DESIGN, STRATEGIES, AND ISSUES TOWARDS AN AUGMENTED REALITY-BASED CONSTRUCTION TRAINING PLATFORM

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SUMMARY: *This paper provides information on Augmented Reality (AR) and their potential applications in heavy construction equipment operator training. Augmented Reality involves the use of special display and tracking technology that are capable of seamlessly merging digital (virtual) contents into real environments. Augmented Reality technology has been applied in many application domains outside construction (e.g., medical applications and surgeries, military training and warfare, manufacturing assembly and maintenance, design and modeling, precinct specific instant information, and various forms of entertainment) and the ever-increasing power of hardware rendering systems and tracking technology should motivate the creation of AR-based systems to benefit construction industry. This paper discusses the potentials of AR in construction equipment operation and operator training. A construction application for AR technology focused in this paper is an AR-based real world Training System (ARTS) that trains the novice operators in a real worksite environment populated with virtual materials and instructions. This paper focuses on the conceptual design and development of mechanisms/strategies for the ARTS in the context of certain identified application scenarios. Discussion of limitations of Augmented Reality technology for construction applications include mature of technology, data resource, technology transfer, social attitude, etc., is also presented.*

KEYWORDS: *augmented reality, virtual reality, system design, training, virtual training.*

1. INTRODUCTION

Current practice for heavy equipment operator training is limited to off-site training programs that give a novice limited opportunity to experience the real working conditions. As an alternative, on-the-job operator training is not only costly but also prohibitive due to requirements for specialized equipment and an on-the-job trainer. However, only appropriate and extensive training enables operators to control large equipment safely and efficiently.

Researchers in the construction community have begun to explore innovative methods to effectively train novices with low cost and minimized hazards. Virtual Reality (VR) as a training vehicle has been investigated by researchers for the last decade. Although VR generates a complete virtual environment, where unlimited training scenarios could be provided, it gives a novice no opportunity to experience the real working conditions. In addition, research has shown that the key to acquiring the necessary motor skills to control complex systems, such as a backhoe excavator, is hands-on and coached training (Cuqlock-Knopp et al., 1991). Other researchers considered the need of such hands-on experience by developing physical training systems for operating backhoes (Bernold et al., 2002) and hydraulic elevation platforms (Keskinen et al., 2000). As a promising alternative, Augmented Reality (AR) compromises between the virtual (e.g., Virtual Reality simulator) and real (e.g., physical training systems) by creating an augmented workspace where virtual entities are inserted into the physical space where we work. Such an augmented workspace is realized by integrating the power and flexibility of computing environments with the comfort and familiarity of the traditional workspace. The need for good operator training and the access to large amounts of engineering and management information in the construction industry creates conditions making the use of AR techniques most attractive.

The organization of this paper is as follows: Section 2 presents the state-of-the-art review of current construction equipment training methods and identifies issues that may be addressed by employing advanced virtual training technologies. Section 3 compares the two major virtual training methods: Virtual Reality and Augmented Reality and justifies the potentials of Augmented Reality in effective skill-transfer for heavy construction equipment training. Section 4 elaborates the five major technological components which comprise a typical Augmented Reality system. Section 5 discusses the potentials of AR in construction equipment operation and operator training. As the focus of this paper, Section 6 presents the conceptual design and development of mechanisms and strategies for an AR-based real world Training System (ARTS) that trains the novice operators in a real worksite environment populated with virtual materials and instructions. Currently there are no lab-based or industrial Augmented Reality systems available for heavy construction equipment training because technological sophistication of some components for AR (e.g., the accuracy of trackers) have not been advanced enough to create a usable AR system and because past research efforts have focused on construction, assembly, or inspection tasks. Therefore the concepts presented in this paper are the first directed towards that end, presenting the ARTS concept and proposed technological configuration. This concept is presented to encourage and inform future research toward development of ARTS as the capabilities of required technological components are advanced. Section 7 discusses three application scenarios of ARTS. Section 8 outlines an evaluation plan, which could be used to experimentally validate ARTS by quantifying the extent of skill transfer facilitated by the system. Finally, Section 9 discusses the limitations of Augmented Reality technology for construction applications.

2. THE STATE-OF-THE-ART IN TRAINING PROGRAMS

An excellent training program should enable equipment operators to enhance operating efficiency, upgrade safety awareness and practices, and reduce machine operation and maintenance costs. Although, some construction equipment operators learn the skills from a short-period of classroom instruction, current practice predominantly employs formal educational and apprenticeship programs offered by accredited institutions that provide more comprehensive training. Those educational and apprenticeship programs are administered by union-management committees of the International Union of Operating Engineers and the Associated General Contractors of America. Because apprentices learn to operate a wider variety of machines than do other beginners, they usually have better job opportunities. Apprenticeship programs consist of 44 hours a year of related off-site classroom instruction, and at least 3 years, or 6,000 hours, of on-the-job training (Bureau of Labor Statistics, U.S. Department of Labor).

The formal classroom instruction is the typical format of off-site (i.e., off-the-job) training. For example, in order to fulfill the strict requirements of accuracy, safety and speed for operating the hydraulic elevating platform, the operators have to follow specific training courses including different maneuvers under controlled conditions. These courses are developed and provided by the companies conducting technical and operator training for users of heavy equipment. Their mission is to provide safety and skills training solutions to all facets of the heavy equipment and construction industries. Typically, classroom instruction includes lecture and practice operating construction equipment. The typical classroom activities include pre-operation inspection (daily, weekly, monthly), potential hazard awareness, more abstract functions of equipment and applications directions, how to work safely and show concern for fellow workers and the machine, performance of different types of construction equipment maintenance and repair of equipment, mobile construction equipment familiarization, equipment design principles (focus on what it was designed to do), etc. The typical training process involves the following three phases based on reviews on equipment training websites. Examples of these websites are those of West Coast Training Inc., National heavy equipment operator school, Construction health and safety training classes and programs, etc.

- **Classroom lecture***:* During a typical course, instructor(s) will connect classroom theory training with a “walk-around” tour of the equipment. Some more add-on modules associated with the regular course may help meet the operator’s special requirements. For example, a two-hour elective course regarding dump truck operation can introduce the concept of safety and communication between the truck driver and equipment operators who load dump trucks.
- **Equipment operation***:* Hands-on practice of operating construction equipment requires a field site with room for practice exercises such as excavating, soil placement, trench sloping, benching, trench box/shoring placement and use, rigging and lifting, loading of trucks, stockpile re-handling, and other functions associated with equipment use. Usually this practice requires two-way radios for instructor to student communications and personal protective equipment. Student must practice and demonstrate knowledge of safe start and equipment inspection procedures. In their practice, students

must demonstrate understanding of how to safely use equipment to perform general tasks and demonstrate understanding of how to use specific equipment to accomplish a variety of tasks that are encountered in their line of work.
- **Testing***:* Examinations can be conducted in the format of written/oral/practical. The written/oral test generally covers significant operations and safety points made during the course and the individual's comprehension of the more abstract functions of equipment and applications. The practical exam tests the individual performance of various tasks that may be encountered in the field (e.g., demonstrate an ability to follow directions, work safely and show concern for fellow workers and the machine).

