number of readers would be required as well.

In any major subdivision that is actively building in the Jacksonville, FL areawood frame construction is by far most commonlyused for single family and even multi-family dwellings. This fact combined with the increased use of plastics for virtually all aspects of construction: from electrical boxes, conduit, and piping, further limits the complexity of the RFID environment. By operating in the UHF band, greater read distances, measured in feet [31] versus inches [32] are possible. In many situations, this will greatly enhance safety as well as reduce scan times. The option to deploy scanners in the HF range remains available if tracking individual metallic items such as hurricane clips is considered essential.

5.2 Materials Quantity Takeoff

Since the trend is currently toward lean construction, many of the materials would be delivered in multiple deliveries versus a single large shipment. This would reduce the potential for large scale tag collisions or tag identification delays in the drop zone. By the time of completion itself, the house would have the potential of having a fairly large number of RFID tags embedded throughout the building.

In order to estimate the quantity of different materials used in the construction of a typical residential house a format from the Construction Specifications (CSI) is used to indicate the total of different material used per each division of the CSI format based on a set of drawings of a typical residential house the takeoff material is made.

Each part of the construction process is subdivided into sub parts that will be executed sequentially in accordance with the construction process. For example in the CSI Concretedivision # 03000 there is a subdivision 03200 named rebar in which the following construction materials are listed: reinforcing rebar, L dowels, Simpson anchors, anchor bolts, washer and nuts. These materials are called by the drawings of the house. The next subdivisions of concrete will call for the quantification of all materials required to finish the concrete division. The CSI has 50 divisions to cover all types of construction. Table 2 shows the aggregate quantity of materials for a construction of single family residential dwellings.

Table 2

CSI Division	Quantity
03000- Concrete	472
04000- Masonry	20
06000- Wood, Plastic, Composites	1416
07000 -Thermal & Moisture Protection	201
08000- Openings	82
09000- Finishes	481
10000- Specialties	11
22000- Plumbing	205
23000- HVAC	78
26000- Electrical	579
32000- Exterior improvements	8
33000- Utilities	4
Grand total	**3557**

6. Discussion

Rarely during this construction project would there be more than several hundred tags in the actual staging area or being received at any given point in time under ideal circumstances. Using an UHF RFID reader such as GAO RFID's 246006 [31] with a typical read rate of 150 tags per second with a potential peak read of 400 tags per second, verifying materials received in a delivery would take very little time at all. This reader has a range of up to 7 meters outdoors and 7 to 11 meters indoors. Conceivably, all 3557 tags could be read in less than 30 seconds. Depending upon the initial associations set up in the RFID database when the items were first added to the inventory, individual items corresponding to specific lot numbers could be later identified if need be such as in the case of a product recall.

There are numerous ways in which this technology could be applied even on a small scale site. Receiving times could be drastically reduced. A quick count to ensure the quantity ordered was actually the quantity received is a quick count, now potentially measured in seconds. Even daily on site inventories could be run in minimal time to help recognize and reduce potential pilferage. Since in this scenario the actual worksite is small and the quantities of material are limited, a single reader would be sufficient. Initial upfront costs could be primarily limited to a reader, a backend system to download and manage the information and the associated software for the specific RFID system and corresponding training. Some in-house technical knowledge would probably reduce long term support costs.

RFID technology presents some potential advantages for the small scale construction site. EPC Gen2 UHF passive tag and reader technology currently presently presents the most cost effective means of deploying the technology within this environment, though not without its complications. Cost, speed, and range provide some of the greatest advantages. At the same time, those very attributes can contribute to the problems encountered. Though still a developing technology, RFID provides a gateway to many future advances in efficiency and cost management within the construction industry.

7. Conclusion

The state-of-the-art RFID technology available today can provide efficient inventory management forresidential construction projects. A close collaboration between contractor organizations and construction material supply organizations need to be implemented in such a way that construction materials are delivered to the construction site with pre-attached RFID tags to individual items. At the least, small items with high aggregate value such as hardware, plumbing, electrical and HVAC material should have a rigid inventory control to reduce or even eliminate the level of burglary that occurs in the industry today towards those items.

A customized RFID tag can also be used by contractors to control the amount of materials used and unused in a construction project in order to measure the level of efficiency of its construction process. The newest EEPROM equipped passive RFID tags provide the necessary support, because of adherence to both RFID and integrated-chip bus standards.

The cost of RFID tags is very low and for this reason, once a RFID system is installed, it can be used to control not only materials but also tools and equipment used at a construction site. Overall, it appears that RFID can be evaluated as a feasible technology to control resources used in the construction process of single family dwellings.

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