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Improving Human-Machine Interfaces for Construction Equipment Operations with Mixed and Augmented Reality

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1. Introduction

Construction equipment operation and management is a process that operates the machine in different working conditions, monitors the operation condition of equipment, maintains and repairs equipment components by referring to technical specifications, and generates more information for future access (Wang & Dunston 2006a). These construction operations are being carried out on different platforms. This makes it difficult to visualize and process critical information at any time and place. Many evolving information technology (IT) systems bring solutions into the construction field data management and sharing (Yang et al. 2000). Based on the data/information managed and stored in such IT tools, innovative and efficient human-machine interfaces that could visually merge these data into the current workspace of crew can be developed to increase the operators' situational awareness and achieve less information access cost of operators and maintenance crew.

Mixed and Augmented Reality can fulfill this vision by creating an augmented workspace through inserting digital contents into the physical space where operators work. Such augmented workspace is realized by integrating the power and flexibility of computing environments with the comfort and familiarity of the traditional workspace (Wang & Dunston 2006a). Augmented Reality (AR) opens a promising gate for integrating designs into their to-be-built real-world context. For example, AR could assist in quality assurance by comparing as-built facility with corresponding design as well as constructability review prior to the actual construction. Outdoor AR systems could assist in demonstrating architects/designs/constructors/owners what a new structure/building would look like at its final setting for evaluating functions and esthetics of a design. For example, an urban designer could show clients/politicians what a new building would look like as they walk around the neighborhood, to better understand how a tall building might affect surrounding residents.

Outdoor and mobile AR systems have just begun to become feasible due to advances in tracking and computing. Traditional tracking systems used for AR registration are intended for use in controlled indoor spaces and are unsuitable for unprepared outdoor environments such as those found on typical construction sites (Behzadan Kamat 2006). Except wide applications in tabletop and indoor AR systems, fiducial markers could also be an easy way for outdoor AR. For example, Klinker et al. (2001) accurately erected a virtual

wall at a real construction site by using fiducial markers as tracking technology. Shen et al. (2001) developed an Augmented Reality system for urban planning and environmental assessment based on the approach of affine representation. As an image-based method, in addition to saving more time, it also presents more realistic and objective results than traditional graphics-based Virtual Reality (VR). With this system, users only need a digital camera to realize a more realistic VR by fusing the virtual buildings of different sizes or sites into a real 3D scene. Kamat and El-Tawil (2005) conceptualized a system which could allow on-site damage inspectors to retrieve previously stored building information, superimpose that information onto a real building in augmented reality, and evaluate damage, structural integrity, and safety by measuring and interpreting key differences between a baseline image and the real facility view. Thomas et al. (1999) developed an Augmented Reality system TINMITH2 to visualize a simple extension to a building in spatial context of its outdoor final physical surroundings.

Unlike indoor AR where the user is limited to navigating in a restricted space, users with outdoor AR systems needs the ability to navigate freely with minimum constraints. Behzadan and Kamat (2006) developed an Augmented Reality prototype system UM-AR-GPR-ROVER. They used a Delorme Earthmate WAAS enabled Global Positioning System (GPS) receiver and an InterSense InterTrax2 head tracking system to determine the user's position and orientation. These tracking data could achieve generating an accurate representation of augmented space in a real time manner so that the user could experience the world where virtual excavator stay fixed to its real-world location. The tracked information is then reconciled with the known global position and orientation of computer aided design (CAD) objects which are to be registered into the user's real world view. From this computation, the relative translation and axial rotations between the user's eyes and the CAD objects are calculated at each time frame. The relative geometric transformations are applied to the CAD objects in order to generate an augmented outdoor scene.

Observation and monitoring of change and attempts at the creation of more realistic simulations of the evolving environment have also become key research fields. Ghadirian and Bishop (2002) developed an interactive visualization system which combines Geographical Information System (GIS)-based environmental process modeling with use of AR technology to present environmental change and then monitor people's responses to and behavior in real world situations in a 3D immersive environment.

Besides the application of AR to facilitate construction processes, there are other research projects where AR technology is used to visualize hidden information (e.g., wires, pipes, and beams in a wall), non-graphical information (e.g., procedural information, maintenance schedules and records), and invisible information (e.g., heat and pressure of pipes) in assembly, maintenance, and repair of complex facility and machinery. It has been suggested that an AR system might give users "X-ray vision" inside a building, allowing them to see where the pipes, electric ducting, and structural supports are inside walls and above ceilings (Webster et al. 1996). Examples include the Augmented Reality systems by Roberts et al. (2002) and Lawson & Pretlove (1998). In all of these applications the main thrust of the research is to use AR techniques to augment physical objects in the environment with additional information or views of their hidden structure. Maintainer and repairer could use AR as a visualization aid for maintenance and repair. These datasets could then be rendered and combined in real time with a view of the real structure. This would be very useful for minimally-excavation/invasive operation, which reduces the opening of a structure/object

by using small cuts or no cuts at all. AR technology could provide an internal view without the need for larger openings. This might also guide precision tasks, such as displaying where to drill a hole into the pipe for testing. The information from the non-invasive sensors would be directly displayed on the object/structure, showing exactly where to perform the operation. Non-graphical representation can also be used as in the Augmented Reality-based equipment management system (AR EMS) by Wang & Dunston (2006). Invisible information can also be indicated by AR, for instance, a red-to-blue coloring scheme was used by Klinker et al. (2001) to represent temperature variations and distributions within heating pipes.