There are a few other options for off-site training formats. There is the low cost alternative of a video program. Though not designed to provide the extensive training of full-length programs, training timeouts are ideal for covering basic safety information on specific topics as a part of refresher training or for companies on a lower budget. Self study is also an important approach for equipment operators to educate themselves through books, videotapes, and other media. These off-site training programs provide novices with limited hands-on experience with real working conditions, thus resulting in inefficient performance by the novice operator when he/she comes to the jobsite. Actual jobsite conditions may require decision-making proficiency that cannot be developed in off-site training due to limitations in creating varied scenarios.

As the other component of apprenticeship programs, on-the-job operator training (for instance, program provided by West Coast Training Inc.) can be more effective but is time-intensive, expensive, and potentially hazardous, requiring specialized equipment and an on-the-job trainer. For on-the-job training used in industry, a beginning apprentice is allowed to be continually supervised by a more skilled and experienced colleagues during several months or even years (Clements and Bharath 1995). Operators need to be in good physical condition and have a good sense of balance, the ability to judge distance, and possess good eye-hand-foot coordination (Bureau of Labor Statistics, U.S. Department of Labor). Therefore, a trainee needs considerable practice to develop the coordination needed for safe and efficient handling of equipment and materials. The on-the-job training program is time-intensive, expensive, and potentially hazardous. The time element is significant as a trainee needs considerable practice to develop the coordination necessary for safe and efficient maneuvering of materials. The expense results from the need to effectively disable productive construction equipment so that a trainee can use it to practice manipulating materials and an on-the-job trainer. Other additional costs incurred by training providers include: buildings, maintenance, machine operating costs, supervisors and external assessors, and so forth. The summation of these costs (while not exhaustive) can be considerable. Hazards result from heavy loads and the presence of other equipment and pedestrian traffic in limited spaces.

3. VIRITUAL REALITY VS. AUGMENTED REALITY FOR TRAINING

Compensating for the inherent drawback involved in apprenticeship programs, virtual technologies afford new opportunities for effectively training novices with lower cost and fewer hazards. Seidel and Chatelier (1997) have even suggested, for example, that the use of virtual environments (VEs) may be "training's future". Virtual Reality and Augmented Reality represent the two most cutting-edge virtual technologies. Even though VR has already been developed for training of drivers (Mahoney 1997), pilots (Lintern et al. 1990), console operators (Regian et al. 1992), and manufacturing line worker training (Adams 1996), there have been few rigorous investigations of its applications in equipment operator training in construction. The noted examples include an interactive excavator VR simulator for operator training (Wakefield et al. 1996) and VR-based personal tower crane simulator developed by Simlog Company (2004), and Virtual Environment Crane Training Simulator (VECTS) for overhead crane operator training (Wilson et al. 1998). Because objects in a virtual environment are modeled with arbitrary geometric and orientation values, VR is limited in providing a high degree of realism. This limitation might lead to people trained well in virtual environments still not performing with the same proficiency in real world operations. For example, due to restrictions in presence, the operator trained with VR may be unable to develop his or her skills with a level of situational awareness sufficient for safe and efficient task execution in real operations.

Augmented Reality (AR) is a technology or an environment where the additional information generated by a computer is inserted into the user's view of a real world scene. The augmenting information may consist of virtual geometric objects placed into the environment, or a display of non-geometric information about existing real objects. AR systems have been developed in the area of military combat (VTAGS), industrial maintenance

(Schwald and de Laval 2003), and school education (Kaufmann et al. 2000). Currently, there is no noted AR research in the area of construction equipment training. A thorough observation of the AR projects in other industrial training implies that AR technology can expand the potential of "embedded" training in the field to provide training anytime, anywhere, and integrated into performance in a real world environment. ARTS can be especially valuable where training in real-world situations would be impractical because a real field scenario may be unduly expensive, logistically difficult, dangerous, or too difficult to control. ARTS is dedicated essentially to the creation of compelling virtually augmented training environments within which human participants are led to feel meaningfully present. ARTS involves a human participant functioning within some kind of a simulated interaction environment. In ARTS, part of the components involved in the interactive training environment are artificial, the operator nevertheless can experience a compelling sense of being present and interacting with virtual objects via visual, auditory or force displays. ARTS can also assist with the delivery of equipment operation training during inclement weather conditions, and novices have much more time to practice their skills without the pressure of costs. ARTS is envisaged to facilitate progress along a steep learning curve and to enable effective rehearsal of future operations in actual construction sites. These technologies should become the bridge connecting the ideal training objective to the current reality of training programs. The cost of a corresponding real-world training program that could reach the similar extent of diversity as this virtually augmented version would be significantly higher.

4. AUGMENTED REALITY TECHNOLOGICAL COMPONENTS

Augmented Reality allows a user to work with real world environments while visually receiving displays of additional computer-generated or modeled information about the task at hand. Such displays can enhance the user's perception of the real environment by showing information the user cannot directly sense unaided.

AR is typically based on effectual media representation of digital content (e.g. wireframe, text, video etc.), interaction devices — input (e.g. mouse, data glove, tangible etc.) and output metaphors (e.g., visual display, auditory, haptic etc.) that are intuitive, a precise tracking system (e.g. vision-based, GPS, etc.) to provide accurate position and orientation information to keep a virtual scene in sync with reality, and exhaustive computing power (e.g., mobile computers, standalone server) to cope with the real-time requirements of AR (Wang et al. 2004). Except for the media representation that technically relies heavily on computing power, all the other four technological components could involve wearable physical devices that are likely to become lighter, smaller and easier to work with. A current topic of many AR system developers is the incorporation of these four components into one unit that might be housed in a belt-worn device that wirelessly relays information to a display that resembles an ordinary pair of eyeglasses (Bonsor, 2001).

