MOBILE AUGMENTED REALITY FOR SUPPORT OF PROCEDURAL TASKS

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ABSTRACT

Augmented Reality (AR) technology, which could insert digital information into the real workspace scene, is a candidate technology for producing better adherence to correct work procedures by virtue of increasing the means for accuracy. This paper presents the concept of an innovative and paperless method to visually merge digital information into the current workspace of the maintenance crew. As a test-bed for this concept, a prototype named AR-based equipment management system (AR EMS) was developed for procedure-related tasks that are normally guided by reference to some documentation. From the perspective of human factors, AR EMS is envisaged to facilitate the association of document-based knowledge corresponding real equipment systems and components by complementing human associative information processing and memory. This paper explores these potential ergonomics benefits of AR EMS in procedure-related tasks. Future work includes designing experimentation to validate the benefits of AR EMS in procedure-related tasks against prevalent benchmark methods.

KEY WORDS

Augmented Reality, human factors, procedural learning, visualization

INTRODUCTION

Equipment management is a process that monitors the operating condition of equipment, maintains and repairs equipment components by referring to technical specifications, and generates more information for future access. Currently, the field crew heavily relies on paper-based documents to access and record information. The field crew often faces the problem of not finding the right information in a convenient and timely manner, which makes this approach labor-intensive. Although more information technology (IT) tools such as personal digital assistant (PDA) and wearable computers are being explored for storing, conveying, and accessing information instead of relying on paper media, the way information is presented by these IT tools is essential to operational effectiveness for the crew and supervisors from the perspective of human factors. Augmented Reality (AR) can create an augmented workspace by inserting content from the virtual space into the physical space where individuals work. Such augmented workspace is realized by integrating the power and flexibility of computing environments with the comfort and familiarity of the traditional

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workspace. This paper presents the concept of an innovative and paperless method to visually insert digital information into the real workspace of the maintenance crew. As a test-bed to prove this concept, a prototype named Augmented Reality-based equipment management system (AR EMS), developed for procedure-related tasks (e.g., maintenance, repair, etc.) that are normally guided by reference to some documentation is presented.

SYSTEM ARCHITECTURE OF AR EMS

The objective with AR EMS is to provide AR scenes that are annotated with types of information that are normally acquired through training and, in essence, support humans in procedure-related tasks. These capabilities include obtaining information, domain expertise, procedural knowledge, etc. The approach can alleviate much of the information overload and training required from maintenance personnel, which can improve maintenance procedure efficiency. In the proposed AR EMS prototye (see Figure 1), the user is able to browse spatially correspondent digital information about a task within a specific operational procedure. Wireless communication and collaboration with office personnel could also be realized to aid the effective search for "right" information from large amounts of technical specifications that are otherwise cumbersome for the mobile user to carry. As a test bed to evaluate the above concept, an initial technology platform has been developed with the following major components: *display*, *mobile computing unit*, and *tracker*.

Figure 1. Illustration of User's Setup of AR EMS

DISPLAY SYSTEM

The display system (see Figure 1) used in AR EMS is a lightweight ARvision-Stereo head-mounted display (HMD) with a built-in color video camera that is used to capture the real scene for video-based tracking algorithm. The cameras act as the eyes of users and their position and orientation are tracked by special tracker.

