RELATIONSHIPS BETWEEN ON-SITE RFID TAGS – OPPORTUNITIES, BENEFITS AND CHALLENGES

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ABSTRACT

With the increased interest in Radio Frequency Identification (RFID) in the construction industry and related research efforts, future construction sites can be expected to carry an abundance of RFID tags. These RFID tags at site have the potential to be used in order to improve context awareness during the construction phase. Specifically, semantic information about and between components and resources can be projected onto the RFID tags to create a semantically connected RFID network. Such semantic information might already exist when an integrated project model exists for the project. However, in cases where integrated project models for projects are uneconomical or cannot be made available due to other factors, the semantic information can still be made available for supporting context awareness on construction sites. A wide range of on-site tasks, ranging from actual construction to facility management, can benefit from the relationships represented in the RFID network and the resulting increased context awareness. This paper discusses the opportunities for creating such semantic RFID networks, and highlights challenges and benefits that the authors identified throughout their ongoing research activities.

KEYWORDS

Radio Frequency Identification (RFID), Semantics, Knowledge Management, Construction Industry, Context Awareness

1. INTRODUCTION

Radio Frequency Identification (RFID) has been used for many years in domains other than construction (Kern 2004; Kinsella 2005; Lekkas and Gritzalis 2007). The specific characteristics of the construction domain (e.g. harsh working environment, shocks, metallic environment) were factors hindering the implementation of RFID technology in this domain at the beginning. However, technology developments have solved many of these construction specific issues (Jaselskis and El-Misalami 2003; Song et al. 2006). As a result, the application of RFID to the construction domain has increased in recent years. Nowadays, RFID is adopted at construction sites for tool tracking, site access control, facility management and maintenance (Ergen et al. 2007a; Goodrum et al. 2006; Song et al. 2006). It can be argued that RFID applications will gain more interest in construction, possibly resulting in ubiquitous RFID environments on near future construction sites. In such ubiquitous RFID environments, one can expect to see RFID tags being used for different purposes by different parties involved in a construction project. Through these RFID tags, different parties will be able to identify components and resources and share information that is stored on the respective RFID tag or in a database that links additional data to the RFID tag.

Another means for sharing project information with other parties involved in a project is Building Information Modeling (BIM), or more generally Integrated Project Modeling (IPM). Integrated Project Models (IPMs) contain and integrate project information. Thereby, relationships between project constituents, such as relationships between building components and/or processes, can be represented as semantic relationships in the IPMs. The usefulness of this semantically rich information in the construction domain has been proven through the success of BIM and other IPM related technology (Cavallero 2006; Williams 2004). While IPMs are mostly used in the design and planning phases of a construction project, different research has shown that the semantic information in IPMs can also benefit the construction phase (Akinci et al. 2006; Boukamp 2006). Thus, it is desirable to have such semantic information available on-site during construction.

However, not all projects use IPMs. Most IPM efforts focus on building construction, as the name BIM indicates. Thus, most of the time IPMs are not applicable to special construction projects like tunnels, highways or most of the heavy constructions.

As an alternative to relying on IPMs for delivering semantic relationship information to the construction site, the authors propose to create a network of relationships between RFID tags on the construction sites. As tags are expected to become ubiquitous at construction sites and usually identify components and resources, this will allow creating semantic relationships between components and resources without requiring the creation of a full IPM. The objective of the ongoing research discussed in this paper is to investigate the opportunities, benefits and challenges associated with creating semantic relationships amongst RFID tags and making them available to support information technology on construction sites.

2. BACKGROUND

RFID technology consists of a transponder (usually called tag), reader, antenna and required software. The basic functionality supported is to read tags with unique identifiers using readers. Since the technology relies on radio signals, a direct line of sight between the reader and the tag is not required. Tags are divided into two main types: Passive tags without an internal source of energy and active tags with an internal source of energy (i.e. a battery). Passive tags are limited in their read range and in their amount of available memory. Due to their increasing popularity, prices for passive tags have decreased as low as a dollar or less and continue to do so. On the other hand, active tags have longer read range and more internal memory available. However, these additional features add to their prices up to several tenths of dollar. Since they too become more and more popular, their production prices fall – but they are still significantly higher than those for passive tags.

