Improving Construction Quality Control and Management Using Automated Data Collection Technologies

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ABSTRACT

Construction is recognised internationally as an information-intensive industry which involves a lot of disciplines, and requires varying levels of information at various times. Quality inspection and management plays an essential role in managing the construction industry where projects need to be completed within a defined budget and deadline. Radio Frequencies based information and communication technologies, such as Radio Frequency Identification (RFID) tags have matured and become commercially available to potentially support automated data collection. This paper investigates the applications of RFID-based Automated Data Collection (ADC) technologies integrated with Personal Digital Assistants (PDA), and a portal system which focuses on the real-time collection and exchange of information among the material test lab, construction site and off-site office. Transmission of data from the system to the central station will be carried out with the help of Global System for Mobile Communications (GSM). Also, each RFID tag is equipped with a unique Electronic Specimen and Test Code (ESTC). ESTC as a specimen and test identity code is the base of reports which contain related information for a particular specimen and test. This integrated system is automatic, thus reducing the labour costs and eliminating human error associated with data collection during construction quality inspection and management.

Keywords: Construction Industry, Quality Management, RFID.

1. INTRODUCTION

The construction industry is identified internationally as an information intensive industry, where real-time and accurate information sharing amongst all the parties involved are vitally efficient for the effective management of projects. This varying information results in the production of large quantities of complex information, which is all too often managed inefficiently [1]. Quality inspection and management plays an essential role in managing the construction industry where projects need to be completed within a defined budget and deadline. Laboratorial work is of great importance to efficient quality management. Identification of specimens; recording related information; data analysis; information transmissions; rapid and easy access to results and initial data all are significant at laboratorial works either for a research or for testing specimens of real projects.

In a laboratory, there are a lot of materials, vast numbers of specimens which have different sizes and shapes, and large amounts of data, information, and results which need appropriate methods of management to organise them properly. For example, there are lots of specimens of tests such as compressive strength, flexural strength, modulus of elasticity, creep, shrinkage, etc from researches and at the same time from real projects at a concrete testing laboratory. A massive number of specimens could exist at a soil laboratory for short term and long term soil testing such as CBR, consolidation, shear box, linear shrinkage, etc for projects like dam construction. This can be more or less the same for testing other construction materials including mortars, cement, aggregates, asphalt, steel bar, and so on.

Existing methods for controlling and managing the inspection in material test labs utilize manual recording by paper-based documents. Information collected using such time and labour-intensive methods are unreliable and ineffective. Moreover, inputting, retrieving, analyzing and disseminating the result data instantaneously require a significant amount of time and effort [2]. Also, the current situations of on-site information management are paper-based information communication and non-automatic information management activities. These do not provide real-time status information because of the amount of time required to pull all data from different reports together. Data collected using manual methods are not reliable or complete due to the reluctance of workers to monitor and record the flow of large quantities of elements. Human errors (54% of all construction defects are due to human errors, for example untrained workers and lack of proper supervision of construction work [3]); missing information; losing data and results; spending too much time and energy; changing work forces; and difficulties of re-accessing to data make lots of problems in the work.

There is no doubt that computer systems are making companies' business easier, providing better communication and reducing costs [4]. Although using computer systems – after entry data - has an essential role in information management, but current methods for using computer systems do not have an appropriate role in specimen identification. This also needs a lot of labour work and time to enter data and transfer it. In addition, using computers is very difficult and not suitable for on-site projects such as road and dam construction which have harsh conditions.

New communication technology should be used in managing civil engineering tests and laboratories in all aspects to improve working efficiency, standardise laboratory management, and have a modern, automated and reliable laboratory.

Due to the complex, unprepared, and uncontrolled nature of the construction site, not only using of automated advanced identification and data storage technologies for efficient information management is needed but also construction industry has greatly benefited from the implementation of them to improve the efficiency and effectiveness of data exchange and reducing the cost of information transfer [5]. Collection of detailed, accurate and a sufficient volume of information and timely delivery of them are vital to operating a well managed and cost efficient construction project [6]. The process of identification and capturing quantity of test data at a construction project for the reason of quality management needs to be improved in terms of accuracy and completeness to eliminate unnecessary communication loops and secondary tasks caused by missing or inaccurate data. Effective and immediate access to information minimizes the time and labor used for retrieving information related to each part of on-site quality test and reduces the occurrence of ineffective decisions that are made in the absence of information [7].

