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A novel maintenance system for equipment serviceability improvement

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ABSTRACT

Maintenance is crucial in prolonging the serviceability and life span of equipment. As manufacturing facilities become more complex, it is often beyond the skills of an individual to perform a completely satisfactory task. This paper presents a novel real-time equipment maintenance system incorporating augmented reality (AR) for context-aware overlay of textual and graphical maintenance instructions on the maintenance scene. The system provides an online communication interface for remote maintenance between equipment experts/vendors and maintenance personnel. Service and maintenance knowledge and experiences can be accumulated through authoring AR-based contents on-site. The proposed system can improve maintenance workflow and enhance equipment serviceability.

1. Introduction

Maintenance restores and improves equipment performance, and is an important part of a product life cycle [1]. However, increasing equipment complexity poses challenges to the engineers and maintenance technicians nowadays. Several aspects of maintenance can be supported with advanced information technologies [2–4]. Augmented reality (AR) technology, which provides a seamless interface between the real and virtual world, can be used to enhance maintenance activities [5]. AR technology is an enabling technology for man–machine–information interaction that can assist maintenance activities. Using AR, maintenance information in multi-media forms can be augmented and aligned virtually in the maintenance area, and collaborative work between the maintenance technicians and the remote experts and engineers can be enabled and enhanced through visual interactions. Thus, AR provides a better approach for providing maintenance information as compared to paper prints and computers and can potentially improve the workflow of maintenance activities.

Application of AR in maintenance activities began in early 1990s and the research focus has been shifted from demonstrating the benefits of applying AR to maintenance to improving the usability of such AR systems in routine and ad hoc maintenance activities. However, no single AR system has yet been proven to be well accepted by the industry [6]. To improve the usability of AR systems in routine and ad hoc maintenance activities, several issues have to be addressed. Firstly, the maintenance information should provide context-awareness. A system can be deemed as context-aware if it can collect, reason, utilize context information [7], and adapt its functionality to varying contexts [8]. For example, the details of the maintenance instructions provided can vary according to the expertise level of the technicians. Secondly, the maintenance information provided should be updatable, where the technicians can edit and update the AR maintenance contents while performing maintenance tasks. This is useful as it allows technicians to record and share the knowledge and experience on equipment maintenance, and update any incorrect maintenance information in the database. Lastly, suitable remote collaboration tools should be provided to allow experts, who may be located at different geographical sites, to create AR-based instructions effectively to assist on-site technicians who may need assistance.

This paper addresses these issues and presents a novel AR-assisted maintenance system (ARAMS) for routine and ad hoc maintenance activities. ARAMS provides (1) context-aware information to the technicians, (2) a mobile user interface that allows the technicians to interact with the virtual information rendered, (3) a remote collaboration mechanism that allows the expert to create and provide AR-based visual instructions to the technicians efficiently and effectively, and (4) a bi-directional content creation tool that allows dynamic AR maintenance contents creation offline and on-site. ARAMS can analyze the contexts of maintenance tasks to provide relevant and useful information to technicians through registering and rendering the information on the real equipment correctly. Thus, the system can enhance the efficiency and productivity of maintenance operations. In addition, a content development tool is proposed to allow engineers and technicians to construct context-aware AR-based maintenance contents on-site or offline that can be adapted to the various contexts.

2. ARAMS

ARAMS (Fig. 1) consists of (1) On-site authoring (OSA) for maintenance technicians to create, edit and update AR contents; (2) Offline authoring (OFA) for maintenance experts to develop context-aware AR maintenance contents, and OFA and OSA together form the bi-directional tool; (3) Online authoring (ONA) for experts to create AR-based instructions during remote maintenance activities; (4) Database stores virtual and AR maintenance contents; (5) Context management (CM) collects

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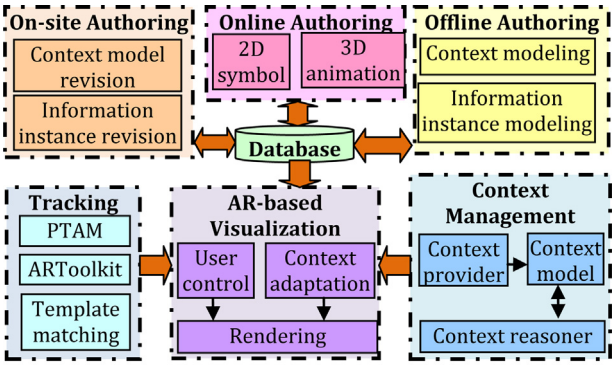

Fig. 1. ARAMS system architecture.

and reasons maintenance contexts; (6) Tracking and registration; and (7) AR-based visualization (ARV) for rendering the AR contents in the maintenance environments.

2.1. Context-aware AR maintenance information

In many reported generic AR maintenance systems, maintenance information can be provided to the users based on the users' contexts. However, these systems usually require users to predefine the virtual contents that are augmented spatially and temporally fixed in the AR environment, such that these contents cannot be adapted to the changing contexts or updated.

In ARAMS, context-aware maintenance information is modeled as information instances to describe preventive maintenance activities, alerts, maintenance instructions, etc. An information instance comprises of virtual objects to describe maintenance information, and has the properties of *Content*, *Format* and *Registration*. *Content* (what to render) is a static property, *Format* (how to render) and *Registration* (where to render) are dynamic properties, and they are adapted to different contexts using static and dynamic rules respectively.

