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Enhancing Facility Management Using RFID and Web Technology in Construction

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1. Introduction

Facility management (FM) has become an important subject for research and academic study in real estate and construction. To benefit most, organizations need to understand that they must be informed clients in managing their facilities and properties. Managing facility management effectively are extremely difficult owing to various environments. With the advent of the Internet, web-based information management solutions enable information dissemination and information sharing among related participants. Generally, facility managers and staffs require access to the facility location to handle inspection and maintenance work at any facility locations. However, current desktops and notebooks are not suitable for using on facility locations because of problems in transportability. Facility managers and staffs generally handle various types of information, including specification, checklists and reports. Facility managers and staffs generally use sheets of paper and/or field notes. Consequently, there is serious rework progress regarding the data capture and input in inspection and maintenance progress.

Managing the facility maintenance information play an important role in the view of facility management. Therefore, controlling and managing facilities effectively are extremely difficult owing to the environment of various facilities conditions. With the advent of the Internet, web-based information management solutions enable information dissemination and information sharing among involved facility management participants. Furthermore, integrating promising information technologies such as Personal Digital Assistants (PDA), Radio Frequency Identification (RFID) scanning and data entry mechanisms, can help improve the effectiveness and convenience of information flow in the tracing management. This study presents a novel system called Mobile RFID-based Facility Management (M-RFIDFM) System for the acquisition and tracing of facility maintains information on locations and providing a facility maintains information sharing platform among all participants using web technology and RFID enabled PDA.

2. Problem statement

Facility management and control performance can be enhanced by enabling participants to share information with each other. However, two major key aspects of information sharing are information acquisition and information communication. Information acquisition problems in facility management follow from most of the data and information being

gathered from the facility location, which is an extension of the facility management. The effectiveness of information and data acquisition influences the information flow between the office and the facility locations. However, facility managers and facility staff members generally use sheets of paper and/or field notes for maintenance progress. Restated, existing means of processing information and accumulating data are not only time-consuming and expensive, but also compromise maintenance management in information acquisition. Such means of communicating information between facility locations and offices, and among all participants, are ineffective and inconvenient. According to the questionnaire survey from 3 facility manager and 10 facility staff members, the primary problems in inspection and maintenance regarding to data capture and sharing are as follows: (1) the efficiency and quality are low, especially in the inspection and maintenance progress in facility management though document-based media, and (2) there are serious rework progress regarding the data capture and input in inspection and maintenance progress. However, few suitable platforms are developed to assist facility staff members with capturing and sharing the inspection and maintenance information when facility staff members need to handle inspection and maintenance work. Therefore, to capture data effective and enhance information communication in facility management will be primary and significant challenge in the study.

3. Research objectives

This study utilizes the RFID and web technology to enhance the maintenance progress and effectiveness in facility management service. This portal is controlled by the management division, and provides facility managers, facility staff members and suppliers with real-time facility-related information-sharing services, enabling them to dynamically respond to the entire facility management network. This study develops Mobile RFID-based Facility management (M-RFIDFM) system to improve efficiency and cost-effectiveness of facility management, improve practical communication among participants, and increase flexibility in terms of service delivery and response times. M-RFIDFM system is a web-based system for effectively integrating facility managers, facility staff members and suppliers, to distribute facility services in the appropriate information, to the right locations and at the right times. PDAs can extend M-RFIDFM systems from offices to facility locations. Data collection efficiency can also be enhanced using RFID-enabled PDAs to enter and edit data on the facility location. By using web technology and mobile devices, the M-RFIDFM system for the management division has tremendous potential to increase the efficiency and effectiveness of information flow, thus streamlining services processes with other participants.

Facility managers and staff members frequently waste time by travelling to obtain information in the absence of other efficient means of communication. The portal and PDAs enable facility location engineers to update data from the facility location and immediately upload it to the system portal; suppliers can receive maintenance information and make better decisions regarding future facility management and control.

The main purposes of this study include (1) developing a framework for a mobile facility management system for facility management division; (2) applying such a system that integrates RFID technology with PDA technology to increase the efficiency of facility inspection and maintenance data collection; (3) designing a web-based portal for facility management and control, providing real-time information and wireless communication

between offices and facility locations, and suppliers, and (4) apply RFID technology to carry brief maintenance data in the facility itself. Figure 1 illustrates solutions used in a real case utilized M-RFIDFM system in a factory building in Taiwan. With appropriate modifications, the M-RFIDFM system can be utilized at any facility inspection and maintenance service for facility management divisions or suppliers in support of the M-RFIDFM system.

