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Integrating RFID, web-based technology, and artificial intelligence in engineering management

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Abstract. Radio frequency identification (RFID) technology is emerging as an important technology for improving management efficiency. Web-Based Systems (WBS) are particularly useful for managing operations spread over multiple locations. Artificial Intelligence (AI) can be used to process uncertain and incomplete information which inevitably occurs in the real world. This study aims to enhance managerial efficiency through the integration of RFID, web-based technologies, and artificial intelligence. RFID is primarily used to identify managerial objects, while web-based technology is used for data management, and AI is used to analyze the collected data. A real case is used to validate the applicability of the proposed method. Experimental results show that the integration of RFID, web-based systems, and AI can be effectively applied in a practical environment. The proposed method can improve managerial efficiency, data transfer, data quality, and service process time. This study is one of the first to investigate the integration of RFID technology with web-based technology and AI.

1. Introduction

Radio frequency identification (RFID) technology is characterized by repetitive read/rewrite, non-contact access to multiple tags. In recent years, RFID has emerged as a key technology for management systems [1-6], and its application has been the subject of many studies. Cardellino and Finch [7] surveyed innovations in facilities management and recommended RFID as having promise in the field. Wing [8] investigated RFID technology applications in construction management, presenting a case study in which RFID tags were used to collect data which was then passed through the Internet to supervisors. The location and status of equipment can also be controlled within a building by RFID tags. Legner and Thiesse [9] applied the technology to maintenance at Frankfurt Airport by integrating RFID and a mobile application with the airport's asset management systems. Ergen et al. [10] used RFID to overcome difficulties encountered in facilities maintenance, and thus removed restrictions on data transfer between maintenance workers. Ko [11] proposed a positioning algorithm using a passive location schema to allocate objects using RFID. The developed location sensing algorithm is able to identify the actual location of the target tags by iterative revisions to reduce positioning error.

A Web-Based System (WBS) is a software application that can be executed on web pages through the Internet [12,13]. A WBS can be accessed from anywhere, which is particularly useful for operations spread over multiple locations [14,15]. This advantage has led to web-based systems being widely applied in diverse areas such as resource planning, education, medicine and environmental management [16-19].

Artificial Intelligence (AI) is concerned with building computer systems that solve problems intel-

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ligently by emulating human behavior [20,21]. AI technology provides techniques allowing computer programs to carry out a variety of tasks which are currently better performed by humans. Computer systems can store huge amounts of data and run computations free of subjectivity [22], allowing AI to serve as an alternative approach to deal with decision-making problems [23]. AI is frequently used to solve complex, uncertain and incomplete problems such as Li and Shi's [24] use of artificial neural networks for weather forecasting. To minimize production costs, Taleizadeh et al. [25] optimized multiproduct multi-constraint inventory control systems using genetic algorithms. Ke and Liu [26] used Fuzzy Logic (FL) to allocate resources required by project schedules so as to balance total costs and completion time.

RFID technology, WBSs, and AI are complementary rather than competitive. Engineering management frequently entails simultaneously dealing with a large number of managerial tasks. A method that provides efficient and robust object identification can be very helpful for achieving management purposes. Managerial operations require continuous retrieval of large amounts of data, and enabling the retrieval and analysis of such data from diverse locations in real time would provide significant benefits to managers. Although previous studies have explored the promise of applying these three technologies for problem solving, little research has been devoted to the development of a comprehensive system for their integration. The primary objective of this study is to integrate RFID, web-based technologies and AI to enhance managerial efficiency. This study presents an investigation of RFID technology, WBS, and Fuzzy Neural Networks (FNNs), followed by an explanation of the research methodology used and the integration framework. The efficiency of the proposed system is examined using a real-life maintenance problem, documenting application results and presenting conclusions.

2. Background

2.1. Radio frequency identification technology

RFID is a wireless sensor technology first proposed by Stockman [27] to identify useful applications for "reflected-power communication." One of the first large-scale commercial uses was documented in the 1990s in electronic toll collection on US highways in Texas, Oklahoma, and Georgia [28]. Since then, RFID has been used across multiple industries and has continued to advance in functionality and capability. Today RFID is a generic term for technologies that use radio waves to automatically identify people or objects.

As shown in Figure 1, a typical RFID system consists of three parts: an antenna, a transceiver, and a transponder. In the figure, radio signals are emitted by the transceiver through the antenna. The transponder (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 request sent from transceiver. The transceiver is responsible for acquiring data from signals returned from the transponder. The data can consequently be transferred to any computer system for processing [3]. The antenna can be packaged with the transceiver as a compact reader/writer which can be implemented either as a mobile or a fixed-mount device. The range of radio waves emitted from the device depends on its power output and the radio frequency used.

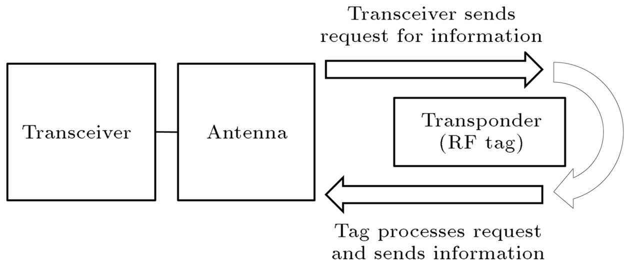

Figure 1. RFID system.