After its early applications in electronic toll collection in the early 90's, RFID was brought to construction domain for material delivery and equipment handling (AIM 2001; Jaselskis et al. 1995). Later the usefulness of RFID for material receiving, tracking and management was proven (Jaselskis and El-Misalami 2003). Also, research investigated the application of RFID technology to other processes, such as supporting on-site inspections (Yabuki et al. 2002), tracking of construction components through the supply chain and on sites (Akinci et al. 2002; Ergen et al. 2007b), tool tracking and management and detection of buried asset and location identification by combining RFID and GPS (Bulusu et al. 2000; Dziadak et al. 2005; Goodrum et al. 2006; Hightower and Borriello 2001).

Due to their lower prices, construction industry is currently mostly using passive tags; however, the advanced features of active tags and further decrease in their prices are expected to make active tags more popular in the near future. In summary, because of diversity in the construction industry and different parties involved in a construction project, it seems logical to expect both types of RFID tags from different manufacturers to be used for different purposes at a construction site. While more and more construction related applications are employed that use RFID tags, it can also be observed that RFID tags often remain on the tagged components and resources since it is too cumbersome (and sometimes impossible) to remove them for reuse after the components have been installed at the site (Ergen and Akinci 2007).

3. SEMANTIC RELATIONSHIPS BETWEEN RFID TAGS – OPPORTUNITIES, BENEFITS AND CHALLENGES

3.1 OPPORTUNITIES:

Much of the information being accessed and being generated at construction sites is context-specific, i.e. it applies to a specific situation or a specific situation category. For example, reports and lessons learned from construction activities benefit from the identification of a construction context to which the information applies – which then can be used as a storage and retrieval index for the reports and the lessons learned (El-Diraby et al. 2005; Rezgui 2006; Zhu et al. 2007). Also, quality or safety inspection relies on specifications that impose requirements for given construction contexts (Boukamp 2006; Wang and Boukamp 2007). The identification of such construction contexts relies on determining *component or resource types* and *their semantic relationships to other components or resources* (Boukamp and Ergen 2008).

RFID tags attached to components and resources allow for quick identification of these components in an automated way. The IDs stored on the RFID tags can be used to retrieve information about the tagged items from an information repository, such as a database or an IPM. Also, any additional information stored on the RFID tags can be accessed. However, since RFID readers read multiple tags within a reader's read range and given the anticipated increase in RFID tags on construction sites, it becomes difficult to identify specific RFID tags of interest within the group of read RFID tags.

Defining semantic relationships between RFID tags will allow identifying related groups of RFID tags (see Fig. 1), such as components that are "*PartOf*" a structural frame. It will also enable access to semantic relationships between tagged components and resources on construction sites, which can be used to support automation of construction tasks. A specific example application that can benefit from such semantic information is construction site inspection.