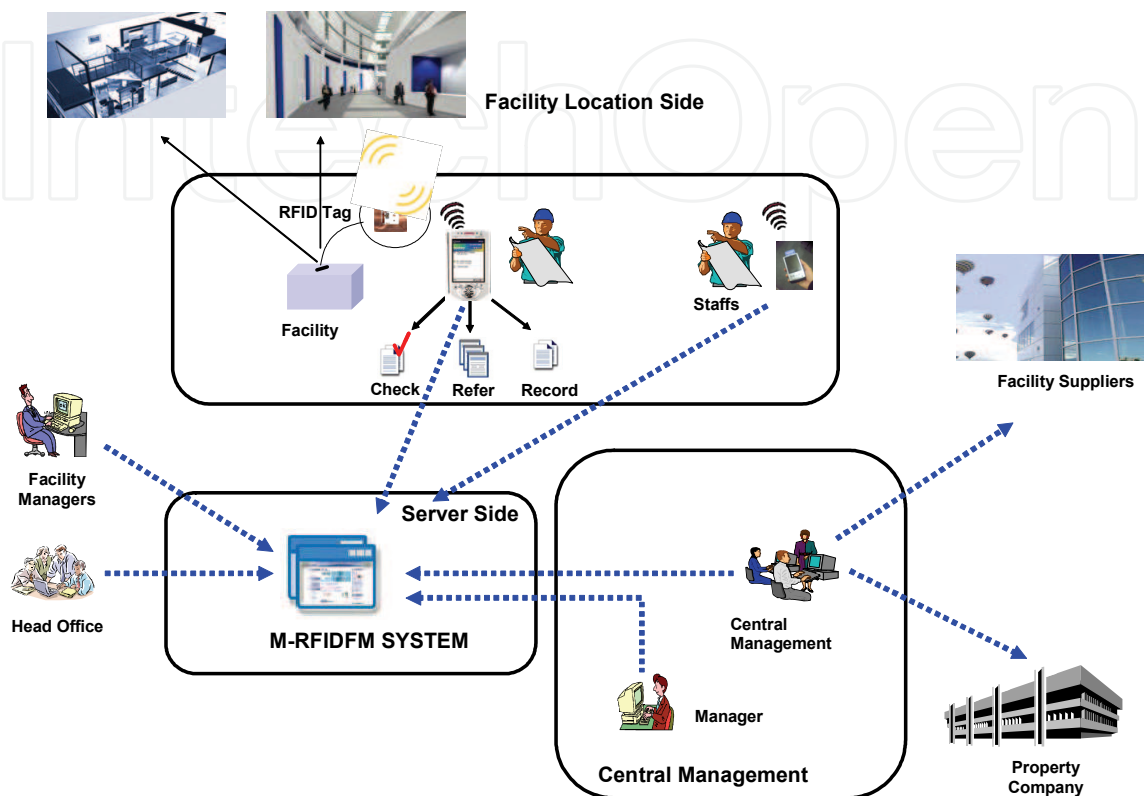


Fig. 1. M-RFIDTM System Framework Overview

4. Background research

RFID is an automatic identification solution that streamlines identification and data acquisition, operating similarly to bar codes. Automatic identification procedures have recently become very popular in numerous service industries for purchasing and distribution logistics, and in manufacturing companies and material flow systems. Jaselskis & Anderson (1995) investigated the applications and limitations of RFID technology in the construction industry, and attached read/write RFID tags to the surfaces of concrete test that were cast from the job site to test lab. This RFID technology has been widely applied in many areas in the construction industries for the following reasons: (1) to provide owners and contractors with information to enhance operation using RFID technology (Jaselskis and Tarek, 2003); (2) to propose a novel concept of “parts and packets unified architecture” in order to handle data or information related to a product carried by product itself by utilizing RFID technology (Yagi et al., 2005); (3) to apply RFID technology as a solution to problems in pipe spools, and identify potential economic benefits from adopting RFID technology in automated tracking (Song et al., 2006); (4) to apply RFID combined with GIS technology in order to locate precast concrete components with minimal worker input in the storage yard (Ergen et al., 2006); (5) to improve the efficiency of tracing tools and tool

availability using RFID (Goodrum et al., 2006); (6) to develop mobile construction supply chain system integrated with RFID technology (Wang et al., 2006); (7) to describe a prototype of an advanced tower crane equipped with wireless video control and RFID technology (Lee et al., 2006), and (8) to improve tracing of material on construction using materials tagged with RFID tags (Song et al., 2006).