Unlike barcodes, RFID technology can dynamically transmit and receive information to help identify objects without "line-of-sight". Information stored in the tag can be modified, providing flexibility for managerial modification. Information Technology (IT) using RFID can be applied to overcome the problems which limit traditional solutions (e.g., alphanumeric codes and barcode labels) [29].

2.2. Web-Based Systems (WBSs)

WBS architecture typically consists of three tiers, as shown in Figure 2 [30]. The storage tier is used for storing system data. Data collected during managerial operation period are stored in the database. The application logic involves system modules and database connections. RFID software applications and database management information system function in the layer. The presentation tier is used to interact with the application logic layer, which includes graphical interfaces.

Figure 3 shows how computational efficiency is driven by web and database servers. Web system functions are programmed and transferred through http/https protocols. The system inputs and outputs are stored in the database. Users can implement system functions through their browser. Under this architecture, multiple users can simultaneously and remotely interact with the system through the internet.

2.3. Fuzzy Neural Networks (FNNs)

One of the most popular AI paradigms, an FNN, is the integration of FL with artificial neural networks [31,32]. FL was first developed by Zadeh in the 1960s to

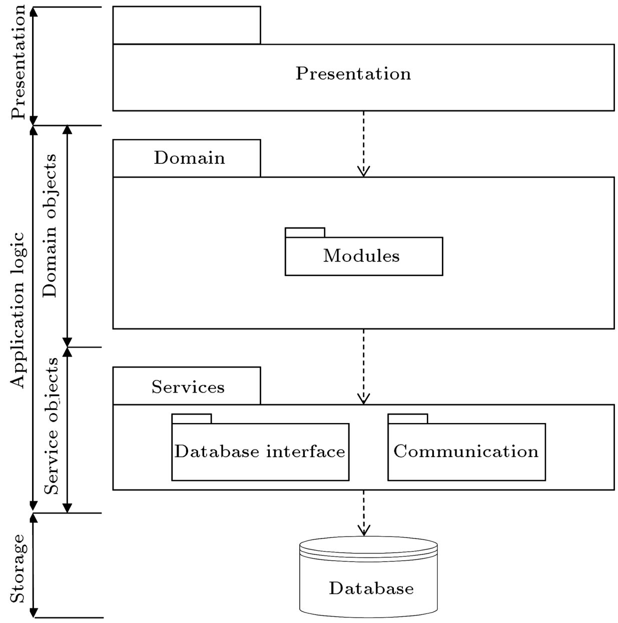

Figure 2. Web-based system conceptual architecture.

represent uncertain and imprecise information [33]. In a broad sense, FL is synonymous with fuzzy set theory, that is, the theory of classes with unclear boundaries. In a narrow sense, FL is a logic system intended to serve as approximate reasoning [34]. Fuzzy Logic Systems (FLSs) simulate the process of high level human decision making, and aims to model imprecise modes of reasoning to make rational decisions in an environment of uncertainty and imprecision. As shown in Figure 4, FLSs generally contain four major components: the fuzzifier, the inference engine, the rule base and the defuzzifier [35].

The artificial neural network concept originated from work modeling the brain in the 1950s. Artificial neural networks are massively parallel distributed processors made up of simple processing units (neurons), which perform computations and store information [22]. Modeling functions of the brain provides an alternative approach to conventional methods. As shown in Figure 5, a typical multi-layer feed-forward network consists of three types of layers: input layer, hidden layers, and an output layer. Combining FL and neural networks into an integrated model has promised in the development of intelligent models capable of recreating qualities which characterize the human brain [36].

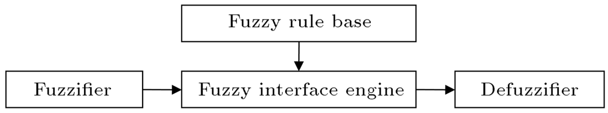

Figure 4. Fuzzy logic systems.

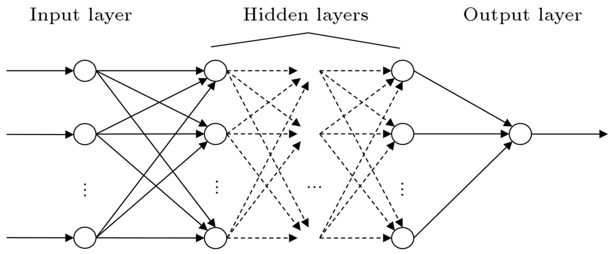

Figure 5. Multi-layer feed forward networks.