4.1 Media representation

AR systems tend to use more varied media representations for augmenting the real environment than VR. The identified major classes of media representations from abstract (schematic) to realistic (3D) are texts, indicators, platform (tablet and screen), 2D image, 3D wireframe, 3D data, and 3D object. It is apparent that a more realistic representation conveys more detailed and richer information to assist a human's comprehension ability thus augmenting the cognitive process and activity. However, such a high fidelity image may cause usability problems associated with lag, and low frame rate simply because computing power is limited. The additional computing power required for such a high fidelity reproduction may outweigh any benefits obtained from it. Therefore, it is rash to conclude that realistic media representation must be superior over abstract media representation because each type of representation has its own appropriate application domains. In addition, two or more types of media representation (e.g., text + 3D object) presented together on a single display, which the authors term as a hybrid representation, can be very useful in situations where multiple cognitive channels need to be provided.

4.2 Input device

An input device is used to manipulate the digital information displayed over the real environment. Most of the input devices used in VR can also be applied in AR systems. Use of an appropriate input metaphor in user interface design is generally considered to be good practice, since they can effectively exploit a users' prior knowledge to increase familiarity of action, procedures, and concepts (Neale and Carroll, 1997). A poor input metaphor may create a number of problems for the user. For example, intermediate devices such as joysticks actually place themselves between users and environments, which require considerable user cognitive mapping to perform tasks. A more direct, natural form of interaction may be achieved through tangible and gestural input. In cases where virtual model interaction implies some specific physical implement (e.g., drilling implies driller, hammering implies hammer), such tangible interfaces may be used as opposed to virtual tools coupled with synthetic force-feedback. The AR systems using tangible interaction are referred as tangible augmented reality (Poupyrev et al., 2002). More information regarding the input device can be found in (Gabbard, 1997). Voice input, a more direct, natural form of interaction, can be incorporated as an extra input to increase input capability of the whole system. Also, haptic devices can also be employed for input through devices like Phantom (Massie and Salisbury, 1994).

4.3 Display device

AR displays can be generally classified as visual displays (e.g., head-mounted displays), acoustic displays (3D localized sound systems), and tactile displays (force feedback devices). Visual displays are the most popular in AR systems with other types of displays as supplements. Stereoscopic visual displays are used to present mixed (real and virtual) worlds, two basic fusion technologies exist: video-based see through mixing and optical see-through combination. While video-based see-through merges live record video streams with computer generated graphics and displays the result on the screen, optical combination generates an optical image of the real screen (displaying computer graphics), which appears within the real environment (or within the viewer's visual field while observing the real environment). Both technologies entail a number of advantages and disadvantages that influence the type of application they can address. An elaborated discussion on advantages and disadvantages of video-based see-through mixing and optical see through combination can be found in (Azuma, 1997). Head mounted displays are still too clumsy not to be distracting to the user. They also have limited field of vision, and they usually lack in contrast and resolution for a reasonably immersive environment.

Almost all work in AR has focused on the visual sense; however, the augmentation might apply to all other senses as well. For auditory displays (Rozier et al., 2000; Lyons et al., 2000), rather than isolating the participant from all sounds in the immediate environment, by means of a helmet and/or headset, computer-generated signals can instead be mixed with natural sounds from the immediate real environment. For haptic displays, information pertaining to sensations such as touch, pressure, etc. is typically presented by means of some type of hand-held master manipulator (Brooks et al., 1990) or more distributed glove type devices.

4.4 Tracking technology

Tracking, also called position and orientation tracking, is used where the orientation and the position of a real physical object is required to achieve proper alignment of virtual elements with the real world scene. Trackers are used to measure the motion of the user's head or hands, and sometimes eyes. Most trackers provide data for six degrees of freedom (DOF) — the spatial location of the viewer (x, y, and z) with respect to a reference point and the orientation the viewer's gaze (pitch, roll, and yaw) — that are required by the AR system (see Fig. 1). For the AR system to be successful, the tracker must update these values continuously in a real-time manner as the user may alter his or her position/orientation. 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. The biggest obstacle to building effective AR systems is the requirement of accurate, long-range sensors and trackers that report the locations of the user and the surrounding objects in the environment.

Tracking technology can be classified as context-free and context-aware according to the need of calibration. As a context-free system, video-based calibration-free approaches (Kutukalos et al., 1996, Iu et al., 1996) avoid the need for any calibration and can overlay digital contents onto the video of real entities without knowledge of camera parameters. However, such matching may not recover all the information required to perform all potential AR tasks, such as true depth information, which is useful when compositing the real and the virtual. Most tracking technologies are context-aware approaches and different technologies are available for tracking depending upon the application. For mixed environments that require large user-roaming areas, sophisticated ultrasonic tracking systems may be used to increase user range. Magnetic trackers are typically limited to a range of a few meters, yet do not require line-of-sight. Magnetics is suitable for mixed environments with small working volumes and minimal electromagnetic interference. Body-mounted magnetic transmitters are powered through small cables, resulting in some user tethering. Ultrasonic, optical, and infrared tracking systems avoid tethering and thus allow greater freedom of motion. However, a possible tradeoff is the fact that these systems are susceptible to body interference since line-of-sight is required. Optical systems can be well suited for real time applications, especially when compared with magnetic position trackers that have lower data rates (Azuma, 1997). Each class of tracker has its own advantages and disadvantages. For detailed comparison of tracking technologies, readers are referred to the surveys in Ferrin (1991), Meyer (1992), Applewhite (1991), and Holloway and Lastra (1995).

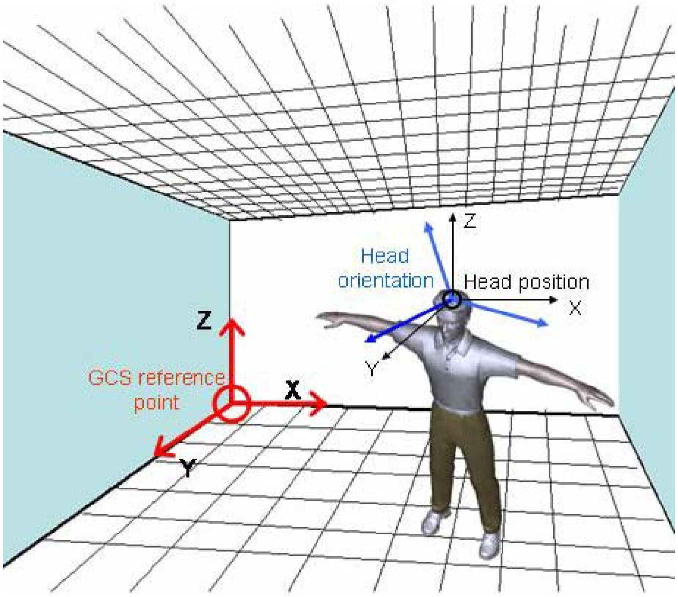


FIG.. 1: Tracking a user in a given space

Future tracking systems that can meet the stringent requirements of industrial applications of AR will probably be hybrid systems, such as a combination of inertial and optical technologies (Azuma, 1997). Hybrid systems attempt to compensate for the shortcomings of a single technology by using multiple sensor types to produce robust results.

