THE DEVELOPMENT OF AN AUGMENTED REALITY-BASED USER INTERFACE TO SUPPORT MAINTENANCE FIELDWORK

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Abstract. This paper discusses computational support for the maintenance of Mechanical, Electrical, and Plumbing (MEP) systems to more effectively use maintenance information. A common cause of inefficient and ineffective maintenance has been the difficulty in getting reliable, just-in-time information for in-situ maintenance work. To reduce this inefficiency in the maintenance environment, accessibility and accuracy of maintenance information must be improved. Our approach, therefore, is the development of a user interface that will produce superimposed computer graphics of equipment/facility-specific maintenance information onto a live video stream on portable computing devices, such as laptops and PDAs. This paper concentrates on elicitation of primary functions needed to support various maintenance activities as well as a prototype application being developed for the approach.

1. Introduction

Operations and Maintenance (O&M) of MEP (Mechanical, Electrical, and Plumbing) systems occurs throughout the lifecycle of a building. Not surprisingly then, this phase incurs the most costs.

These days, most O&M data and documents are generated using computers. However, during the O&M phase, those data and documents are not fully utilized because some necessary information does not exist in their databases and also because quality of those as-built documents is unreliable (Liu et al, 1994; Clayton et al, 1998). Consequently, Facilities Management Services (FMS) personnel frequently rely on their experience as well as coworker’s rather than maintenance databases, which forms a vicious circle of progressive data atrophy. Furthermore, if a FMS person retires, all the maintenance information that has been memorized by the person would not be accessible (Portland Energy Conservation, Inc., 1999).

Moreover, in conventional computing environments, different types of O&M information are managed separately. Drawings, specifications, work orders, equipment performance related data are all managed in their own databases and these databases do not communicate with each other.

GEMnet (Motegi et al, 2003) is one of the projects that aim to integrate different types of O&M information. The system collects sensor-derived data from the Building Automation Systems (BAS) and integrates the data with work orders so that the FMS fieldworkers can carry out initial diagnosis with more accurate information of equipment condition.

2. Objective and Approaches

The main objective of this study is to improve accessibility and accuracy of maintenance information so that the FMS personnel can conduct efficient O&M fieldwork. Our approach is to provide an Augmented Reality (AR)-based user interface that can visualize O&M information retrieved from various databases and BASs.

In addition to literature review, we shadowed FMS personnel, especially tradespersons, to locate bottlenecks in current maintenance process and identify O&M activities that cause the bottlenecks. The results obtained through the shadowing activity were then analyzed to conduct the following outcomes:

- Identifying and classifying maintenance activities
- Defining maintenance process of MEP systems
- Developing an AR-based prototype application for verification and measurement of its performance in order to improve O&M efficiency

3. Shadowing tradespersons

Three graduate students shadowed three electricians and one plumber for four weeks. Each tradesperson has his roles and responsibilities. For example, one of the electricians was responsible for urgent priority and unscheduled daily service, while the others took care of preventive maintenance and installation projects. Also, they work different shifts to be ready for an emergency at any time of the day. Therefore, we were able to observe how they organize their work orders and see the events that happen at various times throughout the day. Table 1 shows the number of work orders we observed for each maintenance type.

Table 1. Types of maintenance and the number of work orders for each type

Daily service	Urgent Priority	Preventive Maintenance	Project	Contract Support	Not specified	Total
25 (39%)	8 (13%)	18 (28%)	4 (6%)	4 (6%)	5 (8%)	64

4. Identification and classification of maintenance activities

Maintenance activities can be classified into three groups: Core Maintenance Activities (CMAs), Maintenance Support Activities (MSAs) and all other activities. CMAs are crucial activities to complete the job and cannot be replaced by any other methods, whereas MSAs are activities that improve tradespersons' performance during CMAs. Many different types of MSAs could exist to achieve the same goal and their impact on the core activity varies. Activities in the last category are simply all other activities. Activities in this category are excluded in this study.

Table 2 shows identified maintenance activities classified into the two groups. The majority of MSAs are activities of collecting information that are necessary to carry out CMAs. For example, FMS personnel look at drawings to locate the target equipment and talk with coworkers to obtain previous maintenance history of the equipment, which is common because it is hard for them to seek those types of information in written documents.