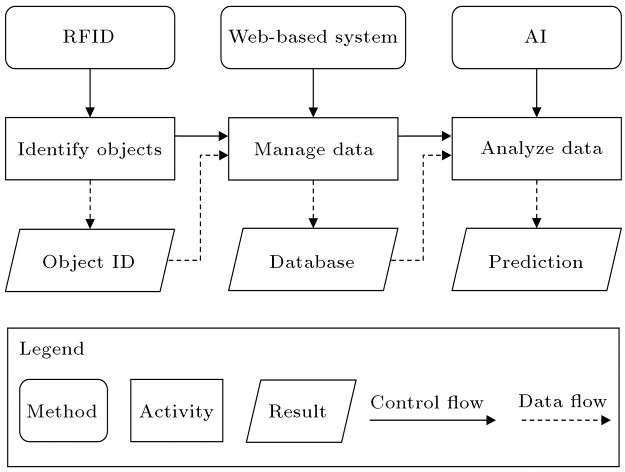

Figure 6. Integration structure.

3. Research methodology

The objective of this study is to enhance managerial efficiency by integrating RFID, web-based technologies and AI. The methodology used to integrate these three technologies is shown in Figure 6. RFID technology uses waves to automatically identify objects. This characteristic allows for the transmission and reception of information without "line-of-sight", providing advantages such as allowing rapid, multiple scanning at a distance [11]. Low-cost passive RFID tags typically have a limited memory capacity but, from a managerial perspective, the identified objects may contain significant amounts of related information which cannot be completely stored in the RF tags. One way to solve

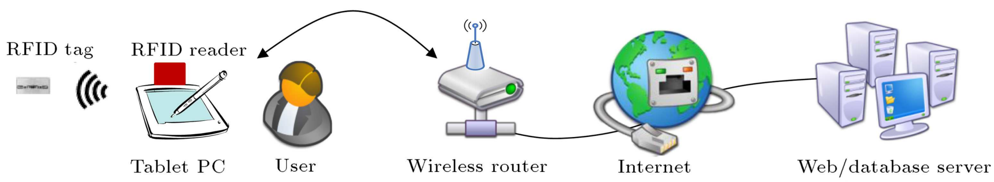

Figure 3. Web-based system application architecture.

this problem is to store object data in the database and provide a linkage between database and the tag. WBSs provide a platform through which data can be managed from multiple locations. Platform integration enhances managerial efficiency through the remote and automatic connection of object ID and related information. The row data linked with object ID stored in the database frequently reveals trends related to the application [37]. AI techniques can capture complex inputs and out mappings, and is thus adopted here to analyze the row data. The proposed method integrates RFID, web-based technology and AI to provide a framework to capture, manage and analyze data. The integration of these three methods has the potential to enhance managerial efficiency.

4. Identifying objects

This research uses RFID technology to identify objects. Portable RFID (read/write) devices are adapted for mobility and managerial purposes. RFID devices are chosen according to weight, transmission power, size, interface, price, and frequency range. Mobile devices require light weight and small size, while transmission power and frequency range are key to optimizing scanning distance; interface control is a key concern in determining appropriate software development tools, and price is considered as part of the deployment cost. Numerous RFID devices can be found in the market, but the list can be narrowed down to a few candidates according to the following conditions: Ultra High Frequency (UHF), light weight, small size, Universal Serial Bus (USB) connection, Visual Basic. NET programmable, PC compatible, and low cost. Ultimately, the Ensyc RFID Block was selected, along with Gen 2 passive RFID tags with the corresponding communications protocol. Active RFID tags were excluded from the current application due to economic considerations. Figure 7 shows the selected RFID hardware. The devices can be controlled using programming languages, such as C, C# and Visual Basic.NET. Specifications of the selected device are summarized as follows:

- RF output frequency range: 860 Mhz - 960 MHz;
- Power supply: USB;
- Dimensions: 114.3 × 114.3 × 50.8 mm;
- Weight: 220 g;
- Communications protocols: EPC Class1 GEN1 and GEN2;
- Software development kit: Visual Basic.NET;
- Tag size: 94.9 × 7.9 mm;
- Tag protocol: GEN2.

(a) RF tag

(b) RF transceiver/transponder

Figure 7. Selected RFID hardware.

The selected RFID device, Ensyc RFID Block, is attached to a tablet PC by USB, as shown in Figure 6. Ensyc RFID Block is used to read from and write to the RFID tag. The Wi-Fi enabled tablet PC then transmits the tag information to the database server through the internet. The process of sending and receiving data between the RFID tag and the Visual Basic.NET project solution is shown in Figure 8. The program integrates an "RFIDBlock" class developed by the RFID manufacturer to control RFID Block Reader. A public class "Reader" is declared to enumerate reader commands. "MyReader" is defined as a Reader. To access the database server, a visual Basic.NET component "SqlClient.SqlConnection" is used to specify the data source and security settings. RFID tag information is read using the "ReadTag()" method defined in the Class "Reader." Tag information can also be written using the "writeTag()" method. Finally, the read/written information can be updated in the database.

