Enhancing Building Maintenance Using RFID Technology

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Abstract

Information technology applications have proven effective in the maintenance of constructed facilities. The objective of the study is to enhance building maintenance using Radio Frequency Identification (RFID) technology. A data management module is first developed to collect building usage and maintenance data. A statistical module is then established to graphically display the collected data. To ensure that building functions perform normally, maintenance activities are arranged using a scheduling module. These three modules are integrated into a web-based RFID building maintenance system. System performance is validated using a real building. Experimental results show that integrating RFID technology with a web-based system, database, and scheduling theory can improve facility and equipment maintenance efficiency.

Keywords: Facilities Management, Radio Frequency Identification (RFID) Technology, Scheduling, Web-Based Management Information System.

Introduction

Deconstructing old buildings requires tremendous cost, including deconstruction works and waste disposal. One of the ways to extend the life of constructed facilities is to maintain them with corresponding maintenance systems (Barco, 1994; Djerdjouri, 2005). Radio Frequency Identification (RFID) technology is one of the most important technologies developed in the last century, characterizing repetitive read/rewrite, non-contact, and the ability to access multiple tags simultaneously (Hunt et al., 2007). This has been regarded as a promising method to improve maintenance efficiency (Fontelera, 2005; Ko, 2009).

RFID has been widely used in various kinds of applications, such as library book management, warehouse management, asset tracking, and security control (Ngai & Riggins, 2008). A few studies can be found in facility and equipment management. Strassner and Chang (2003) applied RFID technology to collect data on oil drilling pipes. They monitored pipe usage and provided the collected information for inventory control. These researchers found that applying RFID in drill pipe management greatly reduced oil drilling operating costs. Cardellino and Finch (2006) examined innovations in facilities management. They pinpointed that RFID is a promising information technology (IT) in the field. Wing (2006) investigated RFID technology applications in construction and facilities management. A case study discussed in the paper collected data using RFID tags and passed information through the Internet.

The objective of this study is to develop a web-based RFID building maintenance system to enhance maintenance efficiency. To achieve this goal, RFID technology is

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investigated first. The RFID and bar code system properties are discussed. Three modules, namely data management, statistical, and scheduling modules are established according to the building maintenance needs. The efficiency of the proposed system is examined using a real case. Application results and conclusions are documented in this paper.

Radio Frequency Identification (RFID) Technology

RFID technology is a wireless sensor technology based on electromagnetic signal detection (McCarthy et al., 2003). One of the earliest papers exploring RFID was written by Harry Stockman ''Communication by Means of Reflected Power'' published in 1948 (Stockman, 1948). This came after radio research undertaken during the Second World War. Today RFID is a generic term for technologies that use radio waves to automatically identify people or objects.

A typical RFID system, as shown in Figure 1, is comprised of three components: an antenna, a transceiver, and a transponder. Figure 1 shows that the transponder (RF tag) is electronically programmed with unique information. Radio signals are emitted by the transceiver through the antenna. Antennas establish communication between the tag and transceiver. The RF tag is activated and data on it are read and written by the requested signals sent from the antenna. The RF tag transfers data according to a specific request. The transceiver is responsible for data acquisition. The data can then be transferred to any computer system for processing (Domdouzis, 2007). The antenna can be packaged with the transceiver into a reader/writer unit. The reader/writer can be implemented either as a handheld or fixed-mount device. The radio wave ranges emitted from the device depends on the power output and radio frequency.

Bar codes have been the most frequently used system for facilities management (Bravman, 1987; Terez, 1992). In a bar code system, labels must be so positioned that they can be detected and identified by a laser scanner. Objects that obstruct the optical communication between the label and scanner interrupt barcode scanning. Besides the physical limitations, bar code labels usually have generous dimensions. Unlike bar codes, RFID technology can dynamically transmit and receive information to help identify objects without "line-of-sight." Information stored in the tag can be modified, which provides flexibility for managerial modification. Information Technology (IT) in the form of RFID is thus regarded as a resource that can be applied in overcoming the problems associated with traditional solutions (alphanumerical codes and bar code labels) (Regattieri et al., 2007).