The use of technology to improve delivery process control is not a novel concept. Many industries have applied barcodes to track materials for many years. Construction companies began to examine the use of barcodes for tool management in the early 1990s. Although barcode is an established and affordable technology, it has presented problems in the construction industry due to the short read range and poor durability of barcodes – a barcode requires a line of sight, and becomes unreadable when scratched or dirty.

An RFID system is composed of an RFID tag and an RFID reader. The RFID tag comprises a small microchip and an antenna. Data are stored in the tag, generally as a unique serial number. The RFID tags can be either passive (no battery) or active (battery present). Active tags are more expensive than passive tags and have a read range of 10–100 meters. Passive tags have a read range of 10mm to approximately 5m (Manish & Shahram, 2005). The vast majority of RFID tags applied in the construction industries are passive.

The RFID reader functions as a transmitter/receiver. The reader transmits an electromagnetic field that “wakes up” the tag and provides the power required for it to operate (Lahiri, 2005). The tag then transfers data to the reader via the antenna. This data are then read by the RFID reader, and transferred to a Pocket PC or computer. Unlike barcodes, RFID tags do not require line-of-sight to be read; they only need to be within the reader’s radio range. Additionally, RFID tags, unlike barcodes, can be read through most materials. RFID tags are shrinking, with some measuring only 0.33mm across. Although RFID systems can apply different frequencies, the most common frequencies are low (125KHz), high (13.56MHz) and ultra-high (UHF) (850–900MHz) (Lahiri, 2005).

Notably, RFID systems are one of the most anticipated technologies that will potentially transform processes in the engineering and construction industries. In the construction industry, RFID technology can be utilized with PDAs, thereby allowing staff members to integrate seamlessly work processes at labs and sites, due to the ability to capture and carry data. With a RFID scanner plugged into a PDA, the RFID-enabled PDA is a powerful portable data collection tool. Additionally, RFID readings increase the accuracy and speed of information communication, indirectly enhancing performance and productivity. Figure 2 shows an application of an RFID-enabled PDA used in facility management.

The advantages of using mobile devices in the construction industry are well documented (Baldwin et al., 1994; Fayek et al., 1998; McCullough, 1997). Moreover, mobile devices have been applied in numerous construction industries, to provide the following support: (1) providing wearable field inspection systems (Sunkpho & Garrett, 2003); (2) supporting pen-based computer data acquisition for recording construction surveys (Elzarka & Bell, 1997); (3) supporting collaborative and information-sharing platforms (Pena-Mora & Dwivedi, 2002); (4) using mobile computers to capture data for piling work (Ward et al., 2003), and (5) utilizing mobile devices in construction supply chain management systems (Tserng et al., 2005).

A portal is a web site that collects information concerning specific themes or topics, and facilitates access to related services and information sources. When using a portal, all case-related information is centralized in a case database that can only be obtained via a web

interface. The portal also has authentication and access control mechanisms that enable participants to access information according to user privileges. However, exchanging information among participants is more difficult in practice than it seems at first glance. For example, several different systems and standards are used to exchange information; peer-to-peer relationships among companies in the network are generally extremely difficult to manage, and most systems do not facilitate seamless information exchange with other systems. Furthermore, most participants are extremely reluctant to share information with other parties because paper-based information is difficult and inconvenient to share each other. Portals can resolve these problems. Standardized interactions with a single portal are easier to manage than numerous peer-to-peer relationships.