These all suggest the need for a fully automatic data collection technology to capture the status information at various milestones, and to integrate this data in a database automatically to minimize errors and to enable real-time reporting. Given the mentioned data collection and information management problems above, the construction industry can benefit from the advantages of combining Radio Frequencies (RF) based technologies with a portal system where Radio Frequency Identification (RFID) can be applied to collect the information by identifying any object automatically. RF-based information and communication technologies, such as RFID tags have matured and become commercially available to potentially support automated data collection in construction [8]. Although various studies exist for using new technologies in construction, studies focusing on detailed application of full automatic data collection and information management models in construction quality management and control are scarce and the application to an open environment like a construction site is still unproven.

This paper investigates the RFID-based automated data collection technology integrated with Personal Digital Assistants (PDA), and a portal system which focuses on the real-time collection and exchange of information among the material test lab, construction site and off-site office. Transmission of data from the system to the central database will be carried out with the help of standard cellular phone communications networks technology such as Global System for Mobile Communications (GSM). In this research, combination of RFID, PDA, portal and GSM technologies as a powerful portable data collection tool enables collecting, storing, sharing, and reusing field data accurately, completely, and timely. Most of the used technologies in this research (RFID, PDA, and GSM) are inexpensive and commercially available. The system concept can be divided into three tiers: clients (integrated RFID and portal system), communication channel (GSM) and the server (database). The remainder of this paper first reviews technologies which are utilized in our research, followed by related application of RFID in the construction industry. It will then reveal the architecture of our integrated system for information delivery and management. Finally a conclusion is given.

2. TECHNOLGY DESCRIPTION

RFID is a method of remotely storing and retrieving data by utilizing radio frequency in identifying, tracking, and detecting various objects that streamline data acquisitions and identification, which can help improve the effectiveness and convenience of information flow in construction industry [9]. An early, if not the first, work exploring RFID is the landmark paper by Harry Stockman, "Communication by Means of Reflected Power" [10]. A RIFD system consists of tags (transponder) with an antenna, a reader (transceiver) with an antenna, and a host terminal. The RFID reader acts as a transmitter/receiver and transmits an electromagnetic field that ‘‘wakes-up’’ the tag and provides the power required for the tag to operate [5]. A typical RFID system is shown in Figure 1.

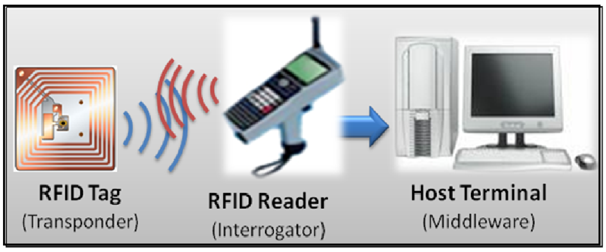

Fig. 1. A typical RFID system

An RFID tag is a portable memory device located on a chip that is encapsulated in a protective shell and can be attached to any object which stores dynamic information about the object. Tags consist of a small integrated circuit chip coupled with an antenna to enable them to receive and respond to radio frequency queries from a reader. Tags can be categorized as read-only (RO), write once, read many (WORM), and read-write (RW) in which the volume capacity of their built-in memories varies from a few bits to thousands of bits. RFID tags can be classified into active tags (battery powered) and passive tags, which powered solely by the magnetic field emanated from the reader and hence have an unlimited lifetime. Reading and writing ranges are depend on the operation frequency (low, high, ultra high, and microwave). Low frequency systems generally operate at 124 KHz, 125 KHz or 135 KHz. High frequency systems operates at 13.56 MHz and ultra high frequency (UHF) and use a band anywhere from 400 MHz to 960 MHz [11]. Tags operating at ultra high frequency (UHF) typically have longer reading ranges than tags operating at other frequencies. Similarly, active tags have typically longer reading ranges than passive tags. Tags also vary by the amount of information they can hold, life expectancy, recycle ability, attachment method, usability, and cost. Communication distance between RFID tags and readers may decrease significantly due to interferences by steel objects and moisture in the vicinity, which is commonplace in a construction site. Active tags have internal battery source and therefore have shorter lifetime of approximately three to ten years [12]. The reader, combined with an external antenna, reads/writes data from/to a tag via radio frequency and transfers data to a host computer. The reader can be configured either as a handheld or a fixed mount device [13].The host and software system is an all-encompassing term for the hardware and software component that is separate from the RFID hardware (i.e., reader and tag); the system is composed of the following four main components: Edge interface/system, Middleware, Enterprise back-end interface, and Enterprise back end [14]. RFID tags are more durable and suitable for a construction site environment in comparison with Barcodes which are easily peeled off and may be illegible when they become dirty. RFID tags are not damaged as easily and do not require line-of sight for reading and writing, they can also be read in direct sunlight and survive harsh conditions, reusable, and permit remote [15].