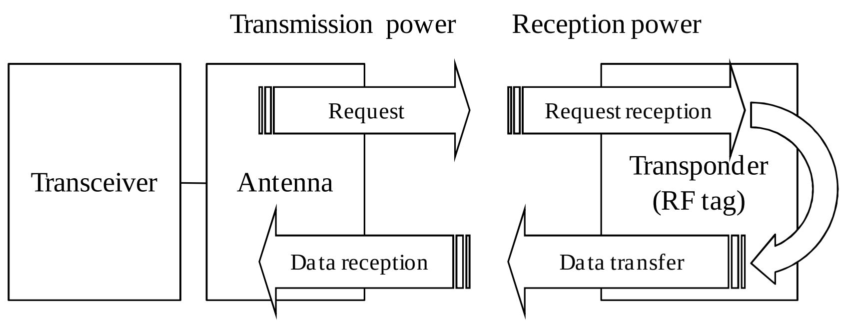

Figure 1. Typical RFID System.

System Development

Application Scenario and Requirements

RFID technology is employed to improve the efficiency of traditional building maintenance solutions. The first step in system development is the scenario design. The maintenance staff carries a tablet PC while executing maintenance activities. A portable RFID reader/writer is attached to the tablet PC. The staff can implement maintenance jobs using a web-based application through an Internet browser. Using the web-based software, staff can read/write information from/into tags. Information related to maintenance jobs are accessed from a single database through the Internet in real-time. As a result, multiple users can maintain various kinds of objects at the same time. To further improve working efficiency, staff can setup maintenance periods for each item. The software can remind users about which items require attention and automatically arrange maintenance sequences. Maintenance preparation and effort can therefore be reduced. Three modules i.e. management, statistical, and scheduling are obtained according to this scenario.

System Development Process

The web-based RFID building management system development process is illustrated in Figure 2. Each activity is explained as follows.

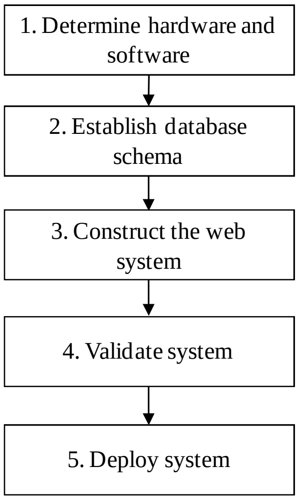

Figure 2. System Development Process.

1. Determine hardware and software: System hardware and software that conform to application requirements are investigated in the first step. ASP.NET is chosen as the development platform to establish the web-based application. ASP.NET is a new technology developed by Microsoft. It supports browsers that execute on various kinds of platforms including personal computer, cell phone, personal digital assistant (PDA) etc. A portable RFID reader/writer, namely UHF-Block, manufactured by Ensyc Technology is selected. This device is compatible with the GEN2 protocol and can be connected using USB interface. Figure 3 represents devices for the staff to implement maintenance work. The system hardware and software used for system development are summarized as follows:

   - Web and database server: Dell enterprise personal computer.
   - Integrated development environment: Visual Studio.NET (C#.NET).
   - Operation system: Windows XP professional.

- Database format: Microsoft Access.
- Tablet PC: HP 2710P.
- RFID device: UHF-Block.
- RFID tag: UHF G2.

Figure 3. Maintenance Kit.

2. Establish database schema: Building maintenance induces numerous records. For managerial convenience, information is stored in a single database. The database is designed using third normal form of the relational model (Codd 1990). The simplified database schema is represented using class diagram depicted in Figure 4.
3. Construct the web system: This web-based system is programmed using C#.NET and transferred through Http/Https protocols.
4. Validate system: System applicability is validated using a real case.

Deploy system: The developed web system is implemented in a real building.

