Expert Systems with Applications 40 (2013) 287–299

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A 3D visualized expert system for maintenance and management of existing building facilities using reliability-based method

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ARTICLE INFO

Keywords:
Facility management
Maintenance
Visualization
Reliability
Decision-making

ABSTRACT

Facility maintenance and management (FMM) is an emerging issue in civil engineering. Decisions involving maintenance-related tasks are generally made based on various sources of accumulated historical data, such as design drawings, inspection records, and sensing data. Systems are developed for storing and maintaining such maintenance-related data electronically in a database. However, the data-accessing method of these systems is based mainly on text input in Web form, which is occasionally insufficiently intuitive to interpret retrieved information for decision making. Besides simple data management practices, the feasibility of implementing analysis on FMM-related data to provide estimated or predictive information for decision making should be examined. This paper presents an expert system model for the maintenance and management of existing facilities. A prototype system was developed for concept proofing. A 3D facility model is introduced in the system as the interface for accessing various maintenance-related data intuitively. Various maintenance-related data and analysis results should be presented visually on the model as much as possible to provide users with an intuitive understanding of the facility status in many aspects. Behind the 3D visualized interface is a database that integrates and stores various maintenance-related data systematically. This database information should be accumulated continuously via input from users and sensors in appropriate formats. Moreover, a reliability-based module should analyze the accumulated data periodically to provide predictive forecast information, subsequently facilitating decision making during maintenance.

1. Introduction

Facility maintenance and management (FMM) is of priority concern upon facility completion. Effective FMM can help managers to identify problems early and maintain the facility effectively. FMM normally requires various data for decision making. Therefore, in addition to storing original design data, the operator must record facility conditions routinely, as well as inspect and maintain facility records timely. Effective FMM of building must integrate and manage information, such as records on environmental monitoring, inspection, and maintenance, as well as drawings, manuals and contracts. Such measures provide facility managers with sufficient information to make a FMM decision.

However, FMM-related data of existing building facilities are maintained largely as either handwritten record books or repair records. Facility managers must verify paper records and develop the maintenance schedule manually. Additionally, maintenance records are most likely distributed to different locations. Discrete information that is not integrated makes it impossible for managers to make optimum FMM decisions based on relevant data. Examining massive volumes of maintenance records is laborious and time-consuming. Under time-sensitive or emergency situations, providing the latest FMM information or even integrating it in decision making is extremely difficult. Therefore, some systems introduce information technology (IT) into facility maintenance for providing digitized maintenance and management (MM) information and even integrating related data for administrative purposes. Although above systems provide digitized information for inquiry and present results in related forms, this presentation method is not intuitive for some data.

As for subsequent 3D model applications to FMM, the functionality of visualization in these systems remains limited despite 3D visual technology applications to visualize facilities for navigation. The visualized information cannot convey current information on facility usability in real time. Additionally, either applied or incorporated into FMM operations, these systems are also not linked to maintenance information, historical records, and design documents of target facilities.

Moreover, analytical functions are also not incorporated in the estimated or predictive information on future facility trends based on accumulated FMM-related data. If all FMM models only record relevant maintenance information, the covert messages, significance, and trends from the information are neglected. Thus, various

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http://dx.doi.org/10.1016/j.eswa.2012.07.045

methods or theories have been developed to resolve this problem, with the intention of producing covert or predictable information in the above data. Through such efforts, post-processing analysis of accumulated maintenance information has greatly facilitated MM work decisions. However, to our knowledge, a multidimensional integration of analytical results and auxiliary information of other MM works has not been achieved using 3D visualization technology.

This work demonstrates the feasibility of incorporating a 3D visualized expert system into the MM of existing building facilities. A 3D facility model is provided as the main system interface. Various FMM-related data and documents are digitized and stored in an integrated database in appropriate formats. All database data are mapped as attributes of appropriate components in various scales for easy access. This database information is constantly accumulated via inputs from various users and sensors. The accumulated FMM data for post-processing information must be analyzed before it can support FMM decisions. This work also develops a data analysis module based on reliability methods. The proposed module analyzes periodically the accumulated data to provide processed information, thus facilitating decision making for maintenance purposes. Consequently, supervisors can determine whether they should conduct facility maintenance or detection before actual damage occurs. Additionally, maintenance tasks involving time, labor, and financial arrangements often encounter scheduling problems. Providing an optimal maintenance schedule by using an optimization approach can help reduce time, labor, and financial expenses, as well as further enhance facility reliability, ultimately reducing the likelihood of sudden damages in a facility.