3. RELATED APPLICATIONS OF RFID IN CONSTRUCTION INDUSTRY

In earlier research, Jaselskis et al. (1995) have summarized RFID technology and surveyed its potential applications in the construction industry including concrete processing and handling, cost coding of labor and equipment, and material control [14]. RFID has been used in some research efforts to improve the process of capturing quantity of work data at a construction site in terms of accuracy and completeness to eliminate secondary tasks caused by missing or inaccurate data and minimizes the time and labor used for retrieving information related to each part of construction [7, 15-22]. Quality management performance can be improved by applying RFID-based system where availability of information leads to enhance the efficiency and effectiveness of collected data acquisition [1, 23, 24].

4. PORTAL SYSTEM

Electronic exchange of information leads to reduction of errors and increased efficiency of the operation processes. When all participants can analyze their projects based on the information sharing from related-participants in the supply chain, the negative effects of uncertainty can be mitigated in theory [25]. A web-based portal is an ideal platform for sharing information in a supply chain system which leads to produce and distribute construction materials in the appropriate quantities, to the right locations and at the right times. When a portal is used, all project-related information that is centralized in a project database can be obtained only via a web interface. The portal also provides authentication and access control mechanisms to allow project participants to access information based on user privileges and activity-related units. However, in practice the exchange of information among participants is more difficult than it seems. Portals represent a solution to these problems. An e-Hub construction supply chain management system is needed for information sharing and analysis among project participants [5, 25]. The portal provides an organization with a single, unified database, linked across all functional systems, both within the organization and between the organization and its major supply chain partners. With the portal and its associated tools, managers and engineers of each participant can conduct effective monitor and controlling activities for the project [25].

5. THE ARCHITECTURE OF PROPOSED SYSTEM

The RFID-based pervasive system which is developed in this research could be divided into two major parts mobile system and central station. The Mobile system mainly consists of three types of hardware components; namely, (i) Personal Digital Assistant (PDA) which is also known as a palmtop computer; (ii) RFID technology where passive High Frequency (HF) and Ultra High Frequency (UHF) band RFID tags will be used for identifying and obtaining the objects related information by using an RFID reader which is plugged into the PDA; and (iii) GSM communication technology where the information (ID, date, etc.) retrieved from RFID readers is transferred to the server using General Packet Radio Systems (GPRS) or Short Messaging Service (SMS). The central station consists of two servers, the application server (portal system) and the database server (project database). In this approach, data collection is done continuously and autonomously, therefore, the RFID as a promising technology is the solution for information collection problems and the portal system will be used to solve information communication problem in the construction industry. A sample of smart tag and PDA equipped with RFID reader which is selected in our research are shown in figures 2 and 3.

