# A 3-dimensional Visualized Approach for Maintenance and Management of Facilities

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***Abstract***

The maintenance and management of facilities is an emerging issue. Decisions on maintenance-related works usually are made based on various types of accumulated historical data, such as design drawings, inspection records, sensing data, etc. There are systems for storing and maintaining such maintenance-related data electronically in database. However, the data accessing mode of these systems is based on text input on web form, which sometimes is not intuitive enough for interpreting retrieved information for decision making. In addition, most systems are only developed for one type of data, and for a specific facility. This limited the completeness and extensibility of these systems. This research proposes a 3-dimensional (3D) visualized approach for maintenance and management of facilities. A prototype system which can apply the proposed method to different facilities is developed for concept proofing. A 3D facility model is provided in the system as the interface for accessing various maintenance-related data intuitively. In addition, the presentations of various maintenance-related data are visualized on the model as possible to provide user an intuitive understanding about the states of the facility in many aspects. Behind the 3D visualized interface is a database which systematically integrates and stores various maintenance-related data together. The data of this database should be constantly accumulated via input from users and sensors in appropriate and suitable formats, and can be analyzed and handled by available methods, such as reliability and knowledge management, to provide processed information for aiding decision making in maintenance.

***Keywords***: Visualization; Maintenance; Management; Facility; 3D Model.

## 1. Introduction

Facility maintenance and management (FMM) becomes relevant once the facility is completed. Proper FMM can help administrators identify problems as early as possible and maintain the facility effectively. FMM normally needs a variety of data for decision making. Therefore, in addition of effective storage of original design data, the operator needs to record the facility's condition regularly, and inspect and keep records of the facility at suitable times. Effective FMM needs to integrate and manage information, such as temperature, inspection records, maintenance records, drawings, and contracts. This provides administrators with enough information to make an FMM decision.

However, FMM data are mostly kept by handwritten record books or repair records. Administrators need to check paper records and calculate the maintenance schedule manually. Under this FMM mode, records are kept "on paper" and are not digitized. In addition, the current FMM is divided into different aspects. Maintenance records are also possibly distributed to different places. For example, maintenance information and inspection records are kept and managed separately and do not link with each other even if they are highly associated in making decisions to maintain a specific facility. Discrete information is not integrated, and administrators cannot make the optimum FMM decisions based on relevant FMM data. Looking through massive volumes of maintenance records is labor- and time- consuming. In time-sensitive or emergency situations, it would be difficult to provide the latest FMM information or integrate it effectively.

Therefore, some researchers introduced information technology (IT) into facility maintenance mode, digitized maintenance and management (MM) information, and even integrated related data, which is convenient for administrators. Examples of such integration in Taiwan are the Facility Graph Maintenance and Management System developed in Sinotech Engineering Consultants, Ltd (2006), the Taiwan Bridge Maintenance and Management System developed for the Ministry of Transportation in Huang (1997) and Lee (2005). These systems provide digitized information for inquiry, and present results in forms. However, this presentation mode is not intuitive for some types of data, such as facility temperature distribution and facility location. When administrators read digitized data or information, they cannot immediately get the distribution and state of the entire facility through the mode, and can only understand it by virtue of experience. Additionally, existing systems put emphasis on only one aspect of maintenance information, for example, the system in Sinotech Engineering Consultants, Ltd (2006) only carries out MM for facility graphs and textual information, and the system in Huang (1997) and Lee (2005) only manages the maintenance and inspection records for bridge facility. In those systems, other information such as contractual documents; monitoring information is not integrated.

As for the subsequent application of the three-dimensional (3D) model into FMM, although some applications have already applied 3D visual technology to visualize the facilities targeted for MM, such as the spatial navigation systems established for museums, campuses, and cities as in Tamada et al (1994) and GSPRS (2005). However, the functionality of visualization in these systems is limited to navigating the overview of the facility. In addition, they have not been applied or incorporated into the operation of FMM, and have no linkage to the maintenance information of target facility.