This chapter introduces information on Mixed Reality (MR) and Augmented Reality (AR), and their existing research applications in the area of construction equipment operations. This chapter also elaborates two systems in the area of construction equipment operations: the first system is a Mixed Reality-based interface for backhoe excavations in dangerous working environments; and the other system is an Augmented Reality-based information management system for maintenance, repair and inventory checking of heavy construction equipment. Conceptual designs for these two systems are developed and presented with certain scenarios identified. Discussion of limitations of Mixed and Augmented Reality technologies in these systems are also discussed.

2. Mixed and augmented reality immersive technologies

Virtual Reality generates a complete virtual environment (VE), simulated or completely synthetic, that surrounds or immerses the users. Mixed Reality, defined by Milgram et al. (1994, 1999), is a special class of Virtual Reality — related technologies for creating environments wherein real world and virtual world objects are presented together in a single display. Augmented Reality that is a sub-mode of MR can create an augmented workspace by inserting the virtual space in which we store and interact with digital contents into the physical space where we work. Mixed and Augmented Reality differs from immersive VR in that it does not try to block the surrounding real environment from user.

Mixed and Augmented Reality systems use more varied media representations to augment the real environment than VR and two or more types of media representation can be presented one single system termed as hybrid representation. Based on the level of fidelity, the identified major classes of media representations are texts, indicators, platform (tablet and screen), 2D image, 3D wireframe, 3D data, and 3D object (Wang & Dunston 2007). High-fidelity representation conveys more detailed and richer information that can assist human's comprehension ability thus augmenting the cognitive process and activity. However, such high-fidelity setting may indirectly trigger usability problems associated with lag and low frame rate simply because computing power is limited (Wang & Dunston 2007). Input device is typically used to manipulate digital information displayed over the real environment. Most of the input devices used in virtual environments can also be applied in AR systems. More information regarding the input device can be found in (Gabbard 1997). Voice input, a more direct, natural form of interaction, can be achieved as an extra input to increase input capability of the whole system. Also, haptic devices can also be input module through devices like Phantom (Massie & Salisbury 1994). The display can be generally classified as visual display (e.g., head-mounted displays), acoustic display (e.g., 3D localized sound systems), and tactile display (e.g., force feedback devices). Visual

displays are the most popular one used in AR systems with other types of displays as supplement. An elaboration on advantages and disadvantages of video-based see-through mixing and optical see through combination can be found in (Azuma 1997). Trackers are used to measure the motion of the user's head or hands, and sometimes eyes. Accurate registration and positioning of virtual objects in the real environment requires accurate tracking of the user's head and sensing the locations of other objects in the environment. Most tracking technologies are context-aware approaches and different technologies are available for tracking depending upon the application. Major trackers include mechanical, inertial, magnetic, ultrasonic, optical, and infrared tracking systems. For detailed comparison of tracking technologies, readers are referred to the surveys in (Ferrin 1991; Meyer 1992; Applewhite 1991; Holloway & Lastra 1995). For mixed environments that require large user-roaming areas, sophisticated ultrasonic tracking systems may be used to increase user range. Future tracking systems that can meet the stringent requirements of AR will probably be hybrid systems, such as a combination of inertial and optical technologies (Azuma 1997).