4.5 Computing device

Computing power is a key requirement in producing a feasible AR system. Raw computing power is needed to minimize latency and to maximize frame rate, both important aspects of a system's reproduction fidelity. The capability of available computing power constrains the format options for media representation. Real-time rendering of 3D high fidelity objects is too computationally-intensive for devices with weak power to bear. More schematic representations such as text or simple indicators are less computationally-demanding and achievable with ordinary computers.

5. VISIONS OF AUGMENTED REALITY IN CONSTRUCTION EQUIPMENT OPERATOR TRAINING

Recent advances in computer interface design and hardware power have fostered AR research prototypes or test platforms for architecture, engineering, and construction (AEC) applications. It is apparent, however, that most of these lab-based prototypes or concepts were explored and investigated by computer science/engineering researchers who arbitrarily selected the AEC applications as test scenarios to demonstrate effectiveness and feasibility of their AR concepts. The resulting outcome is that development of these prototypes did not progress further to a level of readiness for field testing.

Construction equipment can be very dangerous and can be damaged during improper operation. Operator training programs, therefore, are a significant component in equipment management. As the demands of construction projects pursued by a construction company increases, training becomes a more significant factor with respect to potential for saving both time and money.

One of the increasingly important application areas of AR is in training and education, where simulated scenarios can be used to illustrate concepts and provide exercises that allow the learner to train in a realistic environment. Compared to the real exercise, AR could significantly reduce costs and hazards and provide unlimited training conditions/scenarios (system can provide unlimited series of structured tutorials and practice sessions). This is particularly true in the field of heavy construction equipment where real exercises have substantial costs and hazards. For example, the cost of a computer-generated virtual soil stockpile or underground pipe sections will be primarily associated with the computer's processing and memory resources. Breaking or damaging construction materials in this type of training program will cost nothing. Also any ruined materials left by the previous operator trainee can be quickly restored to the original useful state for the next novice to practice, something not so readily accomplished in a real exercise. In addition, AR affords unlimited variability in training elements (e.g., various terrains, shapes and sizes of virtual stockpiles for a loader to move) which gives greater flexibility with minor additional cost. An example of a safety advantage is the avoidance of any personnel injuries from materials accidentally falling while being raised by material handler to an elevated scaffold platform. Also, use of AR can eliminate adverse effects associated with environmental concerns such as noise, dust, etc.

Therefore, it is believed that the state of the art in training can be advanced with AR because of the technology's unique characteristics. In fact, it is envisioned that AR can make some forms of training unnecessary, or at least greatly reduce the need for training as a distinct process. One objective with AR might be to provide scenes that are annotated with types of information that are normally acquired through training. Possible applications include:

1. Operation procedures including conducting before-operation inspections, operating equipment safety, use of safety equipment, etc. can be presented directly into the novice's real view of training scenarios without reference to manuals or experts. Thus the basic training process can thus be efficiently accelerated.
2. Features and objects that do not have constant configuration can be modelled and displayed by an AR system. For example, a specific haul road route and major destinations (loading and dumping sites) can be highlighted with virtual indicators, which the operators can follow as they practice how to operate the equipment in a real environment. Also virtual targets/stimuli such as stockpiles can move and react intelligently to the manipulation of an operator.

To address the above training issues, ARTS (AR-based real world Training System) has been designed to enable construction equipment operator trainees to realistically rehearse work operations on an actual construction site in actual heavy construction equipment. Details of the system architecture and application scenarios are given in the following sections. The primary objectives in development of ARTS are:

- To design and prototype a wearable AR system that will allow a novice to try construction operations using heavy equipment with the support of digital information.
- To explore how effectively the AR tool can support training compared with other training methods.

6. DESIGN OF ARTS SYSTEM ARCHITECTURE

The setup and experimental test-bed should be established in an indoor industrial unit because most medium-range trackers that can achieve high accuracy will require that components be stationed in an elevated position, such as on the ceiling of a warehouse, to minimize obstructions. Six separate modules were configured and Fig. 2 shows the flow diagram for the entire system. The following sections discuss the mechanisms in these modules.

6.1 Representation module

Three types of digital content are defined, panel tag, static object, and dynamic object. Most training information is typically stored in the form of descriptive texts, sometimes with images/photos. Simple media representation may provide much more utility for serving the purpose of certain descriptive and procedural applications where users benefit more from explanatory information rather than the geometrical information that high fidelity virtual images can represent. Therefore, texts are conceived as descriptive information spatially registered to controls on the cabin instrument panel. The media representation for panel tags should be text and/or 2D-image/video (see Representation Module in Fig. 2). A static object is defined as a stationary entity stocked on site such as an untouched soil stockpile or pipes lying on the ground. The dynamic object is defined as a movable entity such as loaded soil, the virtual boundary (edge) of a loader bucket, etc. Both static and dynamic objects should be rendered in a rich manner because the realistic rendering can provide more cues for depth and geometry judgment, likely to be essential for training in transferable. Otherwise, the system may be ineffective as a training environment because of the ambiguous and abstract appearance of virtual stimuli. Therefore, 3D high-fidelity representation should also be applied. ARTS can be further enhanced by adding a hypermedia system that provides contextual information in the form of labels and links. Thus more detailed information can be retrieved from the database via links with the same mechanism as HTML webpage navigation as described by Sinclair et al. (2002). The ARTS concept allows users to experience hypermedia for themselves and manipulate complex information spaces with familiar interaction techniques.