Apart from this, the design and establishment of most existing MM modes are customized to a specific facility and cannot be applied to others. This wastes resources and time. As for the reusability of maintenance information, most existing maintenance modes are used to record maintenance information alone. In practice, some maintenance data can be further processed to produce useful information for FMM. Recently, some researchers such as Dell'Orco & Zambetta (2003), Billinton & Abdulwhab (2001), Donaghy & Omanson (1989), and Lee (2007) conducted studies on FMM based on post-processing of information, but did not adopt visual technology or integrate other MM information.

To sum up, this study proposes a new 3D visual FMM approach to expand the current MM mode. The new approach takes advantage of visual technology to provide effective search and presentation of maintenance data, uses a single database to integrate and link a variety of FMM information, and effectively uses knowledge management, artificial intelligence, and other technologies to analyze and process information to support decision making. All of these allow the new mode to become a superb FMM mode and system featuring 3D visualization, integration of data and monitoring information, information analysis, and decision-making function.

## 2. Research Objective

The objective of this study is to propose a 3D visual FMM approach, and its concept is illustrated in Figure 1. This approach gives the facility a 3D visualized view, which allows administrators to view the virtual facility and the scene, as well as press buttons to rotate, move, or zoom the object in and out. This way, administrators can easily view and click the part needed. Administrators can also easily select each component of the facility, and obtain the maintenance or management information required. The selected part will change color and display the basic information. In addition, the MM information for each facility or component is available, data are presented in the most suitable way, and both single selection and multi-selection are supported.

This approach stores FMM information in a proper digitized format such as image, data, or file, and links information to the 3D model of the facility. When administrators click "Facility Inquiry," all detailed basic data and historical records of this facility will be provided. In addition, this approach has integrated diversified MM information sets such as basic information, examination records, monitoring information, and others. It uses a single database to store and manage information collectively, and presents information through a 3D visual interface so that the monitoring information will directly reflect the real-time state of the facility by color or action, such as facility temperature and lift location. Furthermore, the post-processing of MM information is carried out with knowledge management, artificial intelligence, and other data processing technologies. For example, based on maintenance and measurement information, we can computerize facility failure rate and reliability through statistical formula, and then make a maintenance plan for the facility. Through the knowledge management mode, this mode can sort and present MM information properly, and the result of processed information can effectively bolster decisions on maintenance work.

(a) 3D visual interface

(b) Design and maintenance history of digitized storage facility

(c) Integrated MM and data collection and storage

(d) MM information processing and analysis

Figure 1. Conceptual illustration of the FMM approach proposed by this study

## 3. System Requirement Analysis

This research focuses on the system development for the aforementioned research objective, carries out a study on functional requirements, and develops a system plan. For the system's functional requirements, we analyzed and planned from the six aspects of data type, data resource and digitized format, database skeleton, data presentation, treatment of data hierarchy, and the building mode of facility management 3D model. The following sections give an overview of the analysis and planning based on six aspects.

### *3.1. Data Type*

By understanding and analyzing FMM operation, we decided to use the system to store and manage this type and scope of facility data, as shown in Table 1. The data can be divided into six categories according to their nature, and the coverage of each type is listed in Table 1. When maintaining and managing the facility, administrators need to inquire about the basic information on the facility to determine its situation. From here, they can view the engineering drawings to know the facility's structural design and engineering plan. Administrators will also periodically examine the facility and keep records for subsequent follow-up. Records for damaged facility after repair should also be kept and stored for later review. Combining this with a facility monitoring device will capture real-time, rapid, and dynamic information about the facility, which is beneficial for keeping track of its latest state. FMM work is also expected to optimize efficiency, reduce MM cost, and make MM work stable and reliable. However, the scope of the six kinds of MM information is very large, and this study will establish the prototype system for a few items of maintenance information for each kind to explain the concept proposed by this study.

### *3.2. Data Resource and Digitized Format*

Based on the type of data to store, this study analyzed the data resources and determined the suitable digitized format for future planning of a suitable system interface, data collection, and data storage and management in the database, as shown in Figure 2. It is divided into four parts. The system requires a network client input interface, which uses manual filling or uploading to enter facility information, facility thumbnail, examination records, maintenance records, and incident experience into the database individually for future inquiry. Facility drawings and contractual documents will be uploaded into the system and recorded in the database as scanned files. As for the real-time state of the facility received from monitoring equipment, such as room temperature decreases due to air conditioners, lift locations, and facility fire alarm, they will be recorded into the database and will be presented through the 3D interface. Finally, a statistical analysis of maintenance records such as a statistical comparison of maintenance frequency will compare each facility. Facility failure rate, reliability, and other information will also be obtained through statistical or historical data. All analyzed information will be stored into the database for further MM.