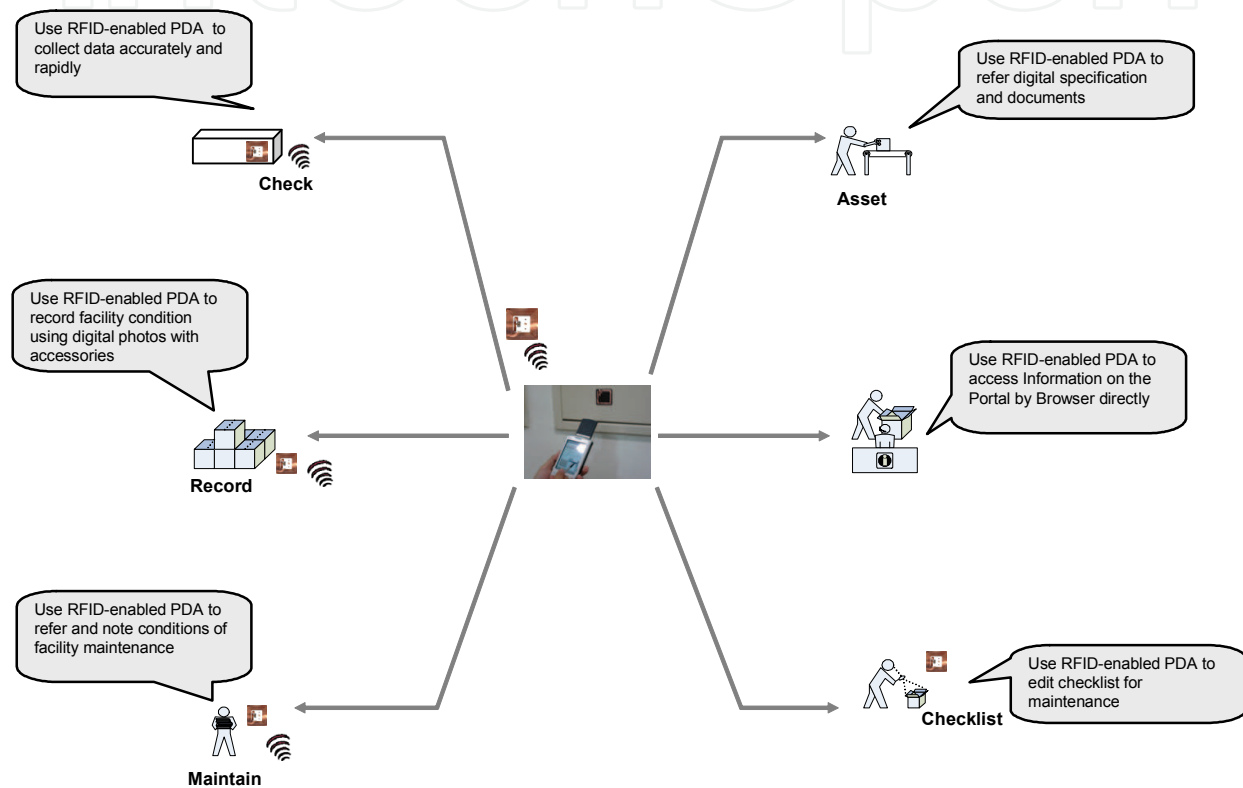


Fig. 2. Application of RFID-enabled PDA Used in Facility Management

5. System implementation

5.1 System architecture

The M-RFIDFM system has three main components, a PDA, RFID and a portal. Significantly, both the PDA and RFID components are located on the client side, while the portal is on the server side. All facility-related information acquired by facility staff members within the M-RFIDFM system is recorded in a centralized FM system database. All participants can access required information via the portal based on their access privileges. Moreover, the portal is limited by design to thirty persons logging in when all participants acquire the same case information at same time. The M-RFIDFM system extends the RFID-based facility management system from control offices to facility locations to assist with inspection and maintenance services, while the HubFM portal primarily deals with data transactions in all departments or systems integration within a facility management system.

When the data are updated on the server side, e-mails are automatically sent from the server to the facility managers of the management division and to participants involved in the relevant activity.

The M-RFIDFM system consists of an inspection and management portal integrated with mobile devices and RFID technology (RFID-enabled PDA). Each module is briefly described below.

Mobile Device (PDA) Module of M-RFIDFM System

The M-RFIDFM system is operated on Windows CE. The programming language and tools used in module development are Visual Basic and eMbedded Visual Tools. SQL Server for Windows CE serves as the PDA database for the Windows CE-based PDA. All data files in the PDA module are first stored in the PDA database, before being transmitted to the server through the Internet.