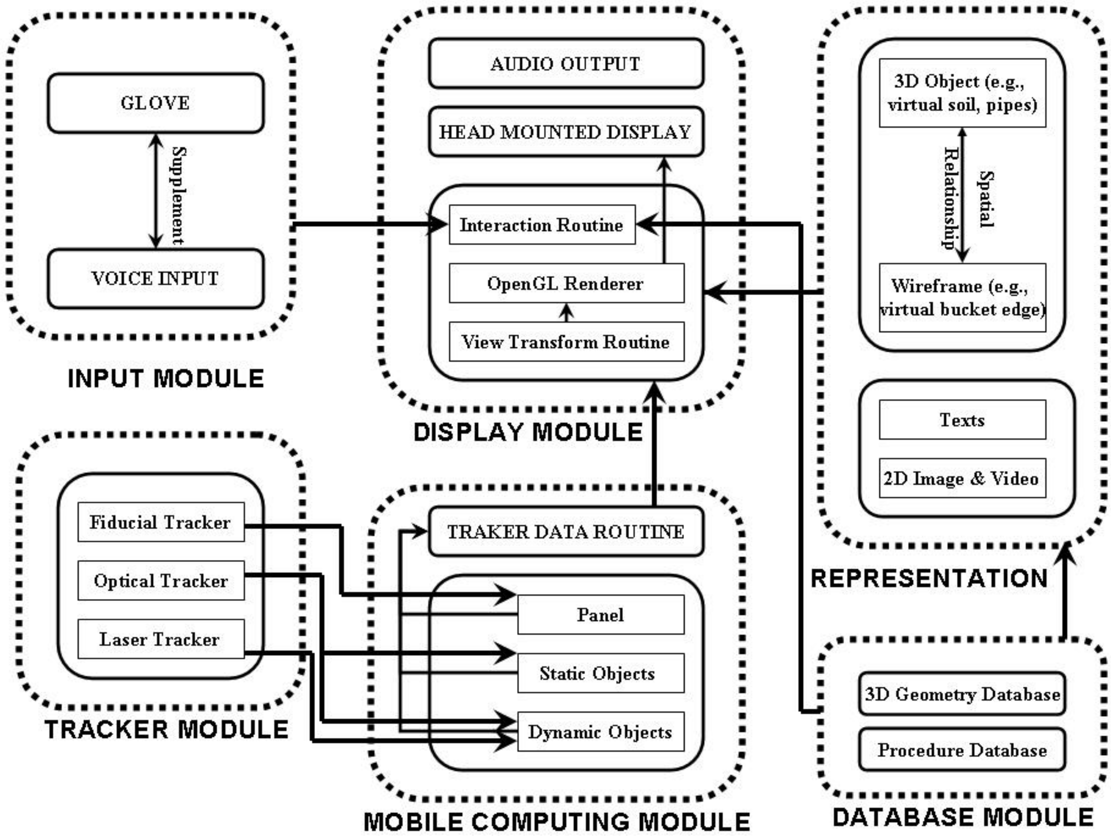


FIG.. 2: System architecture diagram of ARTS

6.2 Display module

This module handles the display of digital information in the AR system (see Display Module in Fig. 2). A head-mounted display (HMD) is used and this HMD should be equipped with two built-in color video cameras that are 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 a special tracker. An audio display that gives warning or directions for allocating attention can also be added to such AR systems (Lyons et al., 2000, Rozier et al., 2000, Benderson, 1995). Haptic feedback (haptic display) can also be provided via mechanical device(s). The assumption is that when, for example, an excavator operator digs hard with a large force, the bucket will move faster, and the speed of bucket can determine the volume and thus the weight of the virtual soil load. Meanwhile, corresponding forces can be "displayed" back to the operator's hand through a computer-integrated haptic device. The control device with a combined force-control algorithm and computer-integrated force feedback will let the novice feel the simulated force resulting from handling the "virtual" materials. For example, the volume of excavated materials can be as noted above by computer and converted to weight using an appropriate soil density. This weight can be the parameter to simulate the force that the boom of the excavator needs to carry. Certainly many other parameters can be simulated the same way (e.g., the digging hardness of soil).

6.3 Mobile Computer Module

This module is located on a high-performance and light-weighted laptop (see Mobile Computing Module in Fig. 2). A customized AR program is the core technical component for rendering for the whole system. Visual C++ is used as the development environment. In addition to OpenGL, there are a few simplified software development toolkits (SDKs) available, such as ARToolKit (2007), and AR software development library — STARlib1.0

(Neumann and Cho 1996), which can be readily used as a function library for developing our own customized AR program. The AR program can receive position and orientation data from alternative trackers (discussed in a later section) and display the panel tags and static and dynamic objects as they should appear in the field of view of the user. The virtual tags attached to the instrument panel are displayed after sending queries to the local database, which returns any labels matching the features of the devices on instrument panel. The static materials are visualized by loading the created virtual reality modeling language (VRML) file into the AR program. The dynamic objects such as the boundary (edge) indicator of the loader bucket are rendered and updated using the real-time tracker data input.

6.4 Database Module

The mechanism of a local database is designed to provide detailed training information and procedures for the controls on the instrument panel (see Database Module in Fig. 2). Sybase SQL anywhere (2004) can be used as the database query. All of the equipment-related data can be stored in the Sybase Database. Existing illustrative images and data about equipment must be collected in order to compile a comprehensive, equipment-specific database of information. The way that the system adds labels is by reference to the identifying fiducial marker beside an instrument panel object. As the object is identified, the system sends a query to the database, which returns any labels matching the object's features.

6.5 Tracker Module

The three different types of digital content – panel tags, static object, and dynamic object – require multiple trackers in order to be combined (see Tracker Module in Fig. 2). Fiducials are used for registering virtual tags to the instrument panel. In some AR applications it is feasible to place fiducials such as LEDs (Bajura et al,. 1995), square marker (Billinghurst and Kato, 1999), color multi-ring (Neumann et al., 1999), colored dots (State et al., 1996), or dots with a circular pattern (Mellor et al., 1995) in the environment. In order to be effective, these strategies assume that one or more fiducials are visible at all times. The resulting registration can be accurate to one pixel, the best that can be achieved with video techniques. Fiducials are appropriate here because they provide more accurate registration with low cost and are easy to affix onto or near the real object the digital information is meant to identify or describe. After the digital information is loaded, the position and viewing perspective of the user are continuously calculated based on the data from the tracker. Simultaneously, the correct visual alignment of the attached digital information is maintained using transformation matrices based on location and direction data.

The user's (camera's) position and orientation can be tracked by a precise, wide-area indoor tracking and digitizing system. One such system is the Hiball system from 3rd Tech, Inc (http://www.3rdtech.com/). This system is capable of tracking handheld devices as well as rapid head motions. With this tracker, the static object can be registered to the location relative to the tracked user. Laser sensing can be used to track the position of dynamic objects such as moving bucket by fixing receivers on the sensed objects. All of these tracking technologies should be configured according to a common frame of reference so that the static objects interact with dynamic objects (e.g., loader bucket shovels some soils).

6.6 Input module

This module deals with how to manipulate the displayed digital content (e.g., clicking hypertext to browse details) and annotate the comments (see Input Module in Fig. 2). For simple command input, speech recognition (e.g., Microsoft speech recognition software) is sophisticated enough to realize this functionality. A data glove is useful to intuitively interact with digital entities and does not occupy the user's hands to the extent of other non-intuitive devices (e.g., keyboard, mouse, joystick). A 3D virtual cursor can be controlled via the data glove.