3. Application in remote excavation of dangerous materials

The existing dangers for human life in construction sites with dangerous materials beneath extort the needs to elaborate the remote and automatic systems for universally used machines and vehicles to make them safer for operators. Even though in this section we will discuss a civil-related system example proposed to use for demonstrating the concept, the concept can comprehensively facilitate the state-of-the-art of the whole teleoperation and telerobotics. This new Mixed Reality-based human-machine interface provides a more immersive, and compelling way to view video from real world scenes than the traditional method with limited field of view. The cameras mounted on the remote vehicle could acquire images of the explored environment. The camera parameters can be tracked by a combination between GPS and mechanical tracker, which are then sent to vision system for rendering the mixed scene as shown in Figure 1. These camera parameters and video
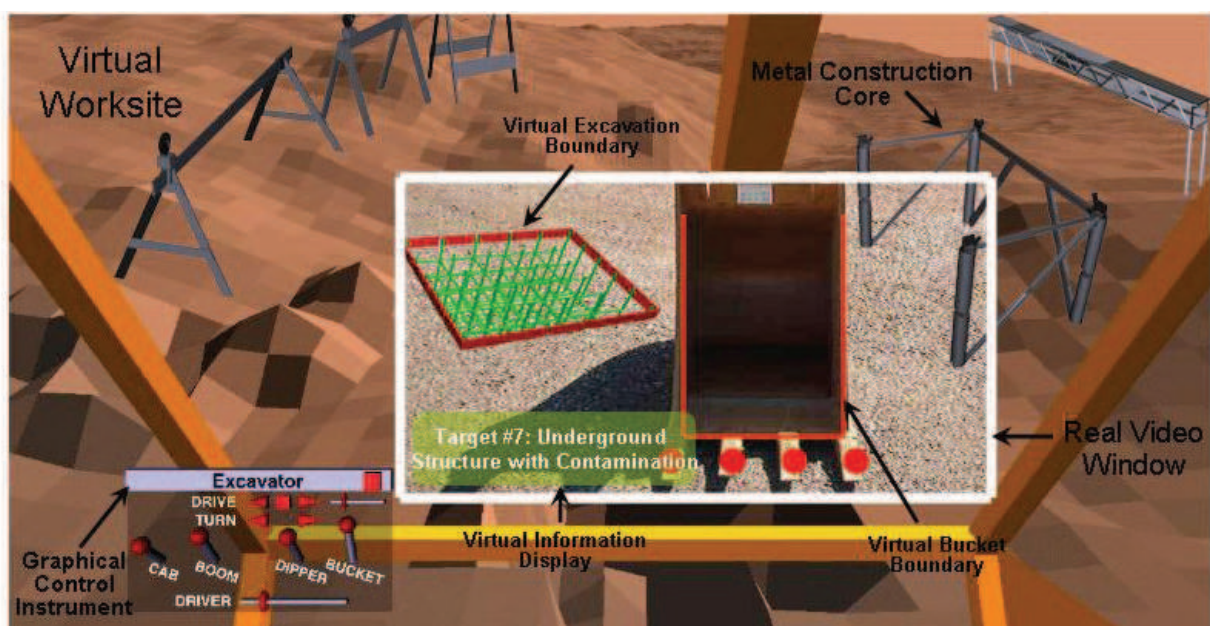

Fig. 1. A Sample Mixed Reality Display Screen for Teleoperation (Wang and Dunston 2006b)

streams are automatically acquired and synchronized in a real time manner. The extent of seamlessness of border between the video and the outer virtual environment depend on the following factors: calibration, the accuracy of modeling the real surroundings, lighting and the angle the camera makes with the objects surface (Wang & Dunston 2006b)

3.1 Current issues in remote excavation

The practical example application area that we are studying is the remote inspection and excavation of accidentally spilled or released hazardous materials in unstructured environments, which is a hazardous and, indeed, largely inaccessible environment. Currently, remote inspection and excavation are performed using a single camera mounted on a remote-controlled vehicle/robot that can transmit monoscopic color video information from the field to the human operator. The operator, using the visual feedback of the video, controls the vehicle and the camera head using certain control device. The inspection and excavation are assessed through the data from sensors, operator's knowledge and experience, inspection conditions, and camera characteristics. The accurate detection and excavation of hazard materials in a large unstructured environment using current methods is therefore a demanding task for the operator. Accurate assessments may not be achieved in practice as the nature of current teleoperation system is often too limited in visual interface/aids, placing high demands upon the skill and concentration of the operator. For example, in traditional CCTV teleoperation systems, the use of monoscopic video displays eliminates all binocular depth cues. The loss of these important cues results in situations wherein the location and size of an object in the remote scene is ambiguous. An additional failing as noted earlier is that it is very difficult to keep a satisfactory level of situational awareness for safe exploration due to inevitable restrictions in the field of view of the remote camera(s) and in the quality of the visual displays fed back from the remote worksite (Wang & Dunston 2006b). To address the above issues, a MR-enhanced visual interface was conceptually designed for remote excavation. The mechanisms and strategies of the teleoperation system are formulized in the next section.

3.2 Architecture of MR-enhanced visual interface for remote excavation

The framework of the teleoperation system with visual interface enhanced by Mixed Reality concept is conceptually designed for remote excavation of dangerous materials in an unstructured environment. Here, the technical components for the application of the MR-enhanced visual interface instead of other automotive and robotic components (e.g., how robots are controlled) are explored, verified and presented. Basically, the entire visual system consists of two basic modules: observation set and operator position. The developed conceptual scheme of elaborated visual system is presented in the Figure 2. In this system, three channels radio link has been applied. Two one-direction channels serve to send television signal while the two-direction channel serves to send steering and manipulation signals. A tethered vehicle is proposed to be built so that, in as many ways as possible, it mimics the basic design of commercial remote excavation platforms. Our goal is to improve the interface between the remote environment and the operator using MR and stereoscopic vision.

Observation Module

Observation set consists of a steering camera-head mounted symmetrically on a rotary beam. Observation module serves to observe the explore environment or chosen objects

with cameras. The remote machine is able to roam around a real space while sending video updates to a virtual world model of the real space. Its construction allows to observe chosen objects with both cameras (carrying out stereovision process) or observation the objects located in different directions. Stereoscopic cameras allow achieving relatively high spatial vision and in comparison with one eye techniques (one-camera) it leads to quantity measurements, more direct and unambiguous. Stereo cameras are mounted on the vehicle via a pan and tilt robotic head system (Pretlove, 1996). The stereo device is capable of independent vergence and common pan and tilt of two remote-head color CCD cameras with independent control of all four degrees of freedom. The change of the axis of rotary beam rotation is done by its steering head. The typical operation of the head is that the pan and tilt axes are slaved to the motion of a human operator's head using two degree of freedom (DOF) of a three-DOF head-tracker mounted on a head mounted display (HMD). The system should allow an operator to intuitively control the gaze of the cameras and provides additional stereoscopic depth cues to enhance their perception of the remote scene. The visual display proposed to be used is HMD through which the operator is immersed into a mixed scene environment disregard the surrounding working environment.

Tracking Module

As elaborated in the last section, the graphics methodology for overlaying two virtual cameras as the same position to the real camera requires the parameters of the real observation cameras. Then the virtual machine might be properly situated in the virtual workspace, that is, its base reference frame can then be positioned correctly with respect to the workspace frame. The accuracy of this virtual/real correspondence is quite critical. In principle, the system must always know the position of the camera frame with respect to the mobile base, any changes in vehicle position should be updated by certain tracker. The following types of trackers are envisaged to be combined to produce the data that can be readily used by graphics module for rendering the virtual entities.

- *Position of observation cameras*: In mobile robotics applications, it is a common practice to use external sensing systems, such as radio frequency beacons, optical tracking, GPS, etc., to report the robot position in the workspace. GPS system mounted to observation camera reads their azimuth and specifies: set location in geographical coordinates, and sea level. The data about camera parameters and the location and orientation of observation set are sent to controller and moreover might by displayed on the monitor screen. Also, the data from GPS might be plotted on digital map which would allow drawing e.g., the route of a vehicle drive (with mounted vision system). Then the route by which the robots have traveled can be displayed in virtual environment as a reference.
- *Orientation of observation cameras*: The orientation of the camera can be tracked by a mechanical tracker mounted onto them, which can reach is high precision in a limited physical volume.
- *Machine states measurements*: Another source of data fusion comes from the remote machines, which typically have a variety of internal sensors that are used to measure and report current states. These states are typically positions, joint angles, tilt angles, velocities, accelerations and forces. These signals are relayed to the system as a real-time data stream.
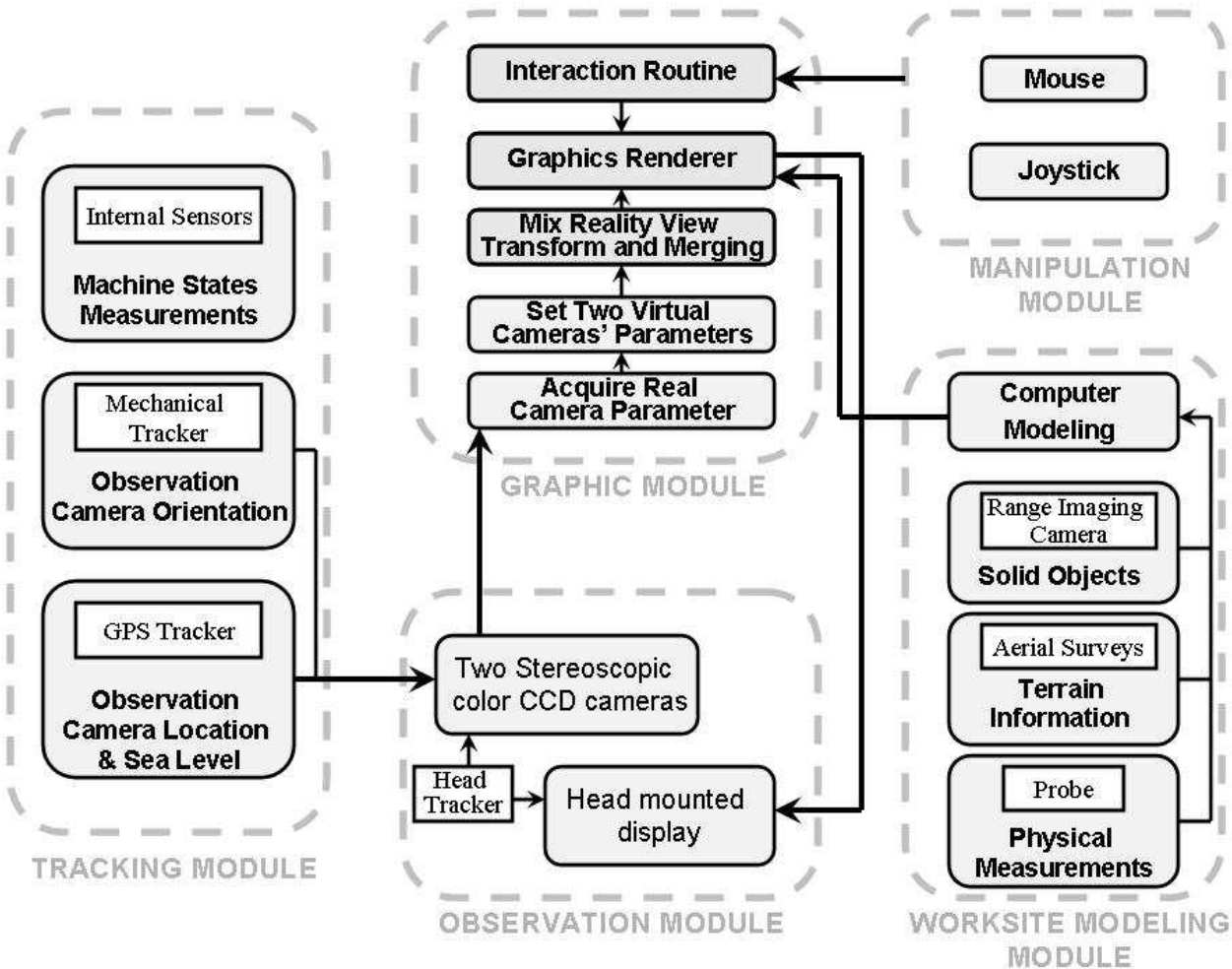
Fig. 2. System Architecture of MR-Enhanced Visual Interface for Remote Excavation

Worksite Modeling Module
The construction of a simplified virtual counterpart of the real environment that is not captured by the observation cameras, relies heavily on sensors and their ability to generate models of the world. The proper method should be exploited based on the features of working space and task requirement. The following sensing methods are proposed to be used together in constructing a virtual working environment.

- *Remote range imaging camera*: The range imaging data can be acquired by 3D laser range scanning system (Greenspan et al 1995). Data sets produced by this system can be displayed as surface representation, and are usually readily interpreted as images by the human operator, especially if the viewpoint is dynamically adjustable. It provides a normal vector at every surface location, thereby enabling artificial lighting models. Range sensors are used to sense solid objects in the working site such as obstacles, humans, other equipment and materials, and working units.

- *Aerial surveys*: This method is able to cover large working area and thus tend to involve very large files due to maintaining tolerable resolution of the data sets. The digital terrain map of working site can be collected and then integrated with other sources of data sets to construct a nearly complete virtual representation of real working environment.

- *Probe*: This can be used to collect readings made at several placements and orientations of a collimated sensor probe. For example, by knowing the probe characteristics, and the position and direction of the probe with respect to the surface that contains the radioactive material, an estimate of the radioactivity level at the surface of the objects being monitored may be calculated. Other measurements which may be treated this way include eddy-current signatures for metal surface inspection, temperature readings and coating thickness. Usually, these physical measurements do not explicitly include those particular locations data in 3D space. These must instead be inferred from the known or estimated positions of the sensor and other local objects at the time the sensors are sampled.

Manipulation Module

In addition to standard mouse-activated pull-down menus, buttons, sliders, and pop-up forms, two 2-axis joysticks can be integrated with force reflection capability, for remote excavator control. In the "dig" mode, joysticks can be used to control the four axes of the excavator arm (e.g., swing, boom, stick, shovel, etc.). The force reflection feature is used to indicate to the operator any collision with the virtual barriers mentioned above. Alternatively, in the "travel" mode, the force reflection feature is used to indicate "movement" by simply vibrating the stick.

Graphics Module

The major task of graphics module is to receive data from tracking and worksite constructing modules and then build the whole mixed environment scene following the methodology presented in last section. For virtual entities in AR portion, the graphics module can import and display 3D CAD models of objects such as scene props, virtual barriers and 3D stencils onto the real video stream. Also, the 3D models and surfaced range images can be used as geometric templates to support the display of other data being measured, such as temperature, pressure, etc.

3.3 Challenges and issues

While providing human viewers with extra-sensory information has a wide range of applications, adding visual information also presents the viewer with several perceptual and engineering hurdles. Some important issues for the development of the teleoperation system, though not covered in depth here, include: managing and controlling the quantity of extra-sensory information displayed, integrating multimodal cues (haptic and auditory sensations) from obscured locations, and interacting with information across multiple depth planes. The author believes that the largest and most challenging class of issues confronted in the MR-enhanced operator interface is depth ambiguity, more specifically relative distance judgment, while visualizing obscured information. The MR-enhanced operator interface can enhance the operator's perception of the real environment by showing information the operator cannot directly sense when unaided. The operator can be endowed with "X-ray vision," enabling him/her to see through the ground surface to view the buried hazardous materials underneath. However, displaying such hidden virtual objects in a manner that a user intuitively understands is not always trivial. It is essential to perceptually convey the difference between what is obscured (not visible) and what would be in plain sight (visible). This is especially problematic for the visual displays that are most often a planar projection (2D) view of a Mixed Reality 3D environment. The position of virtual buried objects in depth can become ambiguous when 3D information is presented on

a 2D planar surface (i.e., information about depth becomes lost and thus is ambiguous). In such a planar view, the exact location (especially in depth) of virtual objects is inherently ambiguous. Thus, in an extended vision environment, where a virtual hazardous structure could be buried 2 feet or 4 feet underground, it is important to properly convey the depth information of the target. The AR display must make this relationship intuitively obvious or it may be more confusing than it is helpful. Approaches of solving this technical issue for effective visualizations of occluded information in the MR-enhanced operator interface can be driven by the application of perceptual psychology and cognitive science principles. In the development of the entire MR interface, one of the proposed future works will focus on developing approaches to accurately visualize the obscured virtual objects relative to real objects such as ground earth and excavation equipment end effecters (e.g., bucket). Alterative approaches will also be validated through experimental techniques.

4. Application in construction equipment repair and maintenance

Everett (1994) revealed that automation and machinery are suitable for physical-intensive tasks, which can be done by machine, and humans are still more cost effective at information-intensive tasks that require judgment, sensing, and adaptability. An interesting finding is that compared to automation and machinery appropriate for the physical-intensive tasks that convert information from the paper to the real work with the physical input, Mixed and Augmented Reality-based technology is suitable for information-intensive tasks, which deal with the information communication between the paper and the work. Virtually all construction activities require performance of some information-intensive tasks, which may also be embedded into physical-intensive tasks. AR can augment human's ability of accessing information and documentation, which can enhance the decision-making abilities. For example, MR system can supply the human operator with related necessary information in order to facilitate decision-making such as when and where to start and stop the equipment, how fast to proceed, and how hard to push or dig. The primary objectives in development of this second AR system are:

- To design and prototype a wearable system that could allow a mobile user to access digital information in the form of virtual media objects and real-time data visualizations that are linked to specific locations (equipment, or parts of equipment).
- To develop methods for annotating information that can be displayed to remote experts or other on-site crew.
- To explore the concept of "context visualization", that is develop design guidelines on how to make explicit organization and display of the layers of information and digital data that are attached to objects, site, equipment, as well as information about the relationships between them for a mobile user.

4.1 Application scenario

As the equipment maintenance crew with the AR system moves around, his display is continuously updated such that the tags drawn on the display stick to the real world elements. He can click on any tag to retrieve its maintenance schedule, maintenance history, the manufacturer's contact information, and component properties etc. He can also view text or hear audio instructions for maintenance procedure. Images or pictures may also be displayed as a reference. He also can view the maintenance record to see when a particular

component was last replaced. He can make any annotations for that component, which would be saved. He or other authorized personnel can log in his maintenance work he carries out any time later in the future. The expert can handle several maintenance jobs at the same time. The reason why the expert is there is not only expertise sharing but also he has large amounts of maintenance and equipment technical specification in his computer or at hand. He can either instruct the crew via audio communication or send the updated data (pictures, video, and parameters) to the crew's local database through wireless network. Then such information can be displayed into the crew's view in a real time manner as reference. For example, from the detailed technical specification/drawings at hand, the expert can determine how the wiring is running behind the equipment and find out any other devices, e.g., a component, which the component might be connected to. Figure 3 illustrate a sequential maintenance scenarios that can be implemented this system where the maintenance crew could test hydraulic oil sampled from S.O.S. sampling valves for preventative maintenance. If the user clicks the repair service mode, the AR system can provide an associated pull down list of small tools, consumables, equipment and materials needed to effectively and safely accomplish a repair work. Also, the user can have easy access to training videos for repair procedure for a specific component.
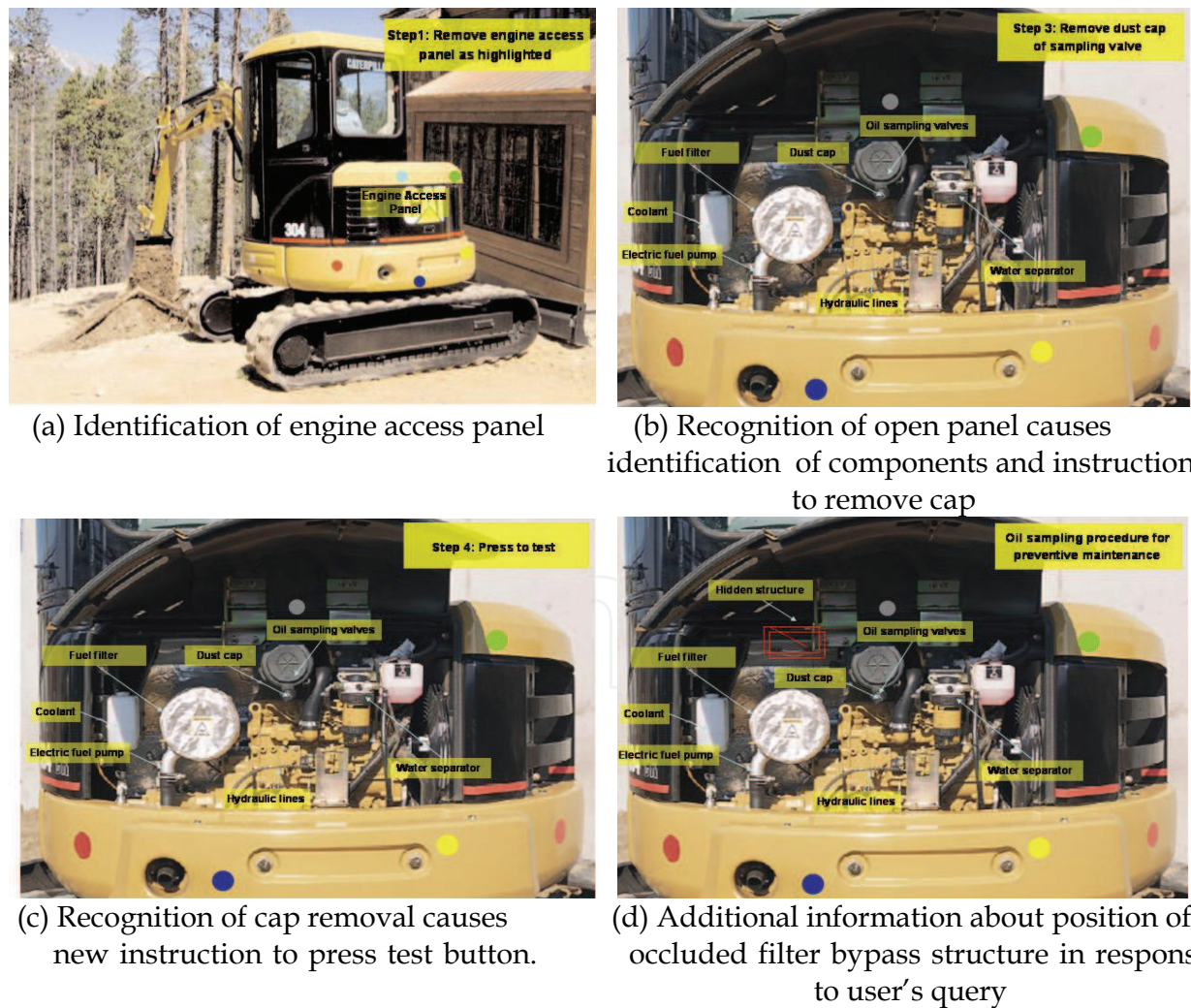
(a) Identification of engine access panel

(b) Recognition of open panel causes identification of components and instruction to remove cap

(c) Recognition of cap removal causes new instruction to press test button.

(d) Additional information about position of occluded filter bypass structure in response to user's query

Fig. 3. Hypothetical illustration of sequence of automatic instructions and information for maintenance task (Wang et al. 2004)

4.2 Conceptual design of system architecture

As a test bed to evaluate the above concept and scenario, an initial technology platform has been conceptually developed that consists of a lightweight stereoscopic HMD system and camera with wireless audio/video transmission that is mounted on a remote user's head and body. Additional subsystems (modules) are added for tracking the user's location and head orientation, interacting with digital contents, accessing data about the equipment and generating data (annotating) to be displayed etc. A total of seven separate modules were configured and Fig. 4 shows the flow diagram for the entire AR system. More details can be found in (Wang et al, 2004). The following sections discuss certain technological extensions which have not been reported in (Wang et al, 2004). They are in the representation module, identification module and input module as shown in Figure 4.
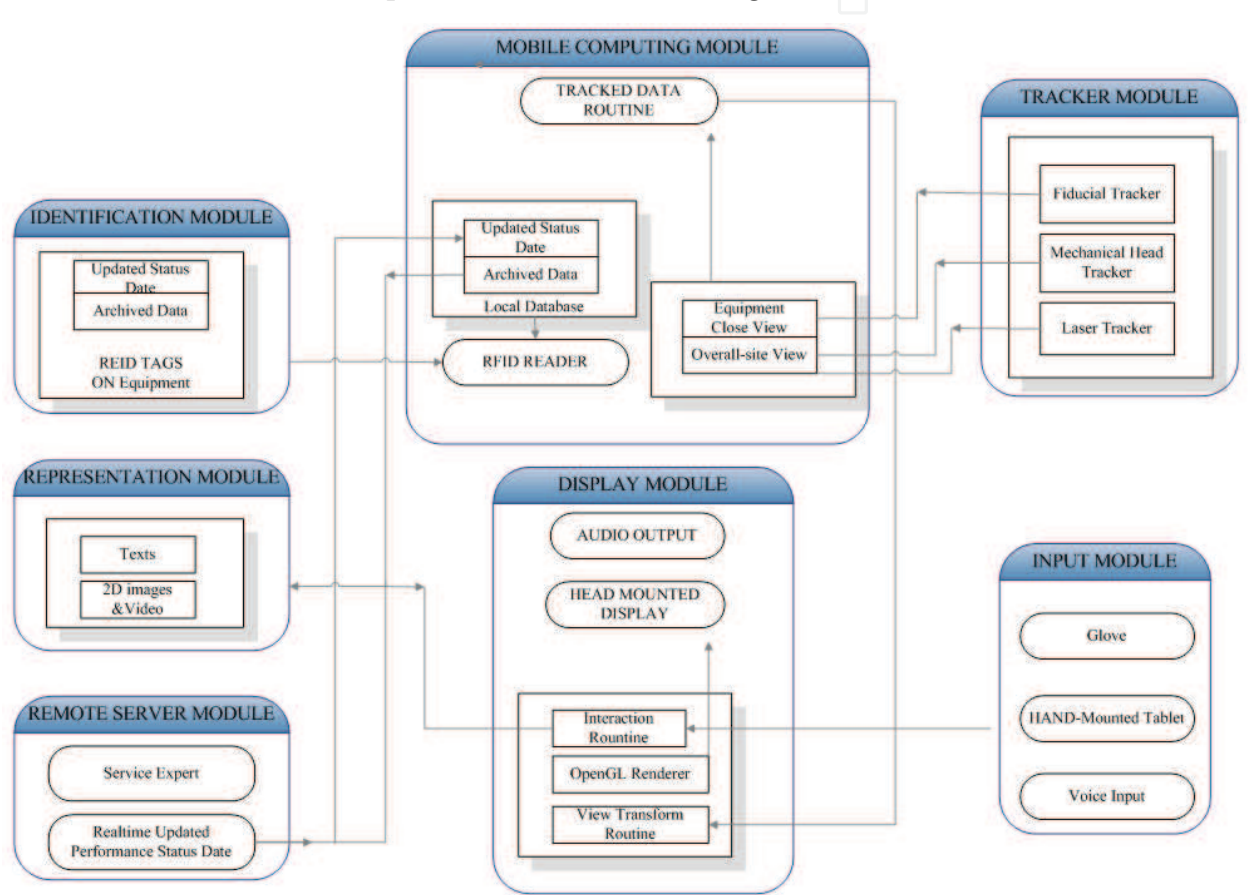
Fig. 4. Generic system architecture and data flow of the Augmented Reality system (adapted from Wang et al. 2004)

Most management information is typically stored in the format of descriptive texts and sometimes images/photos. Simple, informative media representation that actually facilitate real work may provide much more utility for serving the purpose of certain descriptive and procedural applications where users needs much explanatory information from database rather than the geometrical information that high fidelity, true-to-life virtual media can represent. The media representation should be textural description and/or 2D-image/video computationally-intensive (see Figure 4). These representations impose much less intensiveness onto the computing resources of the system.

This AR system can also be enhanced by adding a hypermedia system that provides contextual information in the form of labels and links. Like the use of HTML webpage links, more information can be accessed from clicking the hypertext which is linked to the database. The AR system allows users to experience hypermedia for themselves and manipulate complex information spaces with familiar interaction techniques.

Radio-frequency identification (RFID) technology could be used as the major identification technology to identify equipment (see Figure 4). RFID refers to a branch of automatic identification (auto ID) technologies in which radio frequencies are used to capture and transmit data. Automatic Identification Manufacturers, Inc., Pittsburgh describes RFID systems as those that read data from radio-frequency tags that are within range of the RG-reading equipment. The range is set as 50 yards to the navigating user and outlined working condition information of equipment can be queried from the RFID tags and/or from central server and displayed right beside the equipment via certain tracking technology as DGPS. A RFID tag is mounted onto equipment and signals can be received by readers on the mobile computing unit via antenna. The tags we use is read/write (R/W) tags in which, additional data can be written by overriding or extending the existing data stored in the tags. This enables the whole RFID to be able to update. Jaselskis et al. (1995) provided information on RFID and also discussed potential construction applications and conceptual design systems including concrete processing and handling, cost coding for labor and equipment, and materials control. These potential applications are envisioned to be integrated into the AR system to achieve more application arenas.

The input module stipulates the selection and manipulation of the digital contents. For simple command input, speech recognition (e.g., Microsoft speech recognition software) is sophisticated enough to realize this functionality. Data glove is used to intuitively interact with digital entities (for example, click a linked hypertext) and does not occupy user's hands like other unintuitive devices (e.g., keyboard, mouse, and joystick). A 3D virtual cursor can be controlled via data glove. Hand-mounted tablet can be used to quickly annotate information into the database after daily regular inspection.

5. Summary

Mixed and Augmented Reality is a promising advanced technology for the construction industry that can be integrated into heavy construction operations and equipment management. These technologies can reduce the cost, time, and hazards levels by augmenting relevant activities with digital contents. They are also promising advanced technologies for the construction industry by being integrated into visual interface of teleoperation and telerobotics. This chapter presented two Mixed and Augmented Reality systems and their application scenarios. This chapter also formulated mechanisms and strategies of these two systems.

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Robotics and Automation in Construction

Edited by Carlos Balaguer and Mohamed Abderrahim

This book addresses several issues related to the introduction of automaton and robotics in the construction industry in a collection of 23 chapters. The chapters are grouped in 3 main sections according to the theme or the type of technology they treat. Section I is dedicated to describe and analyse the main research challenges of Robotics and Automation in Construction (RAC). The second section consists of 12 chapters and is dedicated to the technologies and new developments employed to automate processes in the construction industry. Among these we have examples of ICT technologies used for purposes such as construction visualisation systems, added value management systems, construction materials and elements tracking using multiple IDs devices. This section also deals with Sensorial Systems and software used in the construction to improve the performances of machines such as cranes, and in improving Human-Machine Interfaces (MMI). Authors adopted Mixed and Augmented Reality in the MMI to ease the construction operations. Section III is dedicated to describe case studies of RAC and comprises 8 chapters. Among the eight chapters the section presents a robotic excavator and a semi-automated façade cleaning system. The section also presents work dedicated to enhancing the force of the workers in construction through the use of Robotic-powered exoskeletons and body joint-adapted assistive units, which allow the handling of greater loads.

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