5. Managing data

A web-based application is designed to provide database management access to multiple users. As the development platform, we recommend ASP.NET, a technology developed by Microsoft, which can integrate

```
Imports RFIDBlock                                            'Import the Class to control RFID Block Reader
Public Class Reader                                          'Enumerate reader commands
Dim MyReader As Reader                                       'Declare MyReader as a RFID Reader
Dim MyConnection As New SqlClient.SqlConnection              'Declare MyConnection as a database connection string
Dim RFIDCode As Integer                                      'Declare RFID code is an integer

MyConnection.ConnectionString( )="data source and security"  'Connect to database

RFIDCode = MyReader.ReadTag( )                               'Read information from RFID tag

MyReader.writeTag(RFIDCode)                                  'Write information into RFID tag

UpdateInfo( )                                                'Update database
```

Figure 8. Pseudocode for data transmission between RFID and visual basic.NET.

the selected RFID hardware with web application. It supports multiple platforms including the personal computers, cell phones, Personal Digital Assistants (PDAs) and Palm devices. Users can thus manipulate the developed systems using these devices. The integrated WBS may include application modules. The system allows users to manipulate data stored in the system database. Information related to the managerial objects can be queried by entering values or selecting from a list provided by the system. The integrated WBS should be able to generate RFID codes and write them onto tags using the RFID device. When searching for information about a specific object, users can pose queries using the item category, name or RFID code, or can directly identify it using the RFID reader.

The system collects considerable amounts of data while implementing managerial jobs. Statistical tools could help users understand the distribution and properties of the data. Statistical charts, such as circle graph, ogive, bar chart, and line chart could be used to represent the system database.

6. Analyzing data

An FNN is used to analyze the row data, and FL is used to represent the uncertain information and execute approximate reasoning. Artificial neural networks are used to represent fuzzy rules. Complex relationships between inputs (influencing factors) and output (equipment lifetime) are identified through learning algorithms. The FNN architecture used in the prediction module is comprised of four layers, as shown in Figure 9. Each layer is explained as follows.

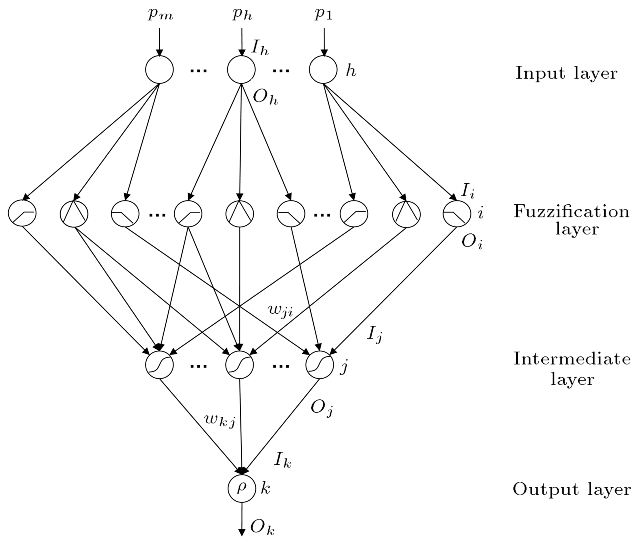

Figure 9. Fuzzy neural network architecture.

1. Input layer: The first layer is an input layer that receives the input data features and distributes them to the next layer (fuzzification layer). This layer contains m nodes corresponding to m influencing factors. As shown in Figure 5, each input neuron distributes an input value to its membership functions. The inputs of nodes h and I_h are crisp inputs as formulated in Eq. (1). The outputs of nodes h and O_h are formulated in Eq. (2):

$$I_h = p_h, \tag{1}$$

$$O_h = I_h. \tag{2}$$

2. Fuzzification layer: This layer converts crisp inputs into fuzzy values using membership functions. This layer has n nodes that can be divided into m groups (input variables). Each node represents a membership function. The input of nodes i and I_i, is expressed in Eq. (3). In the equation, each fuzzification neuron connects with a single input neuron. The output of nodes i and O_i can be expressed using Eq. (4). The notation $\psi(\bullet)$ represents a membership function.

$$I_i = O_h, \tag{3}$$

$$O_i = \psi(I_i). \tag{4}$$

3. Intermediate layer: Neurons at the intermediate layer process the fan-in signals and then perform an activation function (noted as $\varphi(\bullet)$). The non-linear

mapping between the input and output layers is handled primarily in this layer. The input for nodes j and I_j is formulated in Eq. (5). The output for nodes j and O_j is formulated using Eq. (6):

$$I_j = \sum_{i=1}^{n} w_{ji} O_i, \tag{5}$$

$$O_j = \varphi(I_j). \tag{6}$$

4. Output layer: The output layer processes the fan-in signals and produces outputs. Because the prediction module infers a single result (equipment lifetime), the layer has only one neuron which defuzzifies fuzzy values into crisp values (defuzzification). The input for nodes k and I_k is formulated in Eq. (7). The output for the node O_k is formulated in Eq. (8). The notation $\rho(\bullet)$ stands for a defuzzification function.

$$I_k = \sum_{j=1}^{r} w_{kj} O_j, \tag{7}$$

$$O_k = \rho(I_k). \tag{8}$$

6.1. Training method

The connection strength between the fuzzification, intermediate, and output layers (i.e. w_{ji} and w_{kj}), shown in Figure 9, is adjusted by a training method. This research trains the weight connections in the FNNs using the Error Back-Propagation (EBP) algorithm, one of the most popular training methods [38]. There are two stages in the EBP algorithm: forward pass and backward pass. In the forward pass process, features of a learning pattern are inputted to the network to produce actual outputs. Network errors are estimated by comparing the difference between actual outputs and desired outputs. During the backward pass, a gradient descent method is used to modify the weights between interconnections to reduce the errors based on the predictive errors. Weights distributed in the FNN are updated incrementally pattern-by-pattern until the network converges.