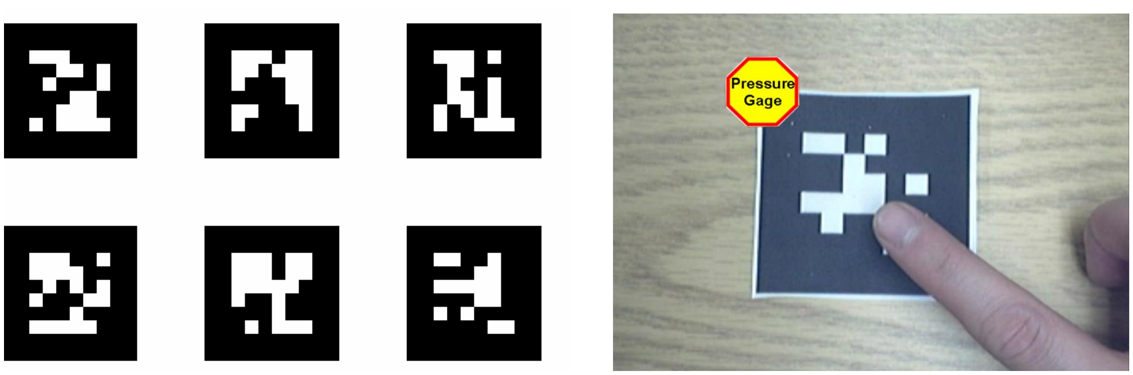
MOBILE COMPUTING UNIT

A high-performance, light-weight tablet PC (see Figure 1) was used as the mobile computing unit that consists of Local Database and AR program. Existing imagery and data about equipment can be collected in order to compile a comprehensive, equipment-specific database of information. The way that the system adds labels is that the fiducial beside an object or component identify the component. As the component is identified, the system sends a query to the Local Database, which returns any labels matching the object's features. The AR program is the core technical component for rendering pipeline for the whole system, just like the brains of the system. Visual C++, OpenGL, and VRML are used as the development environment.

TRACKER

The tracking approach adopted by AR EMS makes use of the ARTag system (Fiala 2004), a 2D fiducial marker and computer vision system for Augmented Reality. Fiducial marker systems consist of patterns that are mounted in the environment and automatically detected in digital images using an accompanying detection algorithm. ARTag uses digital coding theory to get a very low false positive and inter-marker confusion rate with a small required marker size, employing an edge linking method to give robust immunity to lighting effects and occlusion.

The fiducial markers used in the ARTag system are bi-tonal planar patterns that consist of a square border and an interior region filled with a 6×6 grid (a digital 36 bit word) of black or white cells. Figure 2a shows some examples of ARTag markers. Quadrilateral contours are located in the image which may belong to the outside border of a marker. They are found in ARTag with an edge-based method, and edge pixels are threshold and linked into segments, which are in turn grouped into "squads." The four corners of the squad boundary are used to create a homography mapping to sample the marker interior. Then the 36-bit word can be extracted from a camera image of the marker once the boundary is determined. The digital word contains a unique ID number.



(a) **(b)**

Figure 2. (a) Bi-tonal Planar ARTag Marker Patterns Consisting of a Square Border and a 6×6 Interior Grid of Cells; (b) ARTag Marker Detection under a Large Occlusion.

A major advantage to ARTag's edge-based approach over similar fiducial approaches is the ability to still detect marker outlines in the presence of an occlusion. In Figure 2b, one marker has a corner covered but is still detected by heuristics of line segments that almost meet.

FUNCTIONALITIES AND SCENARIOS

A maintenance scenario that can be implemented by AR EMS is demonstrated in Figure 3. A portion of a polysiloxane pilot plant is shown in Figure 3 (left) with varying annotation that is generated in response to the context of a maintenance procedure. The wearble AR EMS prototype setup for a maintenance crewmember has been shown in Figure 1. The recognition of the fiducials causes the identification of components and virtual tags are spatially arranged in the task area for a particular view to identify each component (see right picture of Figure 3). Annotations appear automatically in the camera view; the easy access to information increases usability. Virtual tags relate information to the context of the work area (callouts identifying agitator motor, jacketed vessel, pressure gage, etc.), and guidance on the next action to be performed (see the virtual yellow arrow in Figure 3 showing the next item on the plant to inspect).

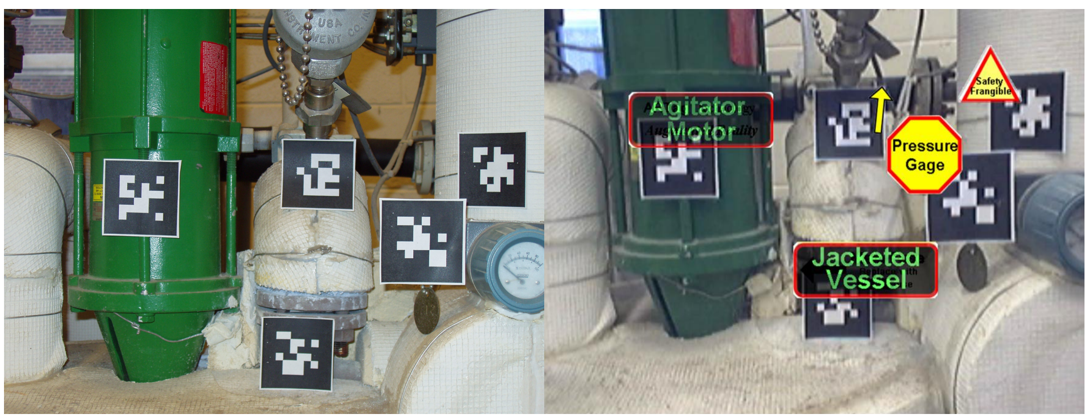


Figure 3. Scene of Markers Arrangement on Equipment (Left) and Augmented Reality Scene with Virtual Tags Overlaid onto the Real Counterparts (Right)