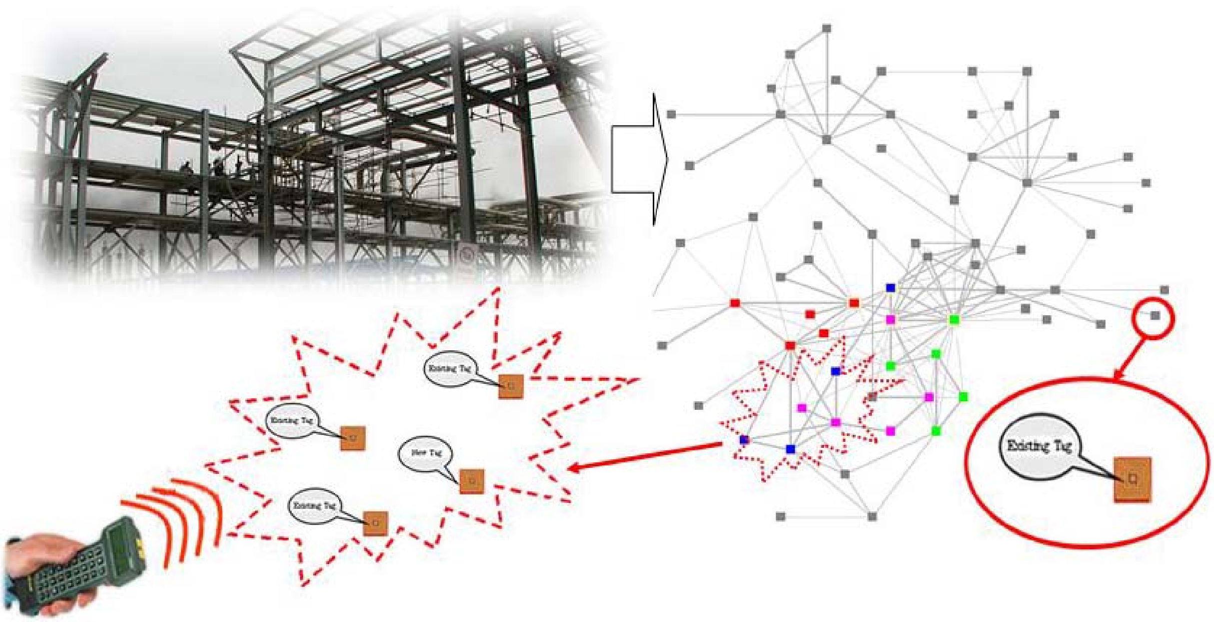

Figure 1: Having defined semantic relationships at site enables the end user to classify hundreds of available RFID tags into smaller groups.

Researchers have long argued that the work with specifications is cumbersome and error prone due to the huge amount of requirements imposed through specifications and the complexity of specifications (Boukamp and Akinci 2007; Burati et al. 1992; Kiliccote 1996). A study identified that different inspectors inspecting a project will draw different conclusions based on their specification knowledge (Hollis and Bright 1999). Approaches have been developed to address these issues and to help automatically identify requirements applicable to a given construction context (Boukamp and Akinci 2007; Kiliccote 1994; Wang and Boukamp 2007). These approaches rely on the availability of semantic information about and between products, processes and resources, which they either assume to receive from digital project repositories, such as IPMs, or through user input.

Making semantic information about and between products and resources available via semantic RFID networks will enable automated identification of these semantics (a) without the need of an IPM and (b) without the need for user input of this information. Thus, an engineer inspecting a site could use a mobile computer (such as a Personal Data Assistant (PDA)) with an RFID reader attached to scan the environment for construction context information.

3.2 DEFINING WEAK SEMANTIC RELATIONSHIPS:

Semantic relationships between components' and resources' RFID tags can be of two different basic types: They can be (1) simple spatial relationships such as *CloseBy* or *InTheSameArea* or (2) stronger semantic relationships, like *ConnectsTo, IsEmbeddedIn*, or *Supports* relationships.

Spatial relationships between components and/or resources can be determined through reasoning about the proximity of scanned RFID tags. The facts that tags need to be in a certain distance from the reader to be detected and that their signal strength varies depending on their distance to the reader can be used as a means to find their proximity to each other and to the reader. This would be the weakest level of semantics, as it would only be able to specify proximity semantics, such as "CloseBy". However, this weak semantic relationship can easily be identified by observation, e.g. by walking on the site and continuously scanning the RFID tags available. Such basic spatial information can later be used alone or in combination with added higher levels of semantics. With respect to the previously mentioned construction inspection, even this weakest level of semantic information, i.e. topological relationships, can be beneficial to an inspector. For instance, if he/she has to inspect the fire resistance of a wall with an embedded door, he/she may want to read the respective RFID tags of the door and the wall in order to determine the door's and the wall's fire protection rating and compare it to a specified minimum fire protection rating. When scanning the environment for RFID tags, the inspector may find that the RFID reader identifies multiple wall and door RFID tags that are in read range of the RFID reader. As a first step, he/she then identifies the RFID tag of the wall in question. By knowing the fact that multiple doors are in read range of his/her reader, but only one of these doors has a "CloseBy" relationship to the wall in question, gives him/her the ability to more quickly identify the relevant door RFID tag. However, the challenge is to determine how and when to establish these *CloseBy* relationships.

Another application that can benefit from these weak semantic relationships is identifying the location of the RFID reader within the construction environment. By interpreting the relationships between RFID tags, the reader would be able to determine its location on the construction site by distinguishing the components surrounding it and their spatial relationships. Building on the recent research efforts regarding indoor positioning (Lim and Zhang 2006; Song et al. 2007), the authors have performed initial tests that show that depending on the distribution of RFID tags on construction sites, it is possible to uniquely identify the RFID reader's location on the site by relying on such spatial relationships between RFID tags. Factors that affect the results are (1) read range of the tags and readers, (2) number of available tags on site area, (3) spatial distribution of RFID tags on the construction site, (4) performance related reader specifications (e.g. "reads per second"), (5) number of tags being attached to stationary objects vs. mobile objects, and (6) rate of read failures.

Knowing the spatial semantic relationship between two components gives us no information about whether they are connected, embedded, or just happen to be both in the proximity of the RFID reader and have no other semantic relation with each other. Additional rich semantic information about the relationships would lead to more accurate context information.

3.3 DEFINING STRONG SEMANTIC RELATIONSHIPS:

As shown in Figure 2, having defined richer semantic relationships can support processes at site even better. In case of the before mentioned example, knowing that a door "IsEmbeddedIn" the wall gives the inspector the knowledge that the door must also have at least the same fire rating as the wall. In the previous example the proximity of these two components helped identify the possibility that one might be embedded in the other, but now, through the richer semantic relationship "IsEmbeddedIn," the possibility has changed to certainty.

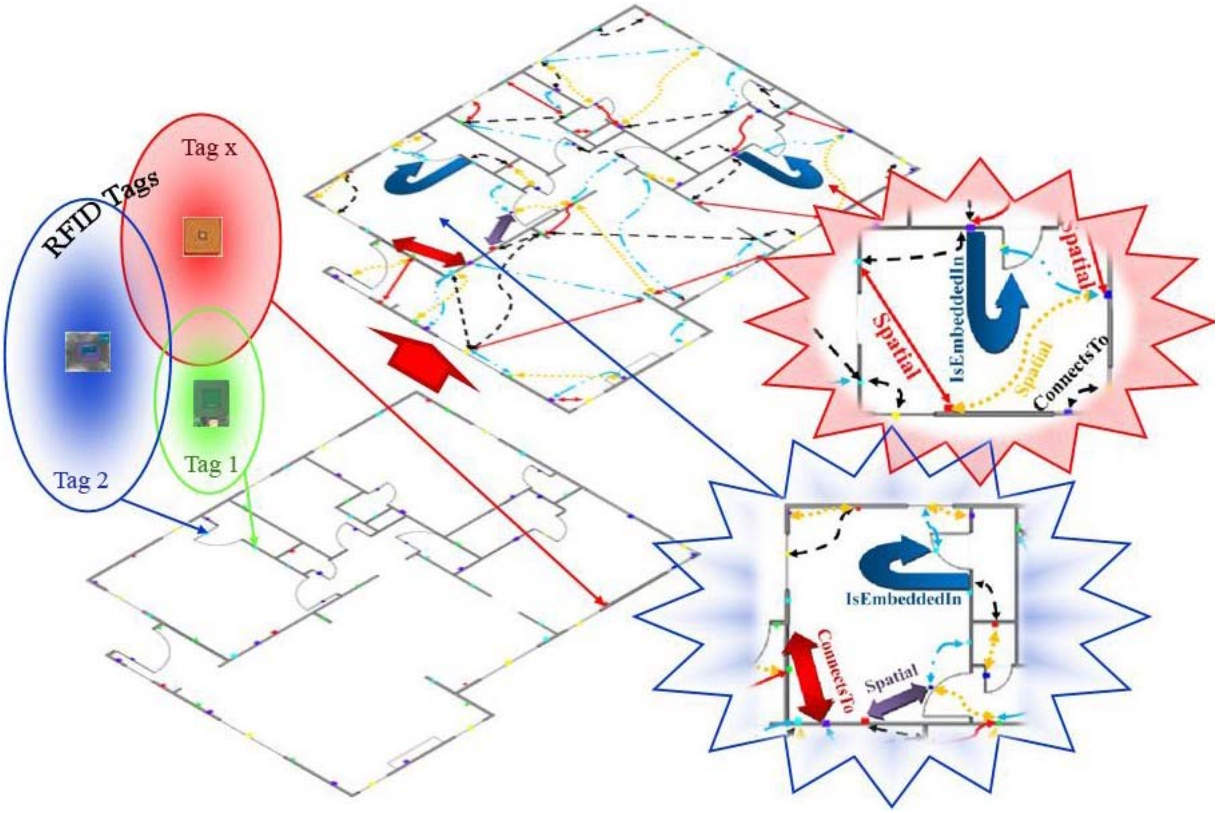

Figure 2: Defining different levels of semantic relationships among the existing RFID tags on a construction site.

Additional semantic information can be added to both the weak and the strong semantic relationships through the use of suppliers' information. Suppliers usually store a component's information either inside each tag or in a separate database for each of the tags' IDs. This information could be used to identify the type of the component and thus increase the semantic richness of the relationship information. Without such information, in the above example, the inspector would potentially only identify that the component tagged with tag 2 is embedded in the component tagged with tag 1. The inspector would not be able to easily identify that tag 1 represents a wall and tag 2 represents a door. This information can be associated with the tag right from the beginning by the supplier, though.

3.4 STORING AND SHARING THE RELATIONSHIPS:

Information about semantic relationships between RFID tags needs to be stored and a reader has to have access to the semantic information at all times while moving through a construction site. Diekmann et al. (2007) described two strategies for storing such RFID related information: (1) Data-On-Network and (2) Data-On-Tag.

Using first of Diekmann's strategies, i.e. Data-On-Network, all the generated semantic information would be stored in an external database. At the construction site, the reader should have a connection to the external database to retrieve the semantic information. However, wireless connection to the external database usually requires expensive equipment and might not always be available at site. Even if available, the wireless network might stop working at times or not be accessible at all places on the construction site. These anticipated difficulties regarding accessing an external database lead to a semi-external approach in which semantic information is stored externally in a database but also copied into a local database stored with the reader. In this case, at areas where the wireless network can be accessed, the shared, up-to-date semantic information can be accessed, while at points where the wireless network is not accessible, the local copy of the database can be used. Whenever a network connection can be re-established, the databases should be synchronized again to ensure that everyone has access to the most up-to-date information.

The second strategy, Data-On-Tag, would use available memory on RFID tags to store semantic information. This has the advantage that it eliminates the need for an external database and that each tag would carry its own updated semantic information. However, a problem for this approach is that in the envisioned scenario, different types of tags may be used by different parties and should be re-used for establishing RFID networks – therefore, it cannot be assumed that all tags have memory available for storing information. In addition, at each reader location, only the semantic information available in the readable tags can be reached, which results in having access to only some of the semantic relationships.

The authors suggest combining these two mentioned strategies. The external database would be used as the priority database and accessed through wireless communication. At specific intervals this external database would be backed up on the local mobile computer attached to the reader for the time when it is not accessible. Also, information about changes made to the relationships between tags should be, if possible, stored on the tags at site.

The idea is to use the local copy of the database for locally accessing the relationship information. When a wireless connection to the primary external database can be established, the two databases should be synchronized immediately, whenever changes are made to the relationships. If a change is made to the RFID network structure, information about that change should be conveyed to the primary external database but also stored on the local RFID tag memory, if possible. This way it can better be ensured that anyone requiring relationship information will be able to obtain up-to-date information – even if a wireless connection to the primary external database is not available.

3.5 BENEFITS:

A network of RFID tags attached to products and resources can provide semantic information about relationships between components and resources. Any on-site task relying on or producing context sensitive information on the construction site could benefit from this semantic information. For example, besides inspections, other domains, such as construction, progress monitoring, and facility management can use the semantic information for retrieving context sensitive information or for storing a context description to the generated context-sensitive information. Quality inspectors can be supported through information technology (IT) tools that gather context information from the semantic RFID network and use it to retrieve context relevant specifications and quality requirements. Progress monitoring inspectors can also be supported through IT tools that gather semantic information between components and workers to identify whether workers are still working on a component and what type of workers are working on a component.

In addition, semantic relationships between tags can also be used to identify missing tags in the network in case a tag is damaged or unreadable. For example, an inspector may be required to perform maintenance inspection of fire valves in ceilings that are not easily found and/or accessible. In such a scenario, the inspector may rely on RFID tags for locating the valves (Ergen et al. 2007a). If an RFID tag of a valve is damaged and cannot be detected anymore, the inspector may overlook the valve and omit the inspection of the valve. Through a semantic “IsEmbeddedIn” relationship between an RFID tag at a the ceiling and the damaged RFID tag at the valve, the inspector could identify that he/she is unable to read the valve’s RFID tag. This becomes especially important in the later phases of a project’s life cycle (e.g. in the facility management phase), when context information still is important, but batteries of active tags have run out of power and are not replaceable or completed finishing reduced the read range of some of the tags behind them.

Even if an Integrated Project Model (IPM) exists that contains semantic information, it can still be advantageous to have the semantic relationships defined in the IPM projected onto an RFID network on site, because not every project participant may have access to the IPM. There are many times when a subcontractor or a contractor has no access or only limited access to the IPM because they either do not have the required technology or because of legal issues (Rosenberg 2006). In these cases, however, similar as in the cases where IPMs do not exist, semantically related RFID networks can be made available to all the parties involved in the construction.

3.6 CHALLENGES:

Before the advantages mentioned regarding defining the semantic relationships between RFID tags can be achieved, challenges and concerns have to be studied and overcome. As mentioned before, we expect to see lots of RFID tags at a construction site that remain attached to many of the components and resources. These tags will be brought to the site by different parties for their own specific different purposes. Thus, it seems logical to expect tags of different brands with different specifications. This highlights the importance of having a standard protocol to communicate with all of these tags with the same reader. Currently there exist a couple of standardization efforts for RFID tags, but a common global standard accepted by all players in the RFID business is still missing. Due to the lack of a common standard, new readers have been developed that can read tags of different brands – however, they are not able to read tags of all brands and they are much more expensive than regular RFID tag readers. Before the development and acceptance of a unique global standard, the problem could be addressed temporarily if the importance of sharing RFID tags information and developing applications, such as the proposed RFID network, during construction is recognized by the client of a project. This would allow dictating an RFID standard for a given project through contractual agreements.

In addition to the RFID technology standards, standards for the semantic relationships have to be defined. Specifically, it has to be specified what type of relationships can and should be established, how they should be stored and when and by whom they should be established.

It should be clarified through contractual agreement or even an internal agreement between involved parties who is responsible for creating the semantic related network of RFID tags and keeping it updated. Responsibilities of each party regarding data provision and usage have to be clarified. If required, different levels of access to the data may have to be defined. This can be achieved, for example, through providing different versions of copies of the relationship database to different parties. The importance of an agreement on these issues is amplified by the fact that data is provided by different parties involved in the design, supply and construction process that are using different system platforms, standards, specifications and even are having different points of views which may result in needs for different semantic information.

In addition, sharing up-to-date relationship data with all of the participants will be a challenging task. As mentioned before, the authors suggest combining an external, wirelessly accessible database with a local copy of that database and a list of changes made to the network stored on RFID tags with accessible memory. Mechanisms have to be identified that allow keeping these different sources consistent with each other.

Due to the nature of construction, it can be expected though that the semantic network will change from time to time. It will become difficult to track these changes. Automated approaches may be developed that help managing the changes in the semantic network. E.g. a mechanism may be able to determine validity of defined semantic relationships through assessing the respective RFID tags' proximity at the time of the relationship definition and comparing it to the RFID tags' proximity throughout the remainder of the project lifecycle. When the proximity value changes, it means that at least one of the respective components or resources have been moved, which could mean that a semantic relationship between the respective components or resources may have to be re-evaluated.

Additionally it may be possible to include probabilities for the validity of semantic relationships in the database. Efforts may focus on adding certainty to the relationship information and may, for example, differentiate between final relationships and temporary relationships. This probability information then may be used in other reasoning mechanisms, e.g. to help determine the likeliness of correctness of the context identified through the RFID network.

Another issue which needs to be further studied is the security of the created network. Only authorized personnel should be able to change the RFID network. Thus, efforts need to be put into making the RFID network secure and only readable and changeable by authorized personnel, e.g. through data encryption.

4. SUMMARY AND CONCLUSIONS

The existence of large numbers of RFID tags in a construction environment presents the opportunity to develop semantic relationships between them in order to make semantic information accessible on site. This semantic information can range from weak spatial relationships to strong semantic relations. The authors propose to expand the existing semantic relationships between building components to the RFID tags attached to them. The advantage of such a network of related RFID tags would be increased context awareness at site through automated identification of semantic relationships. The applications of the proposed system at site could range from supporting progress monitoring to improving safety on construction sites. To store the semantic information and enable better synchronization of the information amongst all interested participants on site, the authors propose to use a combination of an external, wirelessly accessible database, a local on-site database, and spread data-on-tag.

Since the system is based on the RFID tags brought to a site for different purposes by different parties, it is expected to see a large variety of tags with different specifications. Further research is needed to enable interaction with such a diversity of RFID tags. The authors are currently involved in research that aims to define the semantic relationship structures amongst RFID tags that can benefit the safety inspection domain. Also, the researchers are investigating the stability of such semantic RFID networks and the effects of read failures on the ability to interpret the semantic information stored in the RFID network.

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