The input signals propagate through the network from left to right, whereas error signals propagate from right to left. The EBP learning law adjusts connection weights by comparing the actual and desired outputs. The error signal of neuron k at learning iteration p, $e_k(p)$, is defined in Eq. (9):

$$e_k(p) = O_{d,k}(p) - O_k(p), \tag{9}$$

where $O_{d,k}(p)$ is the desired output of neuron k at iteration p. The rule for updating weights w_{kj} is formulated in Eq. (10):

$$w_{kj}(p+1) = w_{kj}(p) + \Delta w_{kj}(p), \tag{10}$$

where $\Delta w_{kj}(p)$ is the weight correction that can be calculated using Eq. (11) [39]:

$$\Delta w_{kj}(p) = \alpha \times O_j(p) \times \delta_k(p), \tag{11}$$

where $\delta_k(p)$ is the error gradient at neuron k and α is the learning rate. For a sigmoid activation function, the error gradient can be represented as:

$$\delta_k(p) = O_k(p) \times [1 - O_k(p)] \times e_k(p). \tag{12}$$

7. Validation and verification

7.1. Case study

This research uses a real instance of fluorescent light maintenance to validate the feasibility of the proposed integration framework. Facility operating conditions directly affect occupant satisfaction, but the fluorescent light functionality of a given facility will deteriorate over time, requiring a well-tuned maintenance program to maintain occupant satisfaction [40]. Assigning an ID to each facility and piece of equipment is a common way to manage facilities, with barcodes frequently being used to acquire the required information. However, paper-based barcodes are easily damaged and optical communications between the barcode and the laser scanner are easily disrupted or blocked, thus limiting their effectiveness in facility maintenance [41].

The performance of the developed integration framework was examined at a university in Taiwan. The university has five colleges, 45 departments, about 10,000 students and more than 140 buildings in a single campus. These buildings serve normal university functions and are primarily used as offices, classrooms, and laboratories. The facilities defined in the study include the facilities and installed equipment. To provide satisfactory service, facility and equipment functions must perform normally, which depends on periodic maintenance. The maintenance data in this case show that fluorescent light replacement takes up 67% of all maintenance effort. As a result, fluorescent light maintenance was selected for validation.

7.2. Identifying objects

In the current setup, the RFID interrogator is detached from the tablet PC, making it difficult to read the RF tag. Another problem is that the equipment is difficult to hold during data entry. A carrying case, shown in Figure 10, was used to enhance mobility by attaching the RFID interrogator to the tablet PC, using a strap to attach it onto the user's wrist (Figure 11), thus leaving the user's hands free to write notes and execute maintenance tasks. In addition, RF tag accessibility is affected by environmental factors such as the presence of metal. Thus, a wooden tag stand (Figure 12) was used to hold the RF tags, providing an adjustable base by which the RF tags can be adhered to a metal surface,

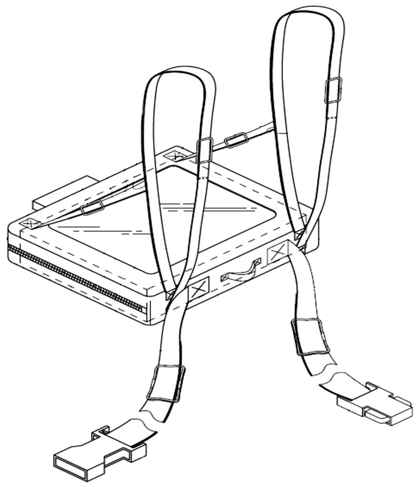

Figure 10. RFID carrying case.

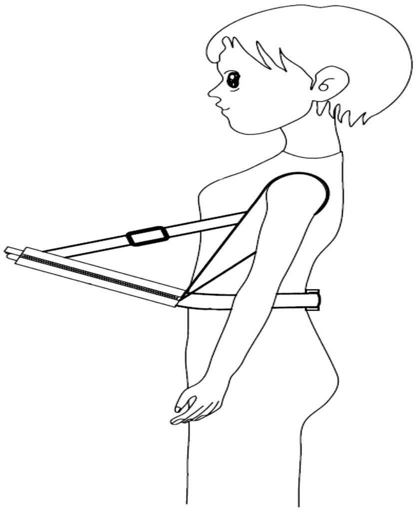

Figure 11. Usage sketch.

Figure 12. RF tag stand.

thus preserving RF functionality in potentially harsh conditions.

7.3. Data collection

The lifetime of fluorescent lights is primarily affected by three environmental factors: (1) use time, (2) on/off frequency, and (3) humidity [42,43]. However, these variables are inconstant across different spaces equipped with fluorescent lights. In addition, these factors are variable themselves, e.g. fluorescent lights have different use times and on/off frequencies every day. Humidity changes every hour due to weather, wind direction, and season. The other challenge to collecting these data is that no records exist for the use time, on/off frequency, and humidity of fluorescent lights in these buildings. This research thus sought to obtain these data by surveying facility users using fuzzy linguistic variables. Three variables are used to describe the use time, viz. "short" (four hours per day), "average" (eight hours per day), and "long" (12 hours per day). The on/off frequency is described as "not often" (twice per day), "moderately frequently" (four times per day), and "very often" (six times per day). Humidity is assessed by the facility location, with a closed basement seen as the most humid location.

Normally, fluorescent light maintenance at the university is initiated by a passive "request sheet" whenever a fluorescent light begins to function poorly. The more fluorescent lights a facility has, the greater the likelihood of a "request sheet" being initiated. Therefore, the number of fluorescent lights in a given facility is also recorded as a variable. The fluorescent light maintenance period was obtained from campus maintenance records, and the collected data are presented in Table 1. In the table, training data are used to train the FNN while test data are used to evaluate prediction accuracy. Fourteen cases (20%) were kept for testing based on historical convention [44,45].

7.4. Analyzing data

The collected data was analyzed using FNNs to estimate malfunctions prior to the next scheduled maintenance check. Equipment should be regularly inspected to maintain high levels of functionality, but equipment lifetimes vary with environmental and usage conditions, and quantifying influencing factors is a process full of uncertainty. For example, it is not clear that 30 minutes of continuous use of a particular facility should qualify as "long-duration" use, nor should usage five times a week necessarily be considered "frequent use". The other challenge in evaluating equipment lifetime is that the impact of the influencing factors on the equipment lifespan is ambiguous. Moreover, these factors are mutually-influential to some degree.

The feasibility of the application of FNNs in fluorescent light maintenance is evaluated using the 14 test cases that were not included in the training process. The prediction accuracy is tabulated in Table 2. The root mean square error (RMSE) is 0.09. This predictive result is satisfactory to facility users, since fluorescent lights can be either replaced before or right after malfunction. Table 2 is represented in

Table 1. Collected fluorescent maintenance data.

Training patterns					
	Input				Output
No.	Use time (hour/day)	On/off frequency (times/day)	Location	Number of light	Maintenance period (day)
1	8	3	Above ground	100	35
2	12	2	Ground	16	25
3	8	3	Ground	26	32
4	8	3	Ground	48	67
5	12	2	Above ground	17	74
6	12	2	Ground	38	39
7	8	3	Above ground	37	28
8	12	2	Above ground	3	32
9	12	2	Above ground	16	22
10	6	5	Ground	45	38
11	12	3	Ground	45	79
12	12	2	Above ground	40	42
13	12	2	Above ground	18	44
14	12	3	Ground	14	31
15	12	2	Above ground	60	22
16	12	2	Above ground	40	59
17	8	3	Above ground	40	89
18	8	3	Ground	16	108
19	8	3	Ground	24	19
20	8	3	Above ground	83	53
21	12	2	Above ground	214	12
22	12	2	Above ground	40	32
23	8	3	Ground	32	59
24	6	5	Above ground	96	72
25	6	5	Above ground	68	68
26	6	5	Ground	96	17
27	8	3	Ground	64	47
28	4	5	Ground	9	46
29	12	3	Ground	146	15
30	4	2	Above ground	80	34
31	12	2	Above ground	26	101
32	12	2	Ground	24	40
33	12	2	Ground	26	158
34	12	2	Above ground	30	17
35	12	2	Above ground	24	60
36	12	2	Above ground	36	79
37	6	5	Ground	128	53
38	6	5	Ground	63	32
39	6	5	Ground	70	23
40	12	2	Above ground	28	56
41	12	2	Above ground	28	62
42	12	2	Above ground	32	166

Table 1. Collected fluorescent maintenance data (continued).

No.	Use time (hour/day)	On/off frequency (times/day)	Location	Number of light	Maintenance period (day)
Training patterns					
	Input				**Output**
43	8	3	Above ground	48	80
44	8	3	Ground	9	28
45	12	2	Above ground	18	28
46	12	2	Ground	40	49
47	12	2	Ground	12	57
48	6	5	Above ground	36	27
49	6	5	Above ground	36	31
50	8	3	Above ground	30	51
51	4	2	Above ground	20	46
52	4	2	Above ground	81	40
53	12	3	Above ground	112	66
54	12	2	Ground	48	38
55	12	2	Ground	48	35
56	8	3	Ground	32	55
57	8	3	Ground	26	71
58	8	3	Ground	48	21
Test patterns					
59	12	2	Ground	24	52
60	12	2	Ground	14	47
61	12	2	Above ground	32	36
62	12	2	Semi-basement	30	61
63	12	2	Above ground	24	45
64	12	2	Above ground	24	49
65	12	2	Above ground	26	37
66	8	3	Ground	48	45
67	12	2	Ground	100	6
68	12	2	Ground	100	33
69	6	5	Ground	23	15
70	12	2	Ground	20	36
71	12	2	Above ground	32	43
72	12	2	Above ground	34	35

Figure 13, which shows that the trend of actual outputs conforms to desired results. The developed FNN could generalize fluorescent light maintenance periods that match the practical distribution.

In this case, maintenance staff members perform maintenance work for the 140 buildings on a monthly basis, but respond to specific maintenance requests daily. To perform fluorescent light maintenance using the current practice, prediction results are transformed into a maintenance period. Predictive outputs are converted into six degrees, viz. 1 month to 6 months. The predictive results shown in Table 3 are converted from Table 2. The acceptance rate is 79% which is practical for maintenance staff.

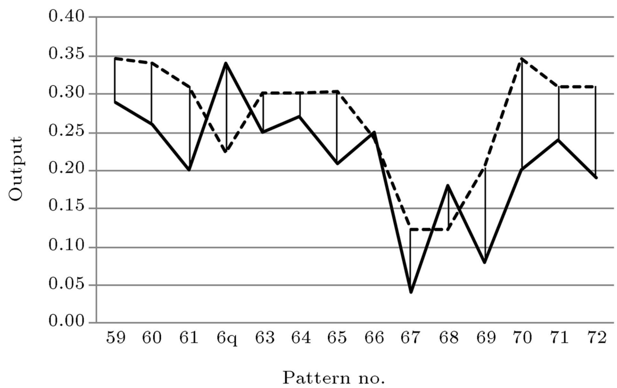

Figure 13. Comparison of actual and predicted maintenance periods.

Table 2. Prediction accuracy.

Pattern no.	Actual outputs	Desired outputs	SE
59	0.35	0.29	0.00
60	0.34	0.26	0.01
61	0.31	0.20	0.01
62	0.22	0.34	0.01
63	0.30	0.25	0.00
64	0.30	0.27	0.00
65	0.30	0.21	0.01
66	0.24	0.25	0.00
67	0.12	0.04	0.01
68	0.12	0.18	0.00
69	0.20	0.08	0.02
70	0.35	0.20	0.02
71	0.31	0.24	0.00
72	0.31	0.19	0.01
		RMSE	0.09

Table 3. Prediction acceptance.

Pattern no.	Actual period (month)	Desired period (month)	Acceptance
59	2	2	Yes
60	2	2	Yes
61	2	1	No
62	2	2	Yes
63	2	2	Yes
64	2	2	Yes
65	2	2	Yes
66	2	2	Yes
67	1	1	Yes
68	1	1	Yes
69	1	1	Yes
70	2	1	No
71	2	2	Yes
72	2	1	No
		Acceptance rate	79%

7.5. Discussion

Maintenance jobs are executed by staff members carrying tablet PCs with portable RFID readers, which are used to identify equipment. As shown in Figure 14, maintenance data were entered into the system using the WBS through a wireless Internet connection. The amount of equipment accounted for in the study case increased daily. The completed RFID system was connected to a single database through the Internet, enabling multiple users to conduct maintenance work at the same time. The proposed system updates the database in real time, which avoids data re-inputting, duplicated maintenance and lost maintenance records. Data stored in the database can be analyzed using statistical graphs from anywhere at any time with up-to-date distributions. An orgiv summarizing the purchasing cost is shown in Figure 15. The proposed system also uses maintenance records to actively forecast the possible lifetime of equipment, as shown in Figure 14. Users can establish a forecast for a specific facility and modify the project with the corresponding

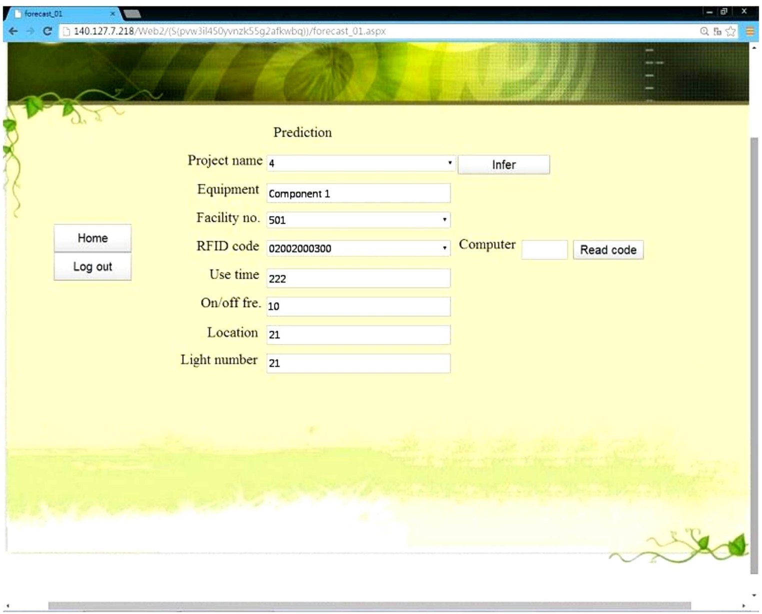

Figure 14. Prediction web-page.