Different shapes of virtual tags are used to represent different kinds of components. Rectangular tags represent the general equipment components. Octangular tags represents gages (e.g., pressure, temperature, etc.). Triangular tags indicate a warning orcaution for certain hazardous components or steps in the inspection. The virtual tags can also automatically change in size — even in their proportion to the fiducial marker — based on the distance between the tag and the user (see the difference between upper left and upper right of Figure 4). While the user views the marker from far away, the tag appears large so that the information can be seen clearly (see upper left in Figure 4). When the user leans in close to the tag, the tag appears smaller, so as not to obstruct the user's view of real object details (see upper right in Figure 4).

The prototype provides two options for orienting the virtual tags based on the associated fiducials. If the orientation of the virtual tag does not matter, the associated fiducial can be randomly oriented, and the virtual tag always appear horizontal (compare middle left and right in Figure 4). If the orientation of the tag does matter, then the appropriate fiducial marker is selected and needs to be placed carefully according to the preferred orientation. In this case, the orientation of the virtual tag is the same as the one of the associated fiducial (compare lower left and right in Figure 4).

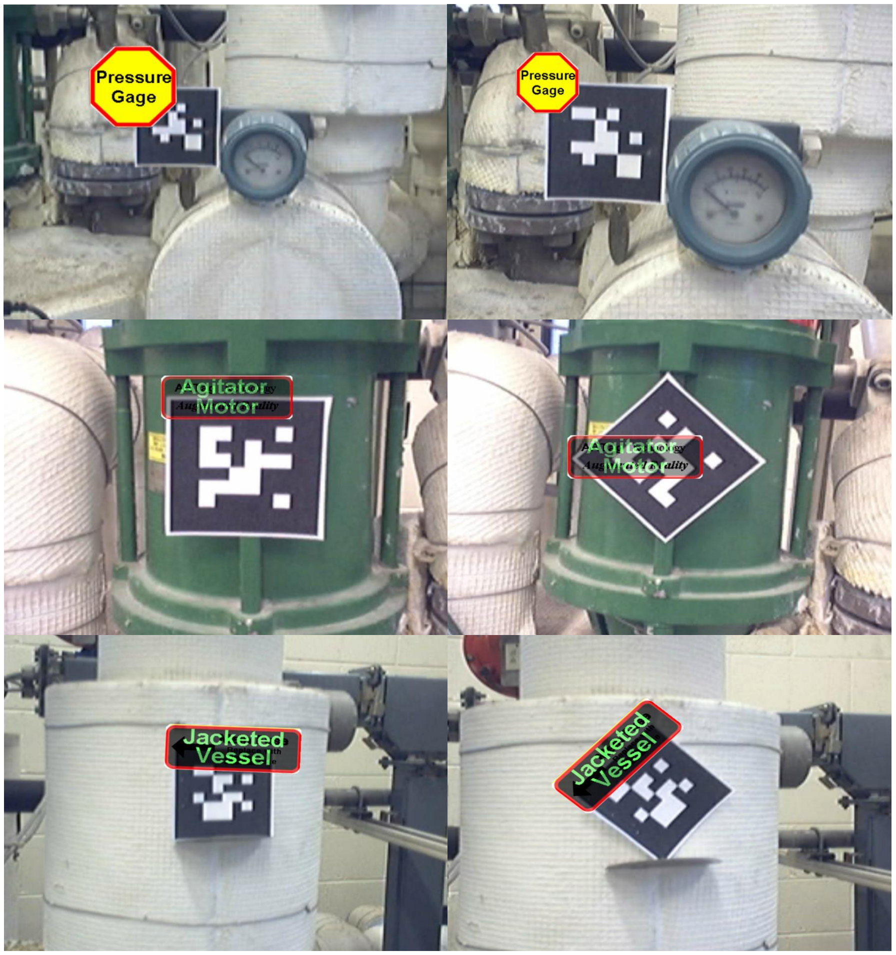


Figure 4. Illustration of Functionalities

INVESTIGATION OF ERGONOMICS BENEFITS OF AR EMS IN PROCEDURE-RELATED OPERATIONS

From the perspective of human factors, AR EMS could facilitate the transition from document-based knowledge to association with the workpiece by complementing human associative information processing and memory. The value of the human making an inspection is the application of unique human abilities to the examination of processes or objects. These are abilities such as detection of meaningful stimuli and patterns that are too difficult or too costly for automated systems to detect and evaluate, comparison to standards, and qualitative judgment. This section explores the ergonomics benefits of AR EMS in procedure-related tasks.