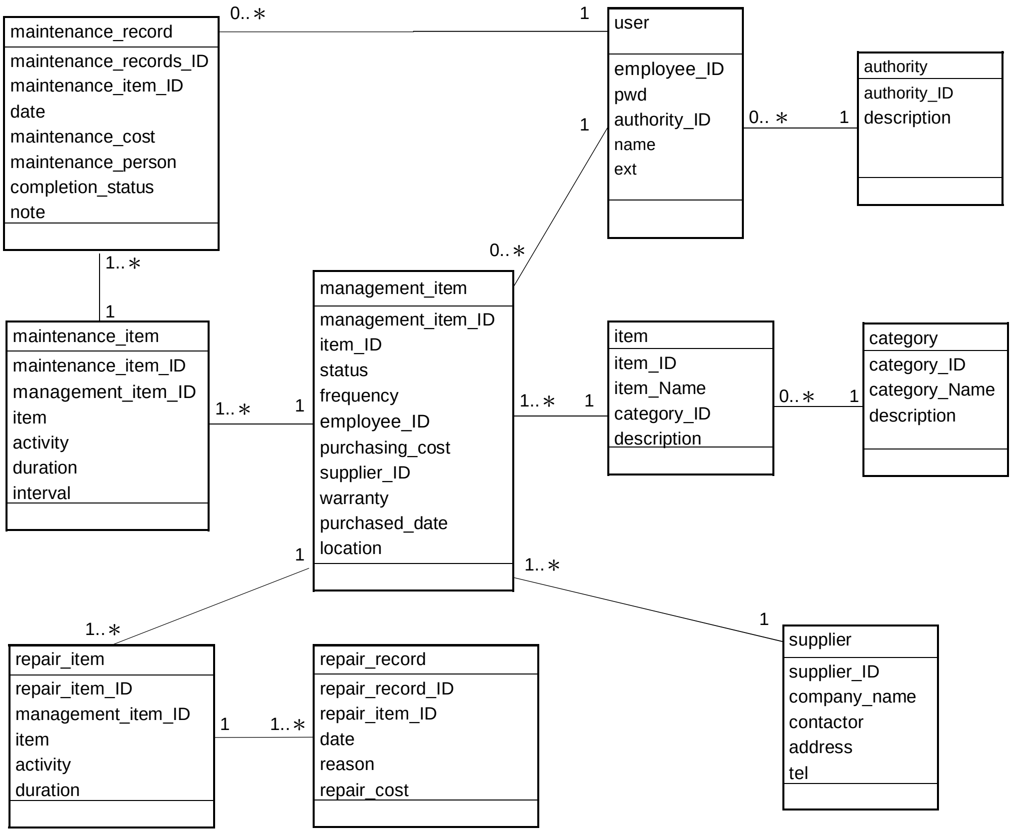

Figure 4. Database Schema.

Data Management Module

The data management module is designed to allow manipulating the data stored in the system database. Functions provided by this module are summarized in Table 1. A maintenance object contains the following information: category, item, name, safety degree, durability, frequency of use, purchasing cost, purchasing date, part list, warranty period, seller, holder, location, etc. Users can fill out the information by entering values or selecting a proper description from a list. Each object is identified using RFID code that is a unique identification number written onto the RFID tag. The RFID code structure is shown in Figure 5. The codification is designed for building maintenance using four sections. The first section, category, is used to store equipment or facility. The second item stores types of equipment or facility, such as universal test machine and electron microscope. Third part involving four cells is used to store serial number. The final area is designed for future extension. RFID code is automatically generated by the module and can be written onto a tag using the RFID device.

Table 1. Functions of Data Management Module

Function	Explanation
Login	Users enter username and password to log onto the web-based system. Two kinds of authorization are provided in the system: manager and administrator.
Manage user	Only administrative users can add/edit/remove system users.
Manage category	Users can add/edit/remove categories that are served as the highest level of maintenance object classification.
Manage item	Users can add/edit/remove items that are served as the second level of maintenance object classification.
Manage parts	Users can add/edit/remove parts for each maintenance item.
Manage object	Users can add/edit/remove a maintenance object and generate its RFID code.
Manage space	Users can add/edit/remove a space for maintenance object.
View history	Users can view maintenance record history for each object. Object can be identified using a RFID reader.
Manage seller	Users can add/edit/remove the seller information for maintenance objects.

1	2	3	4	5	6	7	8	9	10	11	12
Category		Item			Serial number				Extension		

Figure 5. RFID Codification Structure.

For searching for information about a specific maintenance object, users can query by its category, name, RFID code, or identify it using RFID device. The main form of data management module is shown in Figure 6.

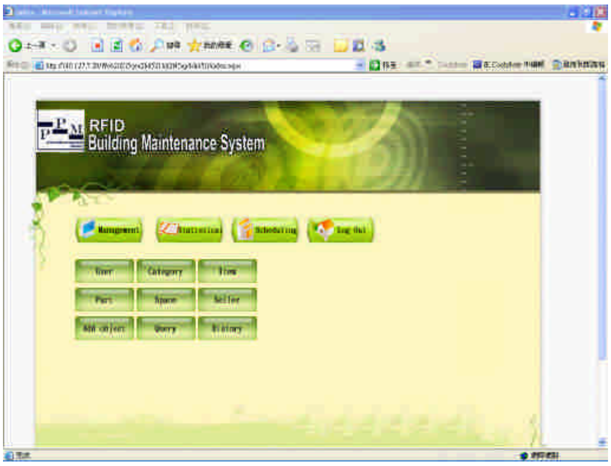

Figure 6. Main Form of Data Management Module.