RFID Module of M-RFIDFM System

The Windows CE mobile device platform was chosen as the RFID-enabled PDA hardware system. The M-RFIDFM system adopts a Pocket PC with an MPR-1230 RFID Reader. The RFID technology can be either a passive or active system. The major difference between an active and a passive RFID system is that an active tag contains a battery, and can transmit information to the reader without the reader generating an electromagnetic field. The case study uses passive RFID technology due to budget restrictions.

Web Portal Module of M-RFIDFM System - HubFM Portal

The HubFM portal is an information hub in the M-RFIDFM system for a facility management. The HubFM portal enables all participants to log onto a single portal, and immediately obtain information required for planning. The portal provides suppliers and customers with information about the inventory levels of other portal users. The users can access different information and services via a single front-end on the Internet. For example, a customer can log onto the portal, enter an assigned security password, and access real-time inspection schedule information. A general contractor can check the test or inspection status, availability of reports and various other case-related data. The HubFM portal is based on the Microsoft Windows 2003 operating system with Internet Information Server (IIS) as the web server. The prototype was developed using Java Server Pages (JSP), which are easily combined with HTML and JavaScript technologies to transform an Internet browser into a user-friendly interface. The HubFM Portal provides a solution involving a single, unified database linked to all functional systems with different levels of access to information, based on user role, both within an organization and across organizations and other participants.

5.2 Modules of system functions

This section describes the implementation of each module in the RFID-enabled PDA system.

Test Report Module:

The report module provides facility staff members with a complete record of inspection and maintenance performed in the facility management. Facility staff members can record data for dates, conditions, inspection result, descriptions of problems and suggestions that have arisen during maintenance.

Inspection and Maintenance Module:

Facility staff members can download the most up-to-date maintenance results from the Internet, and enter maintenance results directly via a PDA. Additionally, PDAs display the checklist for every task. Facility staff members can also mark unacceptable positions, and

select relevant items from lists in the PDA. The module has the benefit that facility staff members can enter/edit inspection and maintenance test results, and all test records can be transferred between the PDA and portal by real-time synchronization, eliminating the need to enter the same data repeatedly.

Progress Monitor Module:

This module is designed to enable facility staff members to monitor the progress of inspections and tests. Additionally, managers, facility staff members and participants can access the progress or inspection condition of critical work. The progress monitor module provides an easily accessed and portable environment where facility staff members can trace and record all information regarding the status of inspections delivered to the maintenance or scheduled for repair.

E-specification Module:

This module allows facility staff members to download specifications in advance, and reference them during inspection. This module also has a search function that enables the information to be found and retrieved easily, which is a valuable feature in dynamic environments. Moreover, facility staff members who do not need paper-based specifications can download e-specifications and access them directly using their PDAs.

6. Case study

This study uses a factory building in Taiwan as the basis for the case study. This study utilizes an M-RFIDFM system in the facility management in Taiwan. Existing approaches for tracking and managing the inspection in facilities adopt manually updated paper-based records. However, information collected using such labor-intensive methods is unreliable and ineffective for tracking and managing maintenance results. The results of the inspection and maintenance results are generally obtained by telephone or fax. The inspection process is currently not easy to trace or monitor. The RFID-based facility inspection and management system is applied to enhance the effective management of facilities inspection and maintenance.

In the case study, facility management division and facility staff members utilized the M-RFIDFM system to enhance facility inspection and maintenance management. Passive read/write RFID tags (radio frequency of 13.56MHz) are used in the case study. Passwords are utilized to protect the data in the RFID tags. After the critical facilities are selected, an RFID tag for the facility is made, and the relevant information is entered into the system. The primary description in the case study is presented to elucidate the application of the maintenance using the RFID-enabled PDA and web portal.

In the initial phase, the facility staff members first discuss which facility will be maintained during special period under the facility management division. Following the facility is designed to be monitored for maintenance, the facility is scanned with a RFID tag to enter the portal information.

During the setup phase, the RFID will be prepared and entered the basic information brief regarding facility basic information and stores before it is delivered to the final location. Moreover, the facility staff member uses the PDA to scan the facility and enters the basic data of the facility. The data in the PDA is used to synchronously update the data/information to the portal, and the manager may understand that the facility has already been setup.