EASY INFORMATION RETRIEVAL

The worker searches a medium (e.g., paper manual, laptop computer) for information, often in the form of a technical drawing or photograph. AR EMS can trigger the appearance of virtual objects simply through the user's view of real equipment. The mechanism of enabling workers to see virtual procedural instructions by looking directly toward a real workpiece is very different from workers' conventional interactions with information about equipment, which is typically detached from equipment. AR EMS could therefore spare the worker search time by triggering information with minimal user effort. By reducing head, eye, and hand movement and increasing eye-on-the-workpiece time, a worker's performance is expected to increase significantly. For example, inspectors with AR EMS interface might be similarly guided through their tasks, which allows them to work without reference to conventional manuals and ensures that every item of equipment which needs to be checked is actually inspected.

LOWER FREQUENCY OF ATTENTION SWITCHING

Rogers and Monsell (1995) have shown that it is easier to keep doing alternate versions of the same task than to switch between different tasks, indicating the presence of some overhead chore, such as retrieving "rules" associated with each task. It is therefore inferred that if cognitive activities in informational tasks can be reduced or if cognitive activities can be integrated into workpiece activities so that they happen concurrently, total task time would be lowered. AR EMS can lower the frequency of attention switching between an information resource and manual tasks at hand by integrating the document accessing activities into workpiece activities and therefore reduce the time and cognition cost associated with the cognitive activity burden required in such repetitive switch.

SPARED WORKING MEMORY

Most of procedure-related tasks rely heavily on the use of working memory. It was recognized that the more items are stored in working memory, the longer time the human needs to retrieve a desired item of information. AR EMS could seamlessly attach the required information to the worker's real world view of the task, releasing part of the working memory occupied by those information items and therefore facilitates efficient retrieval of information from memory.

IMPROVED LEARNING OR RECALL FROM TRAINING

AR EMS could also facilitate effective training of procedure-related opeartions. The trained worker can have an increased extent of skill transfer from training to real operation. The content of a virtual object can be associated with a workpiece feature. AR EMS could create a framework of associations that facilitates recall and learning that otherwise are very essential to the practical operation. Each association of a virtual object with a workpiece feature forms basis for a link in memory that might not otherwise exist. In the procedure-related tasks, as the worker encounters the workpiece features, the item associated with the workpiece would also appear, and is therefore available to working memory. The real items create a framework for a worker that can also hold the relevant information that will be recalled. Therefore the extent of skill transfer from training to real operation is increased.

PROPOSED EXPERIMENT

The potentials of AR EMS in increasing the worker's compliance with correct procedures will be demonstrated by the observations of the prototype trials in a construction equipment engine maintenance scenario. An experimental study is also proposed to compare the effectiveness of the system in procedure learning compared with various prevalent electronic and traditional paper-based medias. The authors are going to invite human subjects into an experiment where they will be asked to use AR EMS, a Virtual Reality system, wearable/portable computers (PDA), and paper-media specifications to perform a routine equipment maintenance procedure task. Their performance measured by various indicators will be recorded and compared.

CONCLUSION

This paper presented a prototype named AR-based equipment management system (AR EMS) developed for procedure-related tasks (e.g., maintenance) that are normally guided by reference to some documentation. AR EMS is envisaged to facilitate the transition from document-based knowledge to completed work unit by complementing human associative information processing and memory. This paper also explored these potential ergonomics benefits in procedure-related tasks. Future work includes designing experimentation to validate the benefits of AR EMS in procedure-related tasks against prevalent benchmark methods.

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REFERENCES

Fiala, M. (2004). "ARTag Revision 1, a fiducial marker system using digital techniques," NRC/ERB-1117, NRC Publication Number: NRC 47419, November 24.

Rogers, D., and Monsell, S. (1995). "Costs of a predictable switch between simple cognitive tasks." *Journal of Experimental Psychology: General*, 124, 207-231.