7. APPLICATION SCENARIOS OF ARTS

When cognitive tasks normally associated with training are reinforced for the operator trainee (novice) by ARTS at the point of application, it becomes possible to design training functions which are enacted concurrently with task performance. Therefore, ARTS can maximize its use when integrated into the real world task. The three application scenarios—earthmoving with a front end loader, pipe-laying with a backhoe, and materials handling with a forklift—are presented to provide a better and concrete understanding of how ARTS could improve the training process. The scenarios are based on the review of traditional training methods, a wide literature review in training and cognitive psychology, and input from industrial practitioners. The generic concept of ARTS is not limited to these scenarios and can be applied to many other types of heavy equipment operation training, as appropriate and necessary. Novices should grow in skill through the opportunity to perform more cycles of the operation than is generally feasible in a real world training setup.

7.1 Earth-Moving Operation with Front End Loader

A novice operator sitting in a real front end loader cabin can manipulate the equipment to move a virtual soil stockpile on the ground (see Fig. 4a) to a dumping container (Fig. 4c) certain distance away. First of all, the novice can see virtual tags surrounding their corresponding real objects and thus learn or reinforce knowledge of the functions of each object on the instrument panel (see Fig 3). Novices can follow step-by-step starting procedure instructions or choose to see a pre-recorded training video. Any multimedia technology can be used. An important function is the automatic display of safety instructions with reminders, such as wearing a hard-hat, checking the machine before moving, making sure no persons are standing around the equipment, etc.

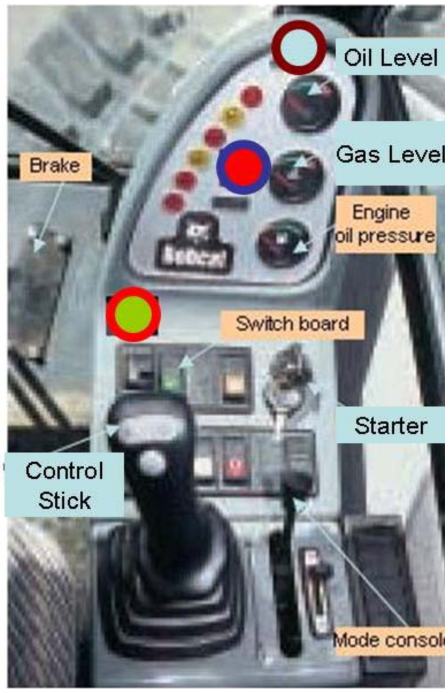
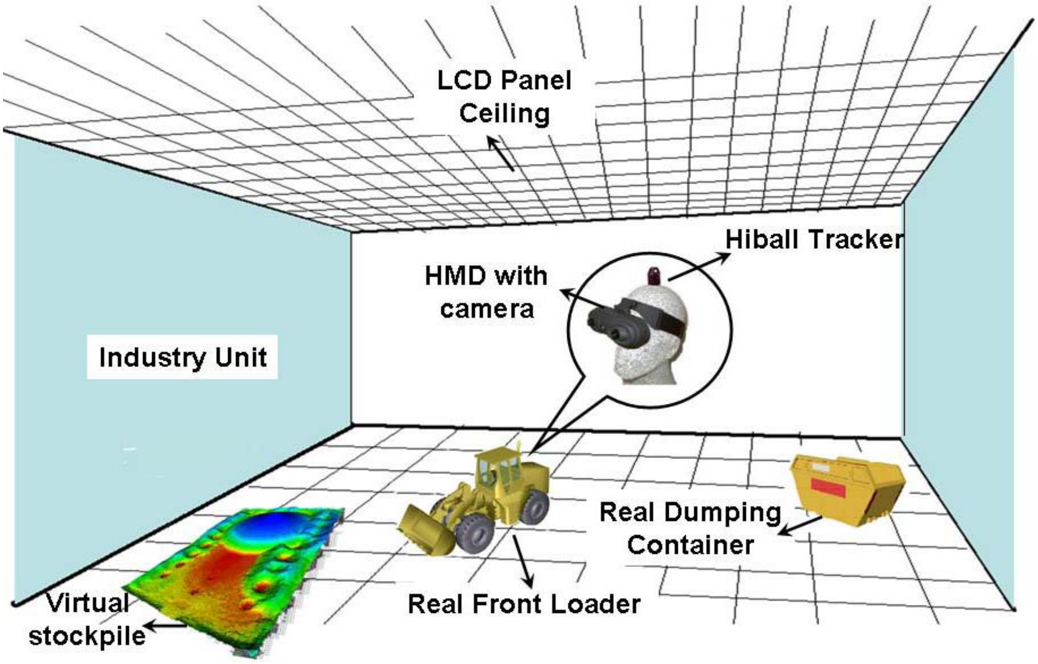
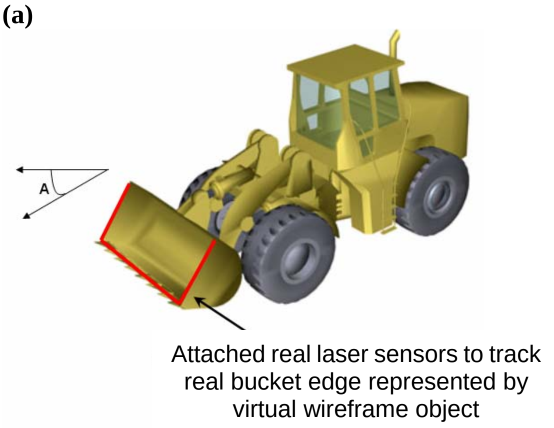


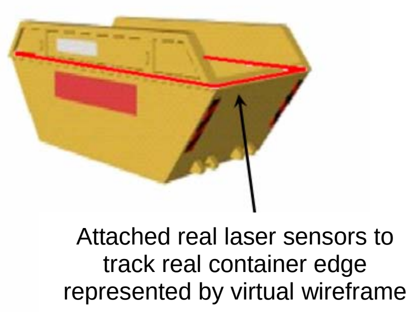
FIG.. 3: Hypothetical illustration of augmented instrument panel with corresponding virtual tags positioned via fiducial recognition tracking (Wang et al. 2004).