Statistical Module

This study collected numerous data while implementing maintenance jobs stored in the system database. However, this data row is meaningless to users. The objective of the module is to represent the system database using statistical charts allowing users to understand the data distribution and properties. This module provides four charts for users to observe the data, i.e. circle graph, ogive, bar chart and line chart.

Statistical graphs can help users understand maintenance status. A recommendation table is proposed to assist users making decisions according to the graphs, as explained in Table 2. An example of demonstrating purchasing costs using line chart is depicted in Figure 7.

Table 2. Decision Support for Statistical Graph

Statistical group	**Decision support**
Maintenance object amount	Number of objects located in an individual space can be identified. Therefore, users can understand the status of maintenance objects such as missing and broken.
Repair frequency	According to the graphs, users can recognize the durability of maintenance objects. The information can be fed back to the procurement department, repair partners, and property holder for preventive analysis.
Repair cost	The information can be used to determine whether the maintenance objects should be replaced or not. The procumbent department can also use the information as purchasing reference.
Object life time	Maintenance efficiency effects life time of property. It can also be used as another index for property durability.
Breakdown causes	Graphs about breakdown causes are ideal for breakdown causes analysis. The information can be used for troubleshooting.

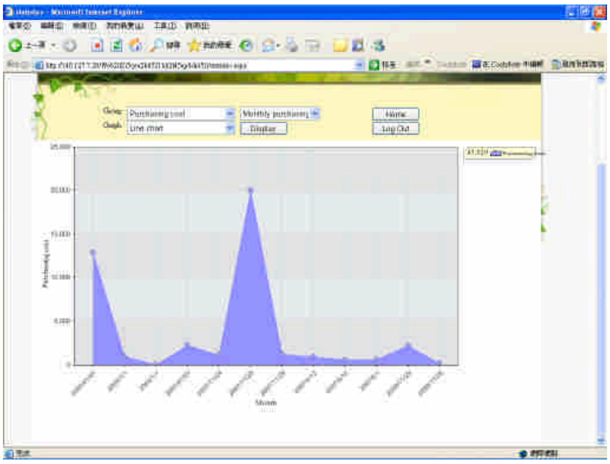

Figure 7. Line Chart of Purchasing Costs.

Scheduling Module

Scheduling involves tasks of making decisions regarding the allocation of available capacity or resources to jobs, activities, tasks, or customers over time. It thus results what is to be done, when, by whom, and with what equipment (Ko & Wang, 2007).

Building functions rely on periodic maintenance. Parts wearing out can induce malfunctions. Worn out parts can be identified and replaced by regular maintenance. However, diverse maintenance objects involve various kinds of parts, which increase the maintenance complexity. A proper maintenance schedule is thus needed to effectively accomplish jobs.

The scheduling module developed in this study focuses on arranging maintenance sequences. Two strategies are proposed to enhance maintenance efficiency:

- Centralize maintenance time: The first strategy enhances maintenance efficiency by reducing preparation time. This strategy avoids frequent maintenance with small batch jobs. It schedules the time for carrying out maintenance activities, such as once a week, once every two weeks, once a month, or even daily maintenance. This schedule can be assigned by users. The logic for determining which object should be added to the maintenance list is expressed in Eq. (1).

$$\text{If } L_i \geq -T, \text{add } i \text{ in the list} \qquad (1)$$

L_i : Time difference ($D_i - C_i$) between the time point the object i should be maintained (C_i) and when it is planned to be maintained (D_i).

T : Extended maintenance period, which can be an arbitrary time. The value is determined according to managerial requirements such as national holidays, man power, complexity of maintenance work, etc.

Minimize the required maintenance hours: To accomplish maintenance activities using the most effective way, the module minimizes the total maintenance time.

- Scheduling methods can be divided into three categories. Mathematical programming is primarily used to solve certain problems. If the problem is difficult to solve, dispatching rules can be considered. However, dispatching rules arrange sequences using certain principles that cannot obtain an optimum solution for complex problems. Heuristic algorithms are adopted for difficult, complex, and uncertain problems. Although heuristic methods cannot guarantee obtaining the optimum solution, they provide satisfactory results within an acceptable time period. Maintenance scheduling is regarded as a job shop sequencing problem that can be solved using a mathematical programming method. The objective function of the scheduling module, shown in Eq. (2), is to minimize total maintenance time t.

$$Min\ \ t = \sum_{j=1}^{m}[\sum_{i=1}^{n}(\alpha_i + \beta_i) + \gamma_j] \qquad (2)$$

α_i : Maintenance time for object i .

β_i : Transportation time from object $(i-1)$ to i . The $\beta_i = 0$ when $i = 1$.

γ_j : Transportation time from space $(j-1)$ to j . The $\gamma_j = 0$ when $j = 1$.

The RFID building management software developed in the study is a web-based system connecting with a single database. Therefore, the system is running in real-time and the information provided by the system is up-to-date. This advantage also enables multiple users to implement maintenance jobs at the same time. The maintenance direction suggested by this study is depicted in Figure 8. A single staff member can implement maintenance work using a top-down or bottom-up approach (as shown in Figure 8). For two staff members, one can implement in the top-down direction and the other bottom-up. For more than two staff members, the two staff member case is carried out and the additional staff members implement maintenance work from intermediate positions. The module reminds users to take cautious attention to the work if the job is related to safety considerations. The scheduling module setup form is shown in Figure 9.

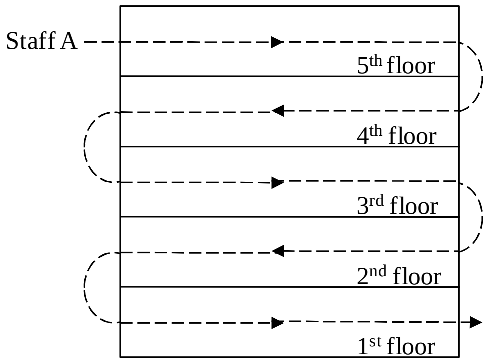

Figure 8. Maintenance Direction.

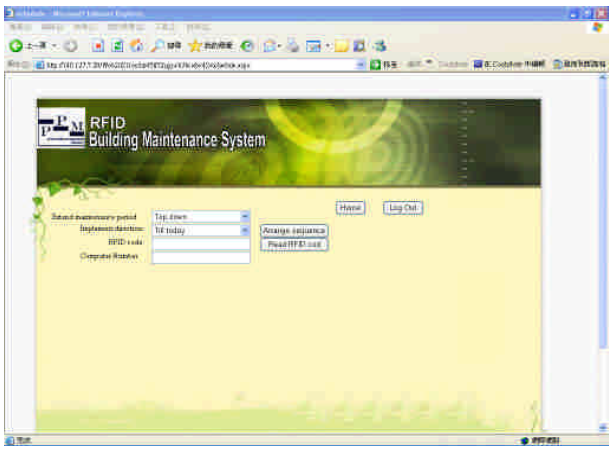

Figure 9. Scheduling Module.

Application

Prior to using the developed system, building managers should know the basic concepts about RFID and web-based system. Maintenance jobs were carried out by two staff members at the test center. User name, password, and authority were identified first in the system. RFID codes were automatically generated by the data management module according to codification grammar. Staff members then enter equipment and facility information with corresponding RFID codes. When staff members complete the web form, the generated RFID code is written onto the RFID tag. The system automatically confirms the writing success. Facility and equipment are available in the system once the data passes confirmation. Staff members can then begin manipulating object data.

The scheduling module was launched to automatically arrange maintenance sequences. Staff members then select items and fill in the maintenance records in the form. The two staff mode was adopted when executing maintenance jobs. For this case study, one staff member selected the top-down sequence and the other chose the bottom-up maintenance direction. Items disappeared from the form once they were completed. Incomplete tasks remained on the form for further scheduling. Because the system accesses the database in real-time, members have up-to-date information shown on the form. Maintenance records and equipment/facility information can be queried using the statistical module.

The current practice that arranges maintenance sequences by hand is time-consuming. In addition, the identified sequence may be subject to an additional optimization effort. The proposed maintenance can automatically arrange maintenance sequences and enable multiple users to implement maintenance work at the same time. Therefore, personnel costs and maintenance makespan can be handled.

Conclusions

This paper presented a web-based RFID building maintenance system. Three modules were included, i.e., data management, statistical, and scheduling. Users implement maintenance work using tablet PCs attached with portable RFID devices. The proposed system performance was examined using a material test center.

The following benefits of applying RFID technology in building maintenance are drawn from real applications: 1) automatically identifying equipment and facility ID avoids typos and saves operational time, 2) data stored in RFID tags can be easily modified, 3) non-contact and non-line-of-sight RFID technology enhances maintenance convenience, 4) RFID tags can be used under practical challenging conditions such as paint, grime, and dust, and 5) RFID technology cooperates extensively with other information technologies.

The developed web-based RFID system is one of the first researches integrating RFID technology, database, Internet technology, and scheduling theory in building maintenance. The proposed scheduling module is also one of the pioneering works applying scheduling theory in RFID applications. This system operates depending on Internet communication. Further deployment may improve this system using an offline web application.

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