The staffs use RFID-enabled PDA to scan RFID tags and select the status when the facility is ready for use to the facility location. The data in the PDA synchronously update the data/information to the portal, and the facility management division is notified to update the status of the facility for starting use.

When this facility has been used in the facility location, the facility staff member scans the RFID tag to update the inspection/maintenance status. PDA displays the basic component and checklist information for each item. Facility staff member enters the result of inspection, edit the description in the PDA and provide the updated information to the portal. Meanwhile, the system automatically sends an alarm message to the facility manager in the facility management office to enter the portal and check the updated information.

Following the facility is inspection/maintenance in the facility location, the facility staff member must check facility quantity and quality, and then record the result via PDA. Finally, the facility tracking process will update the status to pass the test synchronously in the portal, and allows the facility manager or the authorized suppliers to check the process. Furthermore, the facility staff member utilizes PDA directly to write test data in to RFID tag. Once the facility component is ready to install following the maintained process, the facility with the RFID tag must be scanned again by facility staff member to update the information during the maintenance phase. Additionally, the updated information is updated and announced synchronously via the portal.

7. Field tests and results

Overall, the field test results indicate that passive RFID tags are effective tools for facility maintenance management. All tags survived use in the facility environment over one year testing period. The number of facilities for inspection and maintenance progress in field trials was about sixty two (two floors). The M-RFIDFM system was installed on main server in the facility management division. A user's guide of the M-RFIDFM system was briefly explained to staff involved in facility maintenance management progress.

During the field trials, verification and validation tests were performed to evaluate the system. The verification aims to evaluate whether the system operates correctly according to the design and specification; and validation evaluates the usefulness of the system. The verification test was carried out by checking whether the M-RFIDFM system can perform tasks as specified in the system analysis and design. The validation test was undertaken by asking selected case participators to use the system, and provide feedback by answering a questionnaire. The case participators consisted of two facility managers with 6 years of experience; four facility staff members with 4 years of experience, and three repair engineers with one year or less of experience in the case study. To evaluate system function and the level of system capability satisfaction, we distributed questionnaires, and the users of the system were asked to grade the conditions of system testing, system function, and system capability separately, compared with the typical paper-based maintenance method, on the five Likert scale. Some comments for future improvements of M-RFIDFM system were also obtained from the case participators through user satisfaction survey. Table 1 shows a comparison of the approximate time required for a typical facility maintenance service using a traditional paper-based inspection approach and the proposed system. The next section presents the detailed results of the performance evaluation and the user survey conducted during the field trials.

Item	Paper-based Approach		Proposed Approach	
	Method	Average Time (Min)	Method	Average Time (Min)
Find inspected related Information	Referring to inspection menu	1.9	Automatic selection	1.2
Input defect description	Referring to Inspected item and checklist	2.5	Use electronic forms	1.1
Check history record	Paper forms	2.2	Read information from RFID tag	0.1
Entry the problems	Describing and Sketching	3.2	Entry the PDA and store in RFID and system	0.1
Archive data	Re-entry at the office	8.1	Real-time Update database	0.2
Sharing defect information	Send the e-mail or by Fax	2.6	Accee the system directly and share information	0.8

Table 1. System Evaluation Result

The 88% obtained from user satisfaction survey indicates that the M-RFIDFM system is quite adaptable to the current facilities maintenance management practices, and is attractive to users. This result implies that the M-RFIDFM system was well designed, and could enhance the current time-consuming facilities maintenance process.

The 85 % obtained from facility staff members satisfaction survey indicates that the system automatically generated all documentation, and accumulated the related historical data in the central database server. The facility staff members could thus collect maintenance data, and send them electronically to the M-RFIDFM system. No additional work was required for any documentation or maintenance analysis after the data collection.

The advantages and disadvantages of M-RFIDFM system identified from the real case studies application are identified. However, 84% of users obtained from facility staff members satisfaction survey agree that the M-RFIDFM system is useful for improving the efficiency and effectiveness of automated data acquisition and information sharing in facility maintenance service, thus assisting facility managers and facility staff members in managing and monitoring the maintenance progress of facilities in the building. HF Passive tags are less expensive that active tags. Thus, HF passive tags are suited to facility maintenance management.

The use of RFID and web technology to collect and capture information significantly enhanced the efficiency of inspection and maintenance processes of facilities. The case study produced an overall read rate of 91% for the tags on the facility. RFID readers and tags are widely thought likely to improve in the future, thus bringing the read rate to an industrially acceptable level, and significantly improving the operation efficiency.