After the startup procedure, the novice can move the equipment to the virtual stockpile and position the machine to begin loading soil. The bucket boundary position is tracked by laser sensors mounted on it and a wireframe boundary is drawn to represent the bucket in the virtual world understandable by computer (see Fig. 4b). The novice controls the loader and the more forceful the digging, the faster the bucket passes through the virtual stockpile and a greater volume of soil is loaded. The amount of soil can be controlled further by the curvilinear path traversed by the moving wireframe boundary of the bucket while loading. Here, the assumption is that harder loading leads to a flatter curvature of the moving wireframe and then less virtual soil is calculated to be transited into the bucket. For each load obtained, the novice maneuvers the equipment to the real container on the other side of the training area. Laser sensors are installed on the edge of the container, and a virtual wireframe rectangle represents the container's boundary in the virtual world. When the novice positions the loader, he or she can start to dump the virtual soil. While the bucket is tilted to a certain angle, the monitoring computer algorithm will understand that dumping should start and then the virtual soil in the bucket will spill. The realistic cascading of soil can be easily modeled by applying certain assumed physics functions to the virtual material. Kamat and Martinez (2003) developed a particle system library to simulate the falling feature. If the dumping ends with too much soil falling outside of the wireframe boundary of the container, i.e., missing the target, the system will provide warnings indicating the poor performance. A performance score could also be given as quantitative feedback, and another training cycle can be performed if necessary.



(a)





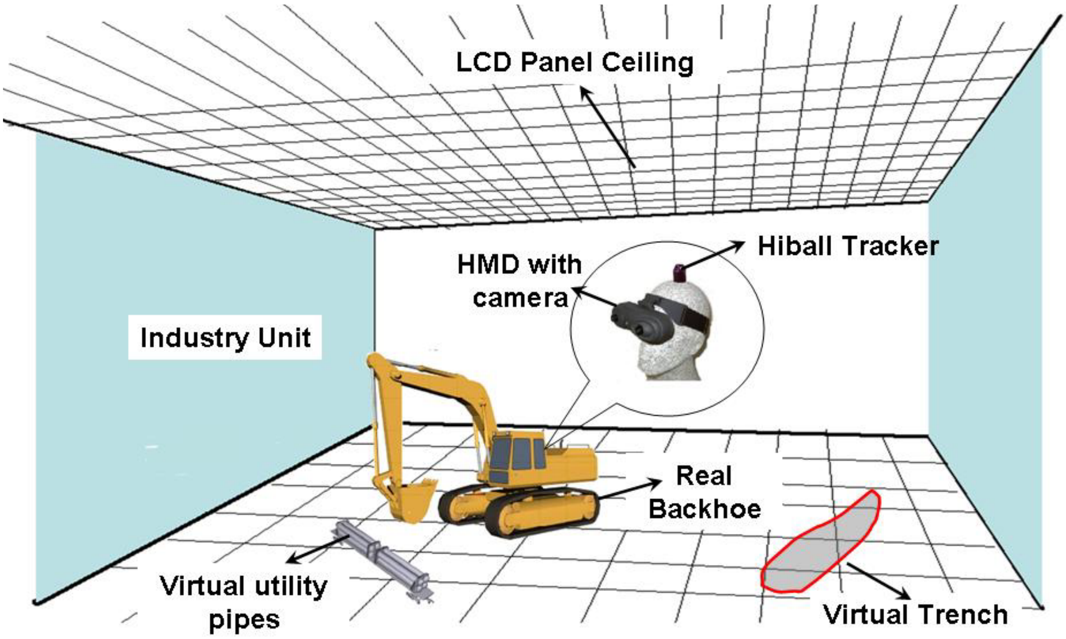
(b) **(c)**

FIG.. 4: Hypothetical concept illustration of (a) an AR system training application in earth-moving with a front end loader, (b) sensor locations and virtual wireframe representation of a real front end loader bucket, and (c) sensor location and virtual wireframe representation of real dumping container (Wang et al. 2004).

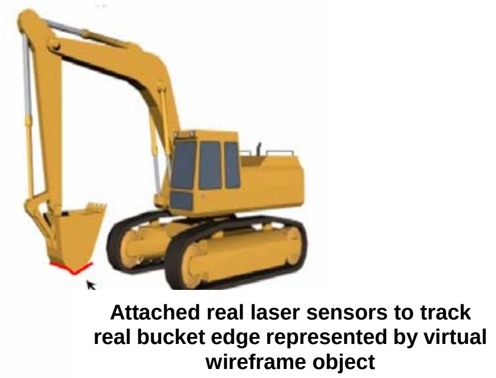
7.2 Pipe-Laying Operation with a Backhoe

In the second scenario, a novice operator sitting in a backhoe excavator cabin can manipulate the equipment to move virtual utility pipes and lay them into a trench (see Fig. 5a) within a specified boundary (see Fig. 5c). The same as the first scenario, the novice can become familiar with the instrument panel and the safe startup procedures by following the virtual instructions overlaid on the real-world view.

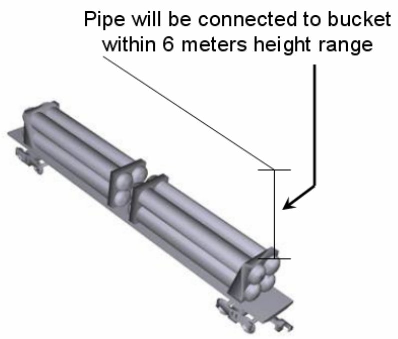
When the novice moves the bucket (equipped with lifting hook) over the virtual pipes, the bucket's position is sensed by mounted sensors and modeled by a virtual wireframe boundary in the virtual world that the computer monitoring algorithm can understand (see Fig. 5b). The real operation requires other people to connect the pipe to the bucket with cables. Here we skip this step and specify that as long as the bucket is within the vertical range of 6 meters over the pipe and within a tolerable horizontal displacement (see Fig. 5c), the pipe will be connected to bucket with a computer-generated virtual cable. Therefore the cable and pipe will move as the bucket moves. The force-feedback from the weight of the pipe can be "displayed" back to the novice's hand via computer integrated haptic device. After the attachment of the pipe, the novice can move the backhoe excavator and position it next to the destination for the pipe in an area that is bounded by laser sensors. The AR system would present a virtual trench into which the virtual pipe would be lowered. The boundary of this location would be based on the tracked positions of laser sensors (see Fig. 5a). The novice can lay the pipe in position and can release the pipe by pressing a certain control button. If the pipe-laying operation ends with too much of the pipe lying out of the wireframe boundary (i.e., missing the target), as in the previous scenario, the system will provide a warning indicating the poor performance. Also, a performance score can be given as feedback before the training cycle is repeated.



(a)



(b)



(c)

FIG.. 5: Hypothetical concept illustration of (a) AR system application in pipe-laying operation training with backhoe,(b) sensor locations and virtual wireframe representation of real backhoe bucket, and (c) virtual pipe.