2. Objective

The proposed expert system model utilizes visualization technology to effectively search for and present maintenance data. The proposed model also uses a database to integrate and link a variety of FMM data that building managers typically seek for decision making, i.e. design and construction drawings, inspection and maintenance records, major events, knowledge documents, user manuals, accumulated real-time monitoring data, and statistical results of facility life cycle. Additionally, the system model integrates the reliability-based method, e.g., failure rate estimation, reliability analysis, and maintenance scheduling, to analyze accumulated inspection and monitoring data in order to provide processed information to facilitate decision making. The above features make the proposed system model a highly functional expert system model for FMM. The model also features 3D visualization, integration of data and monitoring information, information analysis, as well as decision making functions.

Moreover, the proposed system model offers a 3D view of the facility, allowing facility managers to easily view and select a portion of the facility to obtain the maintenance or management information required. The selected portion changes the color and display basic information. Furthermore, the MM information for each facility or component is available; data are presented in the most appropriate manner; and both single selection and multi-selection are supported.

The proposed system model stores FMM information in the proper digitized format, e.g., image, data, or file, and links information to the 3D model of the facility. Accessing the 3D model provides users with all details of the basic data and historical records of this facility. Moreover, the proposed system model has integrated diversified MM information sets such as basic information, examination records, and monitoring information, among others. In particular, a database is used to store and manage information collectively, as well as present information through a 3D visual interface. Consequently, the monitoring information accurately reflects the real-time state of the facility by color or animation, e.g., facility temperature and elevator location. Furthermore, MM information is post-processed with the reliability-based method. Based on accumulated MM information, the system can estimate failure rates and reliabilities of facility equipment. An optimal maintenance plan for the facility is also developed by scheduling optimization. The system also estimates the failure rates of various components of the equipment through a statistical formula by analyzing facility maintenance information. The system then identifies the reliability of facility equipment by analyzing the failure rates of equipment components. Once the reliabilities of all facility equipment are estimated, the system can further provide a corresponding equipment maintenance plan for reference based on the optimization of FMM scheduling.

3. Related research

FMM has received considerable research attention. For facility managers, other than pure FMM, identifying the optimum maintenance and management strategies and repair facilities before faults occur has become increasingly important. Some studies applied the reliability analysis to estimate of the failure rate of facilities, and optimization methods to set the facility maintenance scheduling. Examples include Chun (1992), Chan and Shaw (1993), Jack and Dagpunar (1994), and Yeh and Lo (2001). Beside, some studies further applied AI-based theories and methods to establish decision-support models for the maintenance and management of various facilities. Examples include Morcous and Lounis (2005), Lee, Sanmugarasa, Blumenstein, and Loo (2008), Xiao, Chen, and Zhong (2010), Moradi, Fatemi Ghomi, and Zandieh (2011), and Naderi, Zandieh, and Aminnayeri (2011). In practice, some maintenance data can be further processed to produce insightful information for FMM.

Some studies further developed expert systems based on proposed models to assist FMM works in various areas, such as structural material, transportation, fire-fighting, manufacturing, and warehouse management, automatically and digitally. These expert systems generally provide text-based and 2D graphical user interfaces for receiving users' inputs and presenting analytical results. The examples of expert systems developed for various types of facilities are as follows. For structural material, Mahmoud, Aref, and Al-Hammad (1996) developed an expert system for evaluation and selection of floor finishing materials. Liu, Xuan, Si, and Tu (2008) developed an expert system to realize an appropriate combination of material database, condition database and knowledge database. Many assessment criteria including the multi-defects interaction and combination, invalidation criterion and creep–fatigue interaction are employed in the inference engine of expert system. For transportation facility, Chou (2009) proposed a web-based case-based reasoning (CBR) expert prototype system that compares historical data at the work item-level across the case library and determines preliminary project cost with readily available information rapidly based on previous experience of pavement maintenance related construction to assist decision makers in project screening and budget allocation. Tarighat and Miyamoto (2009) proposed fuzzy bridge deck condition rating method and the parameters of the model are selected as fuzzy inputs with membership functions found from some statistical data and then the fuzziness of the condition rating is calculated by the fuzzy arithmetic rules inherent in the fuzzy expert system. For fire-fighting facility, Kamel, McCaffrey, and Metzler (1996) developed MK92 Maintenance Advisor Expert System (MK92 MAES) for the diagnosis and repair of the MK92 MOD 2 fire control system deployed on U.S. Navy guided missile frigates. For manufacturing facility and