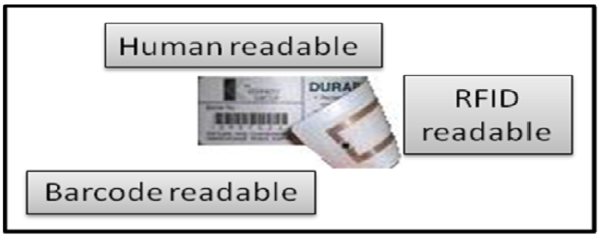

Fig.2. A sample of smart tag

In this research, collecting data begins with a specimen which is equipped with an RFID tag. Lab staff will attach RFID tags to all specimens. In this approach, the tags are used only for identification, and all of the related information will be uploaded and stored in the databases which will be indexed with the same unique ID of objects. In another mechanism, information can be stored directly on the tags and also in the database systems. RFID tags with unique ID can be attached to specimens by either of the two methods. One of them is to place the tag inside of the specimen; the other is to attach the RFID tag outside of the specimen using a rope which makes the tag reusable.

Fig.3. A PDA equipped with RFID reader

In concrete specimens, a tag can be attached to the pre-defined location inside of the specimen and instructions need to be passed to the crew along with the quality control and it may be individual for each specimen. To minimize the performance reduction of selected technology in contact with metal and concrete, RFID tags need to be encapsulated or insulated. During the test process and at the times of moving or picking up of any specimens, the information on the RFID tag is captured and deciphered by the RFID reader and the ID and related information of the specimen is then sent to a database via GSM technology. Information update and announcement is synchronously sent via the portal and the system will effectively increase the accuracy and speed of data entry by providing owners, consultants, and contractors with the real time related information of tests. The application server defines various applications for collecting, sharing, and managing information. One of the challenges of designing an effective construction quality management system is designing an effective construction quality tagging system. Each RFID tag is equipped with a unique Electronic Specimen and Test Code (ESTC). ESTC as a specimen and test identity code is the base of reports which contain related information for a particular specimen and test. This coding system (ESTC) is comparable EPC global UHF Electronic Product Code (EPC) which has developed to provide a degree of compatibility with a global technical standard code in different industries [11]. Using an ESTC makes unique identification of all specimen and test possible. ESTC is divided into numbers, which can identify the lab, material and test type, and it uses a serial number to identify unique specimens. An Illustration of an ESTC is shown in figure 4.

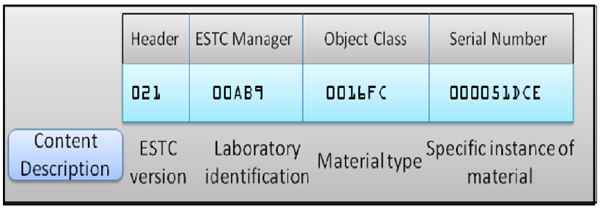

Fig.4. Illustration of an ESTC

The ESTC number is attached to a tag, and by using RFID, ESTC can communicate its numbers to a reader, which passes them on to a PDA system. In choosing the right RFID tag for any application, there are a number of considerations, including: frequency range, memory size, range performance, form factor, environmental conditions, and standards compliance. Citing factors such as screen size for PDA, battery power, physical unit size and robustness are important considerations in the selection of appropriate hardware for the construction site.

6. CONCLUSIONS

This paper investigates the applications of RFID-based Automated Data Collection (ADC) technologies integrated with PDA, and a portal system which focuses on the real-time collection and exchange of information among the material test lab, construction site and off-site office. Each RFID tag is equipped with a unique Electronic Specimen and Test Code (ESTC). ESTC as a specimen and test identity code is the base of reports which contain related information for a particular specimen and test. This system can provide low-cost, timely, and faster quality information flow with greater accuracy by using RFID technology, GSM, and a portal system. In this manner up-to-date information regarding all parts of construction quality is available which permits real-time control enabling corrective actions to be taken. The system enables quality related information to be shared among the involved participants of the construction phase via the Internet which leads to important changes in the construction quality management. The proposed system has numerous advantages. It is automatic, thus reducing the labour costs and eliminating human error associated with data collection during construction quality inspection and management. Applications of ESTC in automation of quality management in the construction industry can dramatically improve the construction management activities which also lead to keep cost and time under control in the construction phase. The authors believe that, in practice, the approached pervasive system can deliver a complete return on investment within a short period by reducing operational costs and increasing workforce productivity.

7. RECOMMENDATION

This study shows that using automated data collection technologies improves construction quality control and management; however, more studies are required to evaluate fully the practical works of industry.

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