7.3 Material Handling Operation with a Forklift

In the final scenario, a novice operator sitting in the cab of a forklift can maneuver the equipment to transport virtual material in crates (or possibly on pallets) and deposit them at various levels onto a real scaffold (Fig. 6a). Just as with the two preceding scenarios, startup and safety check procedures and instrument panel explanations would be directed by virtual instructions overlaid on the novice's real-world view. Then the novice can operate the forklift to move the virtual crates that are stacked in the corner of the room to a scaffold on the other side. Laser sensors are attached on the twin horizontal arms (fork) that support the load, vertical mast, and the edges of the scaffold platforms (Fig. 6b). A typical forklift is illustrated in Fig. 6b. When the forklift starts to load the virtual crate, the novice needs to elevate the fork to such a height that the fork approximately matches the bottom of the box. If the novice guides the fork successfully to a tolerable range, the virtual box will slide onto the fork. The novice then drives the forklift to the front of the scaffold on the other side of the training area. The mast should be tilted to the rear to prevent the load from falling off while in transit. As the novice operator raises the fork, the virtual crate rises accordingly. Judgment will be needed to assess whether the box can be safely unloaded onto a certain level of the scaffold. If so, the novice can tilt the mast forward for load removal. The maximum forward tilt is about 30 degrees, and the maximum rearward tilt is about 10 degrees. If the box is not successfully transited, the box will fall onto the ground, and a warning will be given to announce that the unloading is unsuccessful. A performance score may be give to indicate how well the novice deposits the crate to the target area.

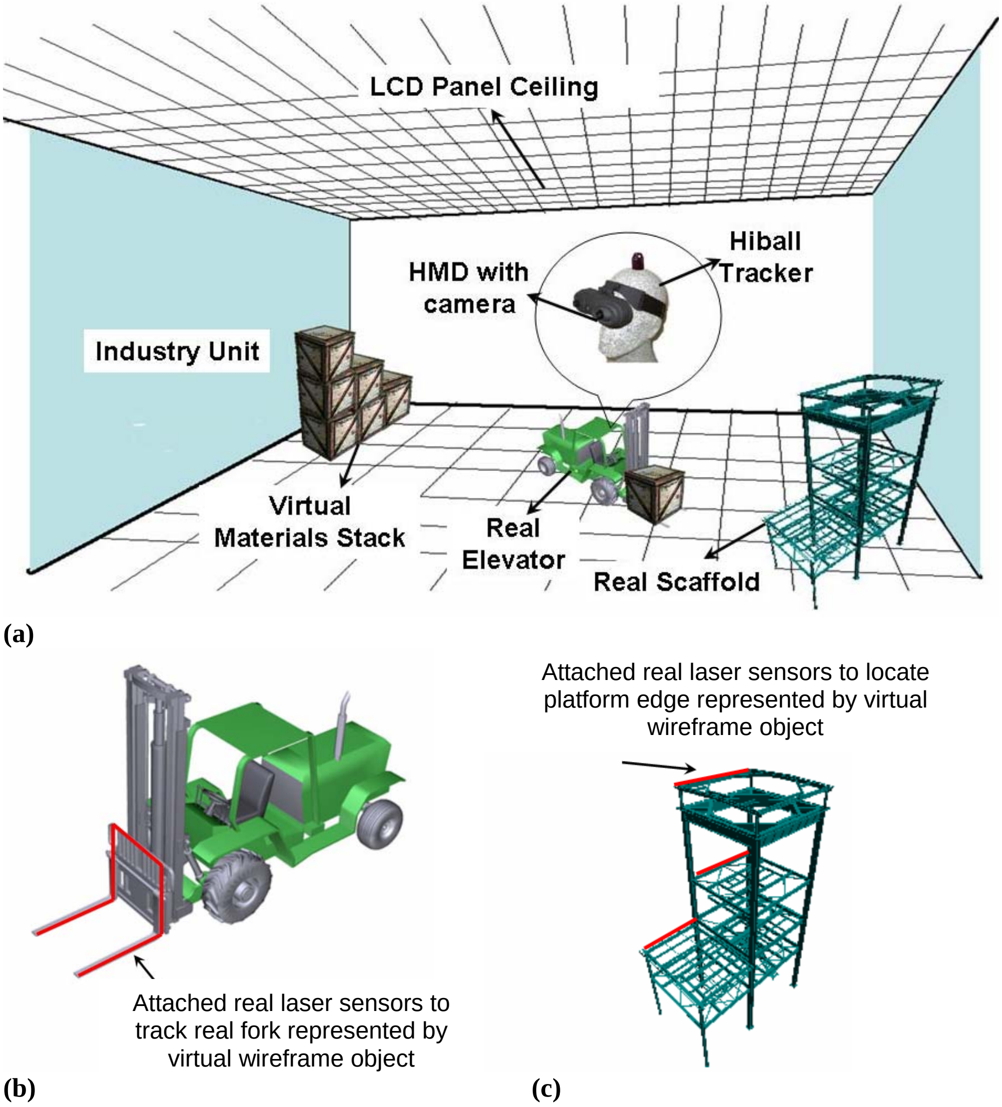


FIG.. 6: Hypothetical concept illustration of (a) AR system application in material-handling operation training with a forklift, (b) sensor locations and virtual wireframe representation of fork prongs, and (c) sensor location and virtual wireframe representations of the edges of scaffold platforms.

8. EVALUATION TECHNIQUES

The effectiveness of ARTS could be evaluated through the extent of skill transfer from the virtual practice experience to the real world performance. Some studies indicate the reliable transfer of skills acquired through virtual training programs to actual on-the-job tasks, provided a high similarity (fidelity) between the virtual and real environments (Rose et al., 2000). Therefore it is important to assess the extent of skill transfer by investigating whether performance of the real world task after training in ARTS is equivalent to performance after a similar amount of training on the same task in the real world. Evaluation techniques to empirically investigate the effectiveness of ARTS in the development of transferable skill from virtual to real environments are outlined in this section. It is known that motor skills gained from training cannot be measured directly, but only inferred by observing behavior or performance. An observation of related research produced a list of objective (quantitative) and subjective (qualitative) indicators. Objective methods refer to the quantitative approaches such as performance time and accuracy. Subjective methods refer to the qualitative approaches and a list of performance indicators for an equipment operator (Bernold et al., 2002) might include assessments of 1) capability for skill improvement, 2) quality of output, 3) proactive thinking, 4) smoothness of bucket motion, 5) oral interview with an expert, 6) adaptability to changing environments, and 7) consistency of operation. These methods can be used to compare performance that could be used to distinguish between an excellent and a less skilