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Radio Frequency Identification in Construction Operation and Maintenance – Contextual Analysis of User Needs*

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Abstract: As early as in 1995 it was stated that automatic identification of objects using RFID was a promising technology for the construction industry. However, 13 years later the applications of RFID in the construction industry are rare and mostly used in prototype projects or used for theft prevention and access control. Recently maintenance applications have been proposed to hold the trigger needed to launch RFID more widely in the construction sector. Therefore the purpose of the research presented in this paper is to identify the actual user needs for automatic identification in construction operation and maintenance. Research results from a contextual design process are presented and supplemented with practical experiences from implementing an RFID-supported operation and maintenance system. The greatest obstacles for successful implementation of RFID-based O&M systems have been found in structuring working processes and information rather than in making the hardware work.

Key words: Radio Frequency Identification; operation and maintenance; contextual design; user needs; mobile IT; system development; pilot test

Introduction

Radio Frequency Identification (RFID) denotes any identification system in which electronic devices occur that use radio waves or pulsating magnetic fields to communicate with identification units fastened to objects. The most referenced components in RFID systems are tags, readers and middleware. Tags are identification units attached to the objects to be localised. The RFID reader is via an antenna used for scanning the data content of the tags. The middleware is the software component which ties the RFID reader together with the other software components (e.g. an operation and maintenance system) in an IT system and, if necessary, also filters the data before it is relayed.

As early as in 1995 it was stated that automatic identification of objects using RFID was a promising technology for the construction industry[1]. However, 13 years later the applications of RFID in the construction industry are rare and mostly used in prototype projects or used for theft prevention and access control[2]. A number of recently published papers describe various examples of tested RFID implementations in construction: 1) Automating the task of tracking the delivery and receipt of fabricated pipe spools is described in Ref. [3], 2) On-site tool tracking is described in Ref. [4], 3) Project progress management with virtual models is described in Ref. [5], 4) Tracking and locating components in a precast storage is described in [6]. Ontologies relevant for linking virtual models with physical objects in construction using RFID are de-

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scribed in Ref. [7]. In all the papers it is concluded that RFID technology can be brought to function effectively even in the harsh construction environment.

Recently maintenance applications have been proposed to hold the trigger needed to launch RFID more widely in the construction sector[2]. Therefore the purpose of the research presented in this paper is to identify the actual user needs for automatic identification in construction operation and maintenance. It is important for both research and development of new IT systems in operation and maintenance (O&M).

In order to identify the user needs contextual inquiries have been carried out on an infrastructure enterprise operating in Denmark and at a Danish municipality operating public buildings (the enterprises preferred to keep their names anonymous). The infrastructure enterprise and the municipality are currently implementing IT supported document and job management for their facility operation and maintenance. They have decided to use the operation and maintenance systems Rambyg[8] and SMART[9] developed by Ramboll.

Rambyg and SMART are applicable for use in the building industry and the infrastructure industry respectively. Rambyg is a web based system with an overall building model description based on the SfB classification system. Rambyg distinguishes itself e.g. by supporting IFC-file import of building models for easier creation of the operation and maintenance model. SMART is a Java application deployable to PC's, Personal Digital Assistants (PDA´s) and smart phones and its hierarchical structure is customised for each client.

Many papers describe case studies and research about IT in operation and maintenance. In Ref. [10] an overview of recent innovation projects within the domain is given, Ref. [11] proposes RFID as a technology to manage and document mandatory maintenance, in Ref [12] a framework for developing interoperable O&M systems based on and as an extension to the Industry Foundation Classes (IFC) is presented. In Ref. [13] a pilot implementation of an administration system for maintenance tasks and timesheets by use of PDA's is presented.

This paper presents the research results from a contextual design process supplemented with practical experiences from implementing an RFID-supported operation and maintenance system. The case used in the implementation is operation and maintenance of a small part of the infrastructures associated with a railway north of Copenhagen, Denmark. Experiences from this implementation show that the RFID technology is fully functional for operational use in the construction sector. The greatest obstacles for successful implementation of RFID-based O&M systems have been found in structuring working processes and information rather than in making the hardware work. The mobile system's usability is also a critical factor for success. Limited current possibilities for access to and reuse of product and process models from design and construction in operation and management are also significant obstacles for a wider introduction of RFID in construction.

Although the demand for RFID in construction is presently limited, it has been possible to identify a number of user needs that can be fulfilled with the use of RFID in combination with mobile computing. The conclusions based on the contextual analysis and the case study include identified user needs for: on-site navigation in the IT-system, subscription to information services from e.g. building component manufacturers, easier update of maintenance information and registration of inspection history.

1 Research method

A contextual design of a prototype IT-system has been conducted to identify user needs in relation to automatic object identification in construction operation and maintenance. Contextual design is a method developed by Beyer and Holtzblatt[14] to handle the collection and understanding of data from field studies to design of software based products. The method is user centred and the following techniques are used in the method:

Contextual Inquiry: Interviews and observations of future users in their actual working environment are carried out to get an understanding of the business problems the system must support. It ensures capture of the real business practice and daily activities and not just self-reported issues and company politics.

Modelling: Drawn models representing the user's work practice allows the developer and end user to attain a common understanding and share their findings. It includes work flow models, sequential models of tasks, cultural models and models of the physical environment and the used artefacts.

Consolidation: All the individual findings from interviews, brainstorming and work modelling are grouped in hierarchies and consolidated to show common work patterns.

Work redesign and visioning: Based on reviews of the models a vision for how the new system will support and streamline the working practice is sketched.

Storyboarding: A sketched and written story is created including sketches of future user environment and narrative descriptions of how it all will work in practice. The story will function as the common understanding between end users and developers about how the system will work and which functionality it will have.

User environment design: Based on the storyboard a single model of the user environment's functionality and organisation is created.

Mockup and test with users: Paper based mockups of the user interface are designed and evaluated by user tests. The level of detail of these mockups is increased through the development process starting with very simple sketches.

The above presented process is iterative and incremental which means that findings from one step in the process will lead to updates to both the preceding and following steps in the process. The design is initiated from rough sketches, notes and simple models which are detailed through iterations in the research and development process.

Compared to other methods from social science (see e.g. Ref. [15] for an overview) used to study human behavior and actions, contextual design offers a complete and easy to-use framework. It is well organised and provides modeling tools to formalise the unstructured connections in work processes with the needs in relation to software development. The work models developed from contextual inquiries provide a basis for a common understanding between software developers and end users.

In this research project the contextual design process is supplemented with reviews of available literature within the field and trail tests of software and hardware to be used in the final system and for the development. Also demonstration software applications are created and tested by future users.

It has been found rewarding to take the design of paper-based mockups of the user interface used in the contextual design method one step further by giving them some functionality and appearance like the real applications. Demonstration software applications with some functionality is therefore created and used for collecting user feedback and ideas. It is important to let the users know that it is only a demonstration application being presented; otherwise they might expect the development process to be in a late state where their input does not matter any more. There is also a risk that they might be disappointed if the final release of the application has a different appearance or functionality due to findings later in the system development process.

Introduction of new IT tools in construction has proven to be a challenging task. For that reason practical implementation tests of RFID technology and a pilot test are conducted. It shall lead to an increased knowledge about how the technology can support the operation and maintenance process and lead to new improved working processes.

The contextual inquiry has been done as informal interviewing and work observations of future users with different roles in relation to operation and maintenance. Also visits to sites where the system is going to be used have been done. The contextual design and inquiry has focussed on use of object identification in both building and infrastructure operation and maintenance. The results from the two industries are presented jointly in this paper because of the major similarities in the identified user needs and working processes. Approximately 10 future users have been involved in the inquiry process. Their identified needs are supplemented with input from discussions with colleagues, software developers and other researchers to form the presented consolidated work models. In Ref. [14] it is stated that interview of 10-20 users are enough to collect most of the user needs. More interviews will not result in significantly more identified needs.

As mentioned before the contextual inquiries have been carried out on an infrastructure enterprise operating in Denmark and at a municipality operating public buildings. Both the railway enterprise and the municipality use IT based O&M systems. The focus of the inquiries is therefore to identify how automatic object identification by RFID can give additional benefits for users of O&M systems.

The users involved in the inquiry are consultants,

building service personnel and managers at the end user. The interviewed person's roles in the case study are the following: 1) The consultants do the initial building registration and job management setup of the operation and maintenance systems for use by their clients (in this case the municipality and the railway enterprise). 2) The service personnel use the O&M systems for planning, retrieving and updating information about operation and maintenance tasks. 3) The managers are responsible for implementing the systems and use the O&M systems to retrieve information for making financial decisions and keep an overview of their organisations budgets and upcoming tasks.

3 Results

The results from the contextual inquiry and design include consolidated work models, affinity diagrams, a vision for a new system, story board, user environment models and paper prototypes of the new system. In this paper an affinity diagram, a consolidated work flow model, a cultural model and experiences from prototype implementations are presented.

3.1 Affinity diagrams

In the contextual design method affinity diagrams are used to organise the individual notes captured during interviews and observations into a hierarchy of common issues. The hierarchy is built bottom up by raising a structure from the content of the notes. A number of future user needs and comments have been collected based on exiting system usage. It can be divided into the five categories presented in Table 1. To keep the broad understanding of the users' needs no distinction is made in the presentation between what in reality is possible or financially desirable to implement.

Table 1 Affinity diagram (shortened edition)

On site O&M system use	Experience gathering	Real time information update	New services and funct.	General features
Improve navigation, tablet PC's have been tried without success, RFID tags can link physical objects with digital models, equipment must be robust, RFID tags will be hidden in the building component	Maintenance condition can be difficult to assess, personal judgements can be very different, guidance from the building component manufacturer should underlie the judgement, history of registrations should be archived	It is time consuming to keep the O&M system updated, Quantity measurement is time consuming, control option to check whether registrations of a given building part are carried out on site and not just from the office.	Documentation of the age of the building components, digital information from manufacturer, post-qualifying education, digital publication of the tender material, link to services containing gathered experiences.	Encapsulation of the digital building objects to units, re-use of digital building model from design, equip building components with RFID tags if they demand maintenance, log for changes in data, context dependent user interface

3.2 Work flow model

Work flow models are used to define and illustrate how work is spread out on people, how they coordinate work and which artifacts (formalised messages) and placeholders (information containers, meeting places etc.) they use to assist the communication. Usually one work flow model is created per person/role interviewed. However, in the consolidated workflow model presented in Fig. 1 several users are included to give a broader overview. Each person or user role is shown in the bubbles annotated with their responsibilities listed below their job title. The rectangles in the model work flow model show the artifacts and placeholders used for information transfer between the people.

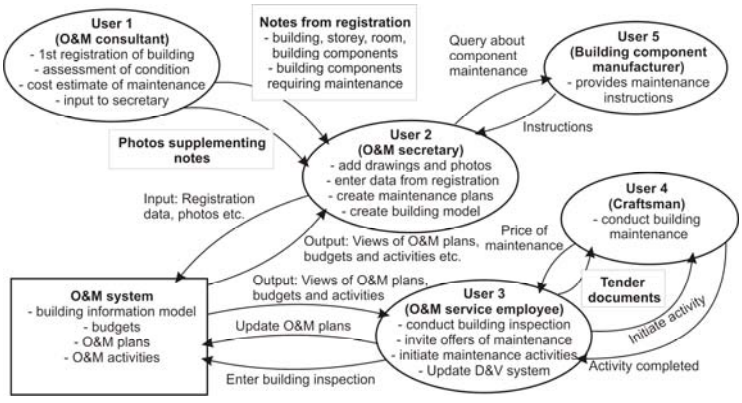

Fig. 1 Work flow illustration for activities concerning operation and maintenance. Bubbles illustrate roles and rectangles illustrate artifacts (formalised messages) supporting the information transfer.

It is found that especially working processes involv-

ing the secretary role can be optimised by use of RFID and mobile IT equipment such as PDA´s, smart phones or tablet PC's. RFID tagged building components can enable easier on-site access and real time update of the O&M system.

3.3 Cultural model

Cultural models are used to illustrate, concretise and capture the invisible and pervasive cultural context that influences the system or product to be developed. The authors' interception of the interviewees' behaviour, their informal answers and unwritten values is presented in Fig 2. Cultural models are relevant in any system development because cultural aspects can have significant influence on people's choices and thereby the success ratio of the new system. The introduction of RFID in operation and maintenance may introduce many potential conflicts, as illustrated in Fig. 2 with the zigzags. In the implementation it will lead to conflicts about who should pay for adding RFID tags to components and what must the detailed registration of people's behaviour be used for? Also public attitude about the RFID technology, which can be hard to tackle, can have major influence on its success.

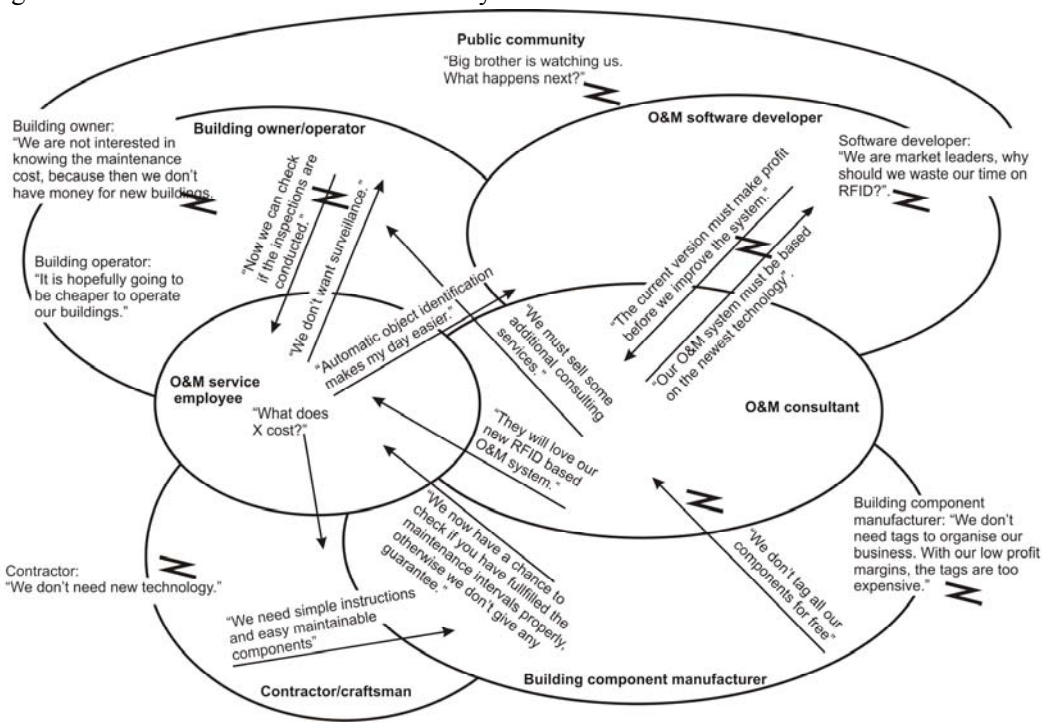

Fig. 2 Cultural model of the context influencing an RFID based operation and maintenance system. The bubbles illustrate users with overlapping interests and the arrows illustrate cultural influence. Zigzags indicate conflicts.

3.4 Lessons learnt from prototype implementation

As described above needs have successfully been captured and they have been used as basis for a pilot implementation. It is developed as an extension to the existing mobile edition of the O&M system SMART[8]. The first edition of the system is currently implemented and will be tested with users during the autumn 2008. An example of the user interface for a Java application for rugged PDA's with attached RFID reader is shown in Fig 3.

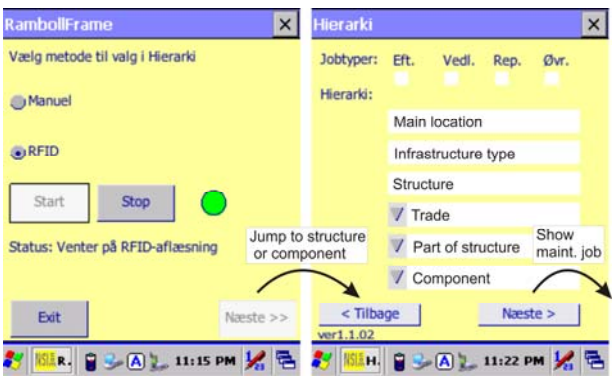

Fig. 3 Example of user interface for SMART mobile edition.

The PDA has access to the O&M database through use of GPRS. By use of RFID technology and the PDA the users have quick on-site access to information (check lists, maintenance jobs etc.) stored in the O&M database and it is also automatically documented that components are inspected regularly. It was decided to use ISO 15963 tags (13.56 MHz) due to the wide availability of supporting hand held readers and good all-round properties (price, readability near metal, size). See Ref. [7] for a discussion about selection of RFID tags for use in construction.

It has been found: 1) That the hardware is working in practice but it is yet not plug and play technology. Software drivers had to be developed by the system developers for the Java application. 2) It is difficult to assess which RFID standard to use for tags and readers. The lack of a de-facto RFID standard in construction is introducing a risk of basing the system development on standards that will be outdated in a few years. 3) Structuring information and working processes for digitalising the O&M procedures is a much more extensive task than implementing the RFID technology.

5 Conclusion

This paper describes a contextual development and needs capture for automatic object identification by RFID technology in operation and maintenance (O&M). The conclusions are: 1) A number of needs can be identified such as easier on-site information access, increased focus on documentation, education of users and re-use of knowledge across organisations by new services. The needs can form as basis for more detailed requirements specifications. 2) The introduction of RFID in operation and maintenance may introduce many potential cultural conflicts about e.g. cost, unwanted surveillance, public attitude which can influence the success for a wider use of this technology. 3) Demand from the property owners is needed to gain the benefits from implementing the technology. 4) The technology works in practice. The obstacles for using RFID in O&M is found in information structuring, need for de-facto technology standards and lack in the use of general ontologies for storing and accessing the information resources.

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