Content has sub-properties of *Item*, *LOD* (Level Of Detail), *SubStep* and *Presentation*. *Item* is the maintenance information described by an information instance. *LOD* is the level of detail of the maintenance instructions described. *SubStep* indexes the instructions of the sub-operations of a maintenance step. *Presentation* describes the type of information, and it can be textual, symbolic or intuitive presentation, where, textual presentation uses texts, symbolic presentation uses symbols, e.g., arrows, and intuitive presentation uses graphics and 3D models. Intuitive presentation is easier for the users to comprehend, and textual presentation consumes the least computing resources. *Content* can be adapted to various contexts according to the requirements of the applications and the users, e.g., the details of the maintenance instructions (*LOD*) can be displayed according to the expertise level of the technicians.

Dynamic properties control the rendering of the information instance. *Format* defines the visual properties, and it has sub-properties of color, transparency, etc. *Registration* controls the registration of the virtual objects in the real environment, and it has sub-properties of translation, rotation and scale.

2.2. Bi-directional maintenance content development tool

A bi-directional maintenance content development tool has been developed for AR developers and maintenance technicians to develop context-aware AR contents. The bi-directional process (Fig. 2) consists of two main steps, namely, context modeling and information instance modeling. Intuitive user interfaces are provided, where a desktop user interface consisting of an authoring panel and the augmented virtual scene is provided in OFA (Fig. 3(a)), and a mobile user interface, consisting of a physical marker and a virtual panel [9] is provided in OSA. The physical marker is tracked in 3D space and acts as a 2D cursor and/or 3D placement

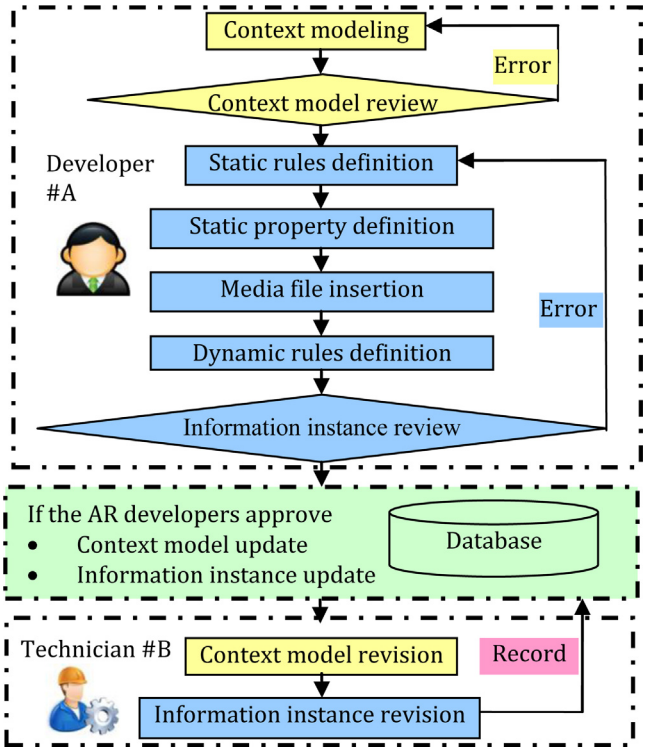

Fig. 2. Bi-directional authoring.

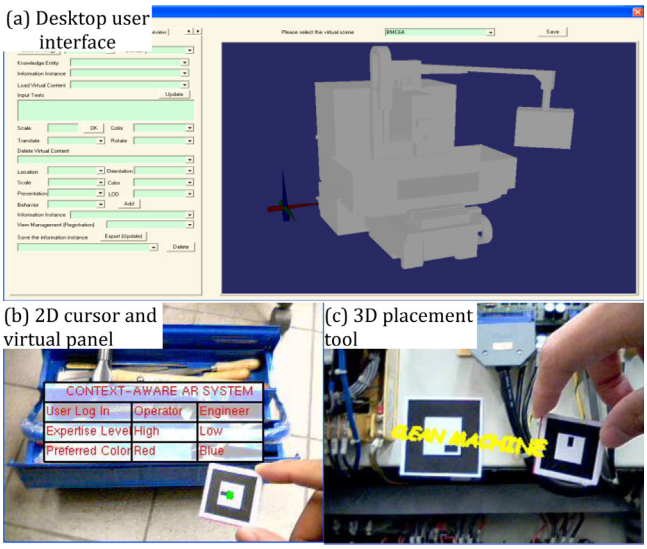

Fig. 3. User interfaces.

tool. The virtual panel is a virtual display of computer augmented information, e.g., virtual buttons. The user can place the 2D cursor on a virtual button for a predefined time range to activate it (Fig. 3(b)). The user can use the 3D placement tool to arrange the virtual objects spatially (Fig. 3(c)).

Information instances of various maintenance procedures and information can be created by defining static property values, inserting media files and defining the static and dynamic context adaptation rules. Various media files, e.g., texts, images and CAD models, can be added to an information instance to be augmented in the virtual scene to assist the technicians during product and equipment maintenance. These media files can be arranged spatially in the virtual scene, and their visual properties, e.g., color, can be modified.

Static rules, which filter the information instances to be rendered and provided to the technicians according to different maintenance contexts, can be defined through relating the desired contexts to the sub-property of *Content*, e.g., a periodic