Table 1. Data type and example

| Data type | Example |
|---|---|
| Basic information of facility | Facility name, builder, designer, power consumption, region, and facility category |
| Engineering drawing of facility | Elevation drawing, sectional drawing, plan view, perspective drawing, construction drawing, and electromechanical equipment drawing |
| Examination record | Equipment records, operation state, daily workload, and time cycle |
| Maintenance record | Maintenance and accident records, failure mode, and maintenance record |
| Facility real-time monitoring information | Temperature, humidity, stress, strain, displacement, elevator position, and fire alarm |
| Analytical result | Equipment reliability, optimum maintenance schedule, and system failure rate graph |

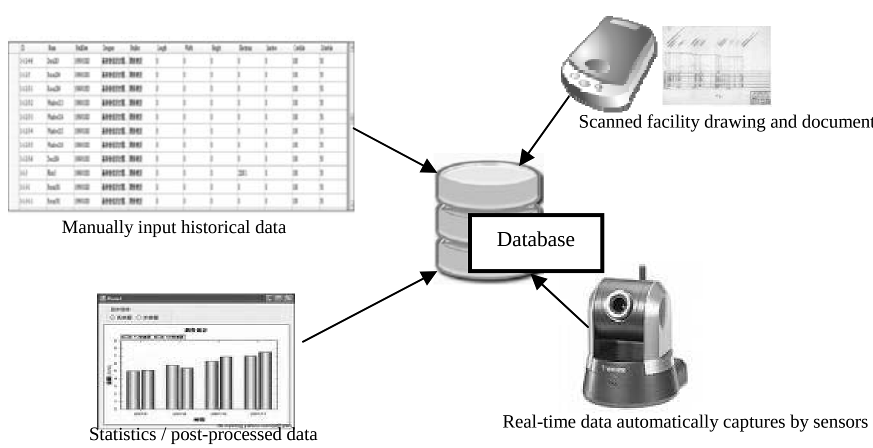



Figure 2. Data sources and digitized format

### *3.3. Database Schema*

This system needs to incorporate all kinds of available facility maintenance information into one database, and obtain the overall integrated information of the facility through a 3D visual interface. This study is based on the correlation between the data required to store and the digitized format. It planned and designed the database skeleton. The information is stored into several datasheets according to type and the facility's basic information. This study has also established the data's dependency according to their correlations, as shown in Figure 3. It takes the facility object as the core and associates it with relevant incidents, maintenance record, monitoring information, empirical files, and the facility's basic information. By using such design, administrators can access all information or states of the facility in the database by clicking the facility on the 3D interface.