Table 2. Classification of maintenance fieldwork activities

Maintenance activity types	Identified maintenance activities
Core Maintenance Activities	• **Receive/Assign/Pick up/Read/Sort** work orders • **Locate** equipment • **Install/Diagnose/Repair/Inspect** equipment • **Get** spare parts/tools/keys • **Document** work order sheets/work order request sheets/spare part request sheet • **Submit** new documents
Maintenance Support Activities	• **Read** manuals/specifications/drawings • **Get** information on parts • **Discuss** problems with coworkers/foreman/clients • **Report** problems to FMS dispatcher/foreman/police • **Arrange** collaboration with coworkers/sub-contractors • **Get** contact information of clients/primary responsible person on the facility

5. Functional Requirements

The structure of an O&M process is formed with the sequence of CMAs. MSAs are then added where they are needed. Therefore, in order to elicit primary functional requirements, we looked at the sequential order of CMAs and associated MSAs. Then, primary functions were elicited if the MSAs can be facilitated by the functions. The following five functions are the initial functions that are necessary to support CMAs, respectively.

- Receive / Assign / Pick up / Read / Sort work orders
  → **Visualize** assigned work orders retrieved from O&M databases
- Locate equipment
  → **Identify** equipment
- Install / Diagnose / Repair / Inspect equipment
  → **Visualize** geometric models and maintenance history of the equipment
- Get spare parts / tools / keys
  → **Visualize** equipment/facility-specific maintenance information
- Document work order sheet / work order request sheet / spare part request sheet
  → **Provide** a documentation interface
- Submit/Upload new documents
  → **Upload** new documents to O&M databases

6. Augmented Reality-based User Interface

Figure 1 shows an IDEF-0 (Information Definition diagram, referring to functional information) diagram with the identified primary functions.

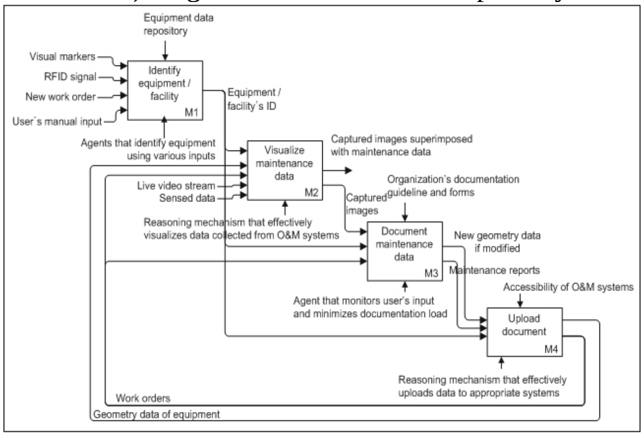

Figure 1. An IDEF0 diagram of the prototype user interface

To identify a piece of equipment, the prototype takes visual markers, RFID (Radio Frequency Identification) tags, information about a piece of equipment in a work order, or user's input about the type of equipment. Output of this function is the unique ID of the identified equipment.

The visualization function takes the unique ID and accesses databases to retrieve data relevant to the identified equipment. Examples of such information include maintenance history, a geometric model of the equipment and sensor-derived data from BAS. The main outputs are integrated equipment/facility-specific data and information in a unified user interface. If the user is in the field, the retrieved data can be superimposed on to a video stream supplied through the camera installed to the AR interface. With this display method, the user will be able to see a hidden portion of the equipment or facility in full scale.

The documentation function attempts to minimize the user's documentation load by automatically filling out known data such as information about the tradesperson who carried out the maintenance work. Available resources for documentation of the maintenance work include images captured through the camera, information about the user, geometric data, and the current work order. Interfaces for editing text and geometric models must also be provided.

Finally, the uploading function parses newly documented data and uploads them to appropriate databases according to the types of parsed data entities.

Figure 2 depicts the structure of the AR interface that utilizes BAS, which provide sensor-derived data in real-time; Computerized Maintenance Management Systems (CMMS), which manages work orders; O&M databases which manage various O&M documents and geometric models of HVAC systems.

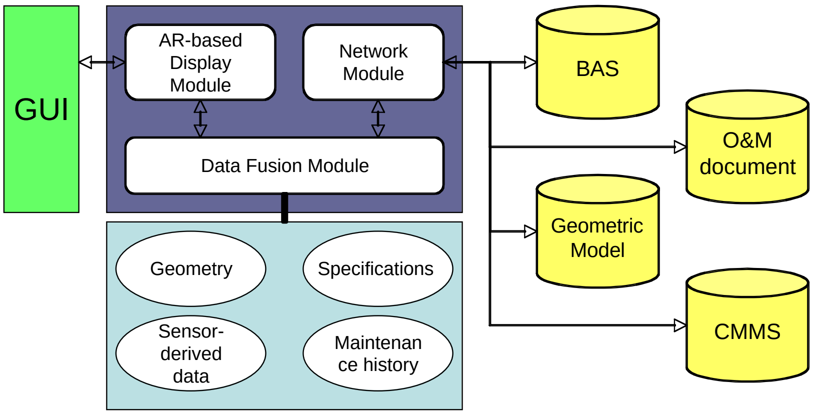

Figure 2. The structure of the AR-based interface

The AR interface comprises three layers: a Graphic User Interface (GUI), a controller, and a data model. The controller consists of three modules to provide the identified primary functions. The three modules are a network module, a data fusion module, and an AR-based display module. The AR-based display module takes a video stream and the user's input, and identifies pieces of equipment in the video stream. Then, the data fusion module takes the ID of the identified pieces of equipment and retrieves O&M data necessary for the specific O&M activities through the network module that communicates with various O&M databases and BASs (Building Automation Systems) using TCP/IP, a common protocol used in networking computers and servers.. The fused data, including geometric models, work orders and maintenance history are then displayed on the GUI.

Figures 3 and 4 show screenshots of the prototype application being developed. This application uses ASE (ASCII Scene Exporter) and VRML (Virtual Reality Modeling Language) formats for geometric models, and communicates with active RFID tags for local data storage devices (Figure 3). These devices contain fundamental information about the equipment and work orders. The prototype can also retrieve temperature data measured by the RFID tag. In addition, as depicted in Figure 4, the prototype application displays a live sensor-derived data stream retrieved from a BACnet-compatible HVAC system. BACnet is "A Data Communication Protocol for Building Automation and Control Networks." (ASHRAE, 2004) During our verification test, it retrieved a relative humidity value every second.

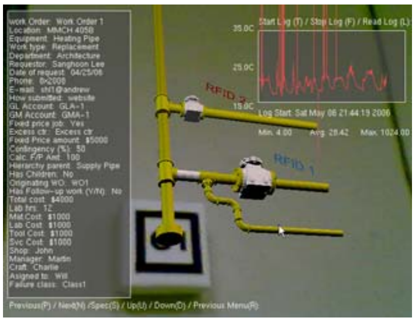

Figure 3. A screen shot of the prototype user interface with RFID

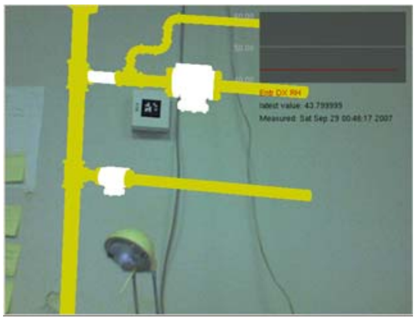

Figure 4. A screen shot of the prototype user interface integrating BACnet protocol

7. Conclusions

This paper discusses the development of an Augmented Reality-based user interface. To identify maintenance activities and associated maintenance information, tradespersons' fieldwork was shadowed. From the shadowing activity, core maintenance activities and maintenance support activities were identified to elicit primary functions needed for the development of effective computational maintenance fieldwork support. Based on this analysis of fieldwork, the architecture of the proposed AR-based interface as well as a prototype application are being developed.

8. Future work

The development of the prototype application will be completed for verification of primary functions as well as conducting performance tests in terms of usability and efficiency in O&M fieldwork.

Although currently available building information exchange models, such as IFCs and AEX, provide opportunities for identifying object types and their attributes, there are still many unaddressed issues of data access and use. For interoperability and seamless integration of various types of O&M information, the data model developed for this user interface will be refined for compatibility with such building information standards.

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References

Liu, L. Y., Stumpf, A. L., Kim, S. S., AND Zbinden, F. M., 1994. Capturing As-built Project Information for Facility Management. *In: Proceedings of the First Congress held in conjunction with A/E/C Systems '94*. USA, 614-621

Clayton, M. J., Johnson, R. E., Song, Y., AND Al-Qawasmi, J., 1998. A Study of Information Content of As-Built Drawings for USAA. *Retrieved January 14, 2007, from http://archone.tamu.edu/crs//documents/publications/asbuilt.pdf.*

Motegi, N., Piette, M.A., Kinney, S., AND Dewey, J., 2003. Case Studies of Energy Information Systems and Related Technology: Operational Practices, Costs, and Benefits. *In: International Conference for Enhanced Buildings Operations*, Oct. 13-15. Retrieved February 24, 2007, from http://energy.ucsb.edu/_client/pdf/news/LBNLCaseStudy.pdf

Portland Energy Conservation, Inc., 1999. Fifteen O&M Best Practices for Energy-Efficient Buildings. *Retrieved February 10, 2007 from http://www.peci.org/library/PECI_15BestOM_0302.pdf.*

ANSI/ASHRAE Standard 135-2004: BACnet-A Data Communication Protocol for Building Automation and Control Networks, 2004, American Society of Heating, Refrigerating and Air-Conditioning Engieers, Inc., Atlanta, USA.