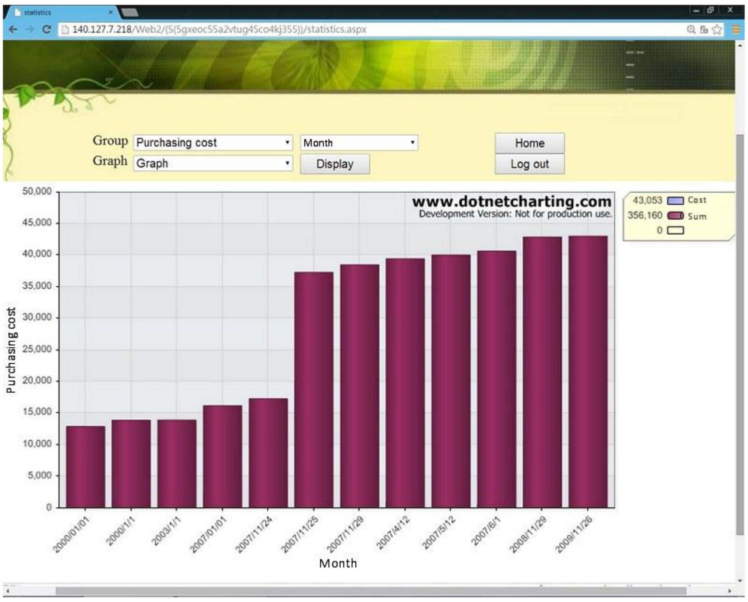

Figure 15. Statistical module.

Table 4. Comparison of integrating RFID, web-based, and AI methods.

Research	RFID	Web- based	AI	Application
Luvisi et al. [46]	X	X		Vineyard traceability system
Samad et al. [47]	X	X		Livestock management
Elghamrawy and Boukamp [48]	X	X		Construction document management
Lee et al. [49]	X		X	Logistics workflow
Brilakis et al. [50]	X		X	Construction entities tracking
Dias et al. [51]	X		X	Supply chain management
Park et al. [52]		X	X	Web search
Cruz et al. [53]		X	X	Geospatial analysis
Tenorio et al. [54]		X	X	Disease diagnosing
Proposed method	X	X	X	Fluorescent light maintenance

requirements. Proper facility functionality can therefore be ensured prior to the next maintenance round. Other advantages of the developed RFID web-based intelligent system include the ability of the tags to capture information without contact or line-of-sight. Tags can be read through a variety of visual conditions such as paint, grime and dust, which are inevitable in a working environment. These properties enhance the applicability of RFID in real-life facilities maintenance.

Table 4 compares previous efforts to integrate RFID, web-based technologies and AI methods. For those combining RFID and web-based technologies, RFID is primarily used to identify objects, whereas WBS is used for displaying/entering data. Lee et al. [49], Brilakis et al. [50] and Dias et al. [51] combined RFID and AI methods in an application to deal with object management, e.g. logistics, supply chains and tracking systems. Web-based and AI combinations cover a wide range of topics. In these kind applications, WBSs are not only used for displaying results, but for web searches, while AI is used as a data analysis tool. However, few studies have attempted to combine RFID, web-based technologies and AI methods, especially in the field of engineering management. The case study presents a novel application for the integration of these three methods.

In this case, the greatest challenge to the use of AI technologies is data acquisition. FL is an appropriate way to acquire environmental data for practical maintenance needs. FNNs are able to learn complex input-output mappings through historical maintenance records. The functionality of fluorescent lights is affected by complex factors that can be hard to describe. For these reasons, precisely predicting malfunction times is difficult. In terms of approximate reasoning, the validation results indicate that the developed prediction module is applicable to real life maintenance.

8. Conclusion

This paper presents a framework for the integration of RFID, web-based technologies and AI to enhance managerial efficiency. RFID is used to identify object IDs while WBSs is used to manage data and AI deals with incomplete and uncertain information. The feasibility of the developed framework was verified using a real problem of fluorescent light maintenance.

This study integrated RFID technology with Internet technologies, management information systems and AI to develop a web-based RFID intelligent management system. The system automated object identification, reduced input errors, and saved operational time. Unlike barcode systems, data stored in RFID tags can be easily modified, and the technology's non-contact, non-line-of-sight characteristics allow RFID tags to be used in challenging practical conditions.

The developed WBS can be implemented from anywhere, at any time, on any platform using wired or wireless Internet connections. Managerial efficiency is also enhanced in that the system enables multiple users to simultaneously implement maintenance work directly through the web-system. FNNs enable users to predict equipment lifetimes with 79% accuracy. The inferred results can allow for timely inspection, repair or replacement which can reduce malfunctions and breakdowns.

The proposed framework presents a novel approach to facilities maintenance that integrates RFID technology, databases, Internet technology and computational intelligence. The developed method potentially breaks new ground in applying FNNs in RFID applications. Lifetimes of fluorescent lights are affected by a range of complex factors, and cathode voltage and Current Crest Factor (CCF) could be considered to obtain more precise predictions. In the future, different kinds of AI techniques could also be explored for better results.

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Biography

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