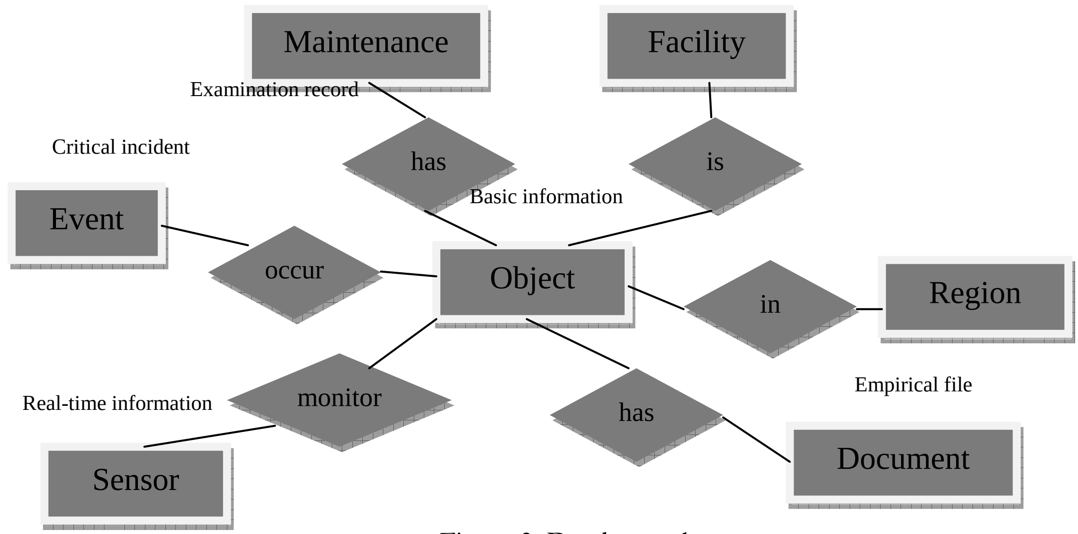



Figure 3. Database schema

*3.4. Data Presentation*

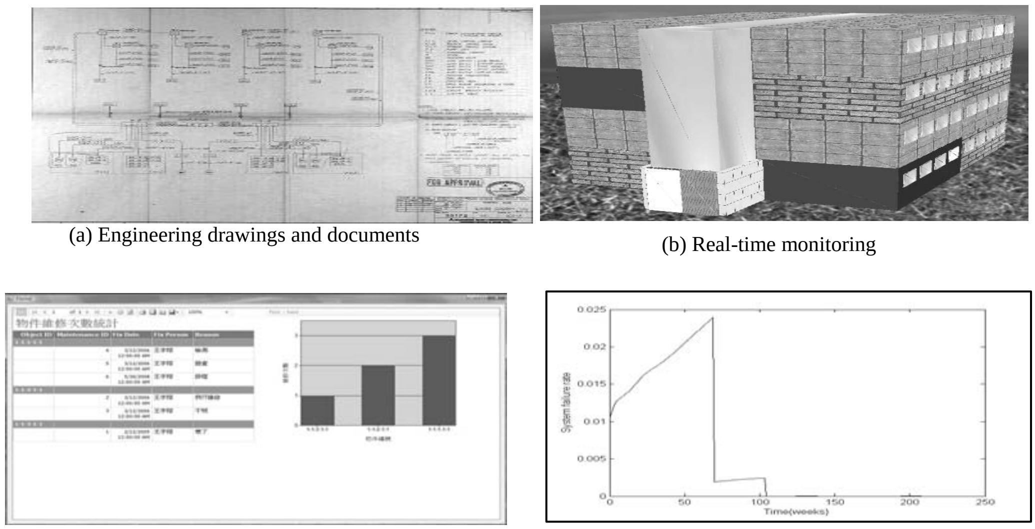
FMM information has different types and aspects, and each kind of information has its own suitable presentation in view of its unique category. According to the information of different types and aspects, this study proposes the best visual presentation mode, and allows administrators to understand it effectively and intuitively and make decisions by considering comprehensive facility maintenance information. The visual presentation modes proposed by this study for the maintenance data of each kind of facility are shown in Figure 4.

Most engineering drawings and historical information are text or graphs, and conventional management is used to manage them through text or form. Therefore, this study takes “form and text inquiry” as the presentation of such information.

Real-time monitoring information is mostly monitoring data, such as equipment temperature, lift location, and incident occurrence received from the monitoring equipment. If they are presented simply in text or form, administrators can only access the data, which is not very intuitive. Since this study supplies a 3D interface, the monitoring information is also presented by the 3D interface to allow administrators to get close to the actual situation of the equipment. For example, for facility temperature in a 3D interface, it will use the distribution of colors to present the current temperature of the facility. This way, administrators can access the temperature of the facility and compare it with adjacent equipment to identify abnormal temperature. As for lift location, real-time movement is seen in the 3D interface and allows faster follow-up in the floors where the lift is located. In the event of a fire alarm, the 3D interface will warn administrators by blinking. The statistical information is the statistical result of maintenance record or historical information, and the best presentation of the statistical information is by statistical statement. Therefore, this study adopts a statistical table to present such information. Post-processed information refers to information obtained after processing through knowledge management or artificial intelligence mode. In our study, we find that some information obtained is suitable to present in 3D interface, while some are suitable to simply present in text. For example, the analytical result of failure rate is presented in the 3D visual interface through distribution of color; warning of the maintenance schedule is presented in 3D visual interface.

*3.5. Processing of Data Hierarchy*

The match between FMM data and its model has a hierarchy problem. The facility consists of components in different hierarchical dimensions. For example, a building can be divided into floors, and a floor can be subdivided into rooms. The facilities in different dimensions correspond to respective MM information, that is, the building has information on power consumption; the room has information on temperature; and the lift has information on location, which the building does not have. Therefore, this study develops a solution for data hierarchy and allows administrators to switch between and select the components of facilities in different dimensions to inquire about related information. This study adopts the identification (ID) design for the facility model component to solve the data hierarchy problem. Each facility or each component in different dimensions in the facility has a unique ID, with a format of Project No.-Building No.-Floor No.-Room No.-Object No. (-Object Part No.).




(a) Engineering drawings and documents

(b) Real-time monitoring

(c) Statistical information

(d) Post-processed information

Figure 4. Presentation of data


Figure 5. Building Steps of the Model

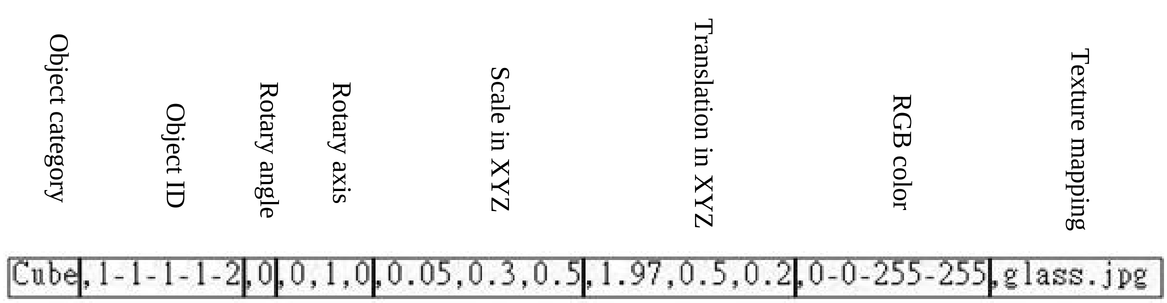



Figure 6. File format and instance

*3.6. Construction Mode for the Facility Management 3D Model*

The 3D facility management mode proposed in this study is created by using the prototype system developed by this study based on OpenGL and VB.NET 2.0 (see Figure 5 for the establishment of the facility management 3D model and mode in relation to varied maintenance information in the database).First, the model builder needs to assign a unique ID to the facility model or its component, (ID is the hierarchical code of different dimensions), then it uses OpenGL libraries to draw the 3D model based on the scale and material of the facility and finally links the ID of these model components to the information recorded in the database. This way, the creation of the facility model is completed. Additionally, in this study, we developed a file format to allow users to store the models built for different facilities, as shown in Figure 6.

Lastly, this study uses OpenGL Select functions to realize single and multi-selection of objects. If objects overlap, we select the upper object and apply rotary or deformed view to select the covered object.

## 4. System Framework

The 3D FMM system platform proposed by this study integrates the four technologies of monitoring, visual interface, 3D model, and data analysis and processing, as shown in Figure 7. The 3D facility model is established based on the application of the concept of Building Information Modeling (BIM) to facility MM. BIM contains attribute information, geometrical information, and correlation of the 3D model; the presentation of visual interface adopts the 3D drawing technique. It draws the visual interface according to BIM information and presents it through animation. The monitoring takes advantage of the data received from a dynamic access monitoring equipment, links to information in the FMM database, and uses the visual interface to present. Finally, it uses knowledge management and artificial intelligence techniques to analyze and process the data. The result can support decision making within the MM. It is estimated that this integration will optimize MM decision making and simplify the experience.

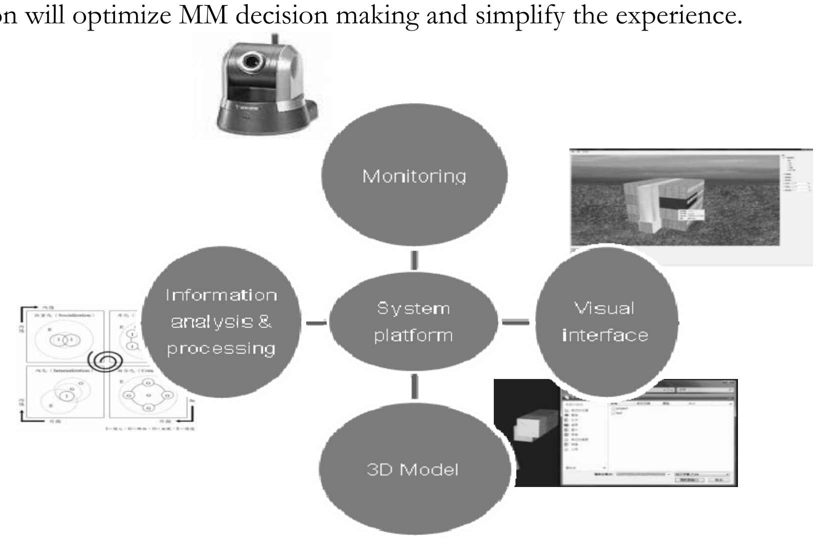



Figure 7. Technologies integrated in the proposed approach

The structure of the prototype system developed by this study is shown in Figure 8. The entire system platform is created based on four aspects. Administrators use 3D visual interface to accomplish facility MM. By inquiring in the back-end database, the system presents information for administrators to view. The monitoring part transmits the monitoring information through the network. The facility model draws established facility items by OpenGL visual technology to allow administrators to click.

## 5. Conclusions

This study applied and integrated visualization and database technologies into FMM work, and proposed a new FMM mode featuring (1) Integrity, capacity to integrate MM information, (2) intuition, allowing administrators to carry out FMM intuitively, (3) real-time dynamics, observing the current state of the facility by facility monitoring, and (4) reusability in which this mode can be used repeatedly via the facility model building. This 3D visual FMM mode can expand the current FMM mode by addressing inadequate digitization, difficult integration of relevant data, and unintuitive data presentation. The system developed by this study can be used for general projects, and the aforementioned model can be effectively applied to other facility management projects repeatedly.

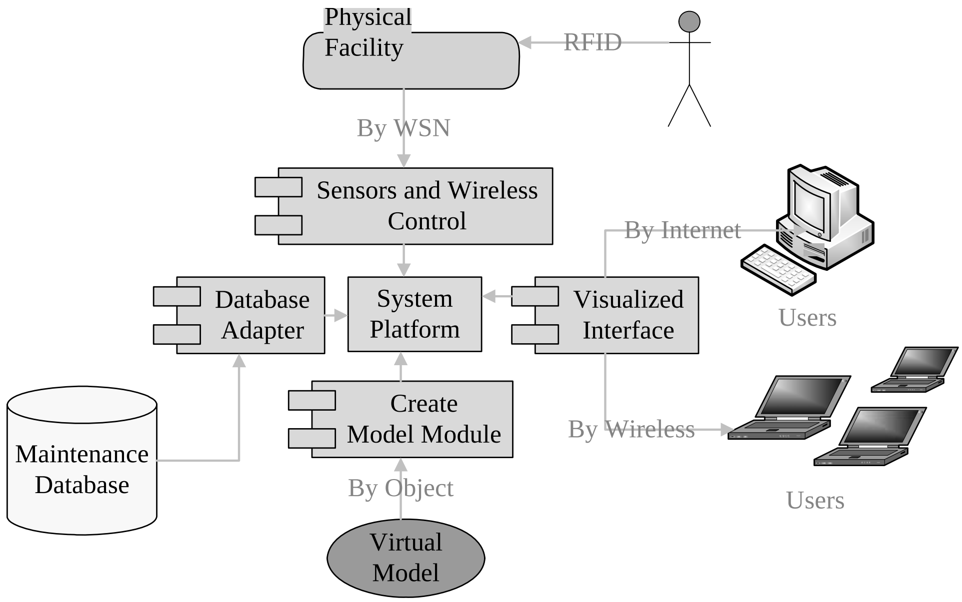



Figure 8. System architecture

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