The tags adopted in this study cost under \$0.5 US dollars each in 2007. The cost of these tags is decreasing every year. The total cost of the equipment applied in this study was \$2650 US dollars (including RFID-enabled PDA reader and one server personal computer). Experimental results demonstrate that M-RFIDFM system can significantly enhance the maintenance progresses. The use of RFID reduces the amount of manual checking activities in the location area and the management area, thus significantly decreasing the overall maintenance operation time.

8. Conclusions

This study presents a mobile RFID-based facility management system that incorporates wireless technology and mobile devices to improve the efficiency and effectiveness of on

facility location data acquisition and information sharing among participants to assist managers in maintenance service. The M-RFIDFM system not only improves the acquisition of data on facility maintenance efficiency using RFID-enabled PDA, but also provides a monitor to service the facility maintenance progress. On the client side, Facility staff members use RFID-enabled PDAs to overcome time and space constraints, enabling them to seamlessly maintenance work processes at facility locations, owing to its accuracy and ability to capture data effectively. Plugging a RFID scanner into a PDA creates a powerful portable data collection tool. Additionally, RFID readings increase the accuracy and speed of information communication, indirectly enhancing performance and productivity. Meanwhile, on the server side, the HubFM portal offers a hub center to provide facility suppliers and facility management division with real-time updated property-related information and to monitor the service progress. In a case study, the application of the M-RFIDFM system helps to improve the process of inspection and maintenance work for the factory facilities in Taiwan. Based on experimental result, this study demonstrated that passive RFID technology has significant potential to enhance inspection and maintenance work in facility management. The integration of real-time maintenance information from facility supplier helps managers to track and control the whole facility management in inspection and maintenance progress. Furthermore, the facility supplier can update the service progress in real time to arrange all services. Real-time feedback on the status of maintenance progress in facility management is provided to management division so process steps can be re-sequenced as required. Compared with current methods, communication of information/data on the facility management can be enhanced by using RFID and Web technologies, and the information sharing among participants can be accelerated and made more efficient via the portal technology.

9. Recommendations

The case study findings indicate that the RFID technology and mobile devices are useful tools to enhance the progress of inspection and maintenance works. Recommendations for implementing the proposed system in the future are given below.

- Cost is a currently significant factor limiting the widespread use of RFID tags in the construction industry. Passive tags are cheaper than active tags. Additionally, most passive tags have small data storage capabilities, thereby decreasing the cost of chips and motherboards. Therefore, passive tags are suited to the facility management.
- The high data storage capabilities will be considered and suggested for use in facility management in the future to carry complete the maintenance information in the facility.
- If the RFID tag needs to place the interface of the metal facilities, the RFID tag should be using the special designed tag that can avoid influence by metal facilities.
- It is necessary to consider the usage time and reading distance of RFID tags. Currently, the average of longest time regarding to RFID tags is ten year. Therefore, if the facility need to track over ten years then the RFID tag should be attached to replace easily and workable.
- This study has indicated that RFID devices are more useful than barcodes, because they can carry information. However, most of tags can't carry all maintenance data because of the capacity of tag data.

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This book addresses several issues related to the introduction of automaton and robotics in the construction industry in a collection of 23 chapters. The chapters are grouped in 3 main sections according to the theme or the type of technology they treat. Section I is dedicated to describe and analyse the main research challenges of Robotics and Automation in Construction (RAC). The second section consists of 12 chapters and is dedicated to the technologies and new developments employed to automate processes in the construction industry. Among these we have examples of ICT technologies used for purposes such as construction visualisation systems, added value management systems, construction materials and elements tracking using multiple IDs devices. This section also deals with Sensorial Systems and software used in the construction to improve the performances of machines such as cranes, and in improving Human-Machine Interfaces (MMI). Authors adopted Mixed and Augmented Reality in the MMI to ease the construction operations. Section III is dedicated to describe case studies of RAC and comprises 8 chapters. Among the eight chapters the section presents a robotic excavator and a semi-automated façade cleaning system. The section also presents work dedicated to enhancing the force of the workers in construction through the use of Robotic-powered exoskeletons and body joint-adapted assistive units, which allow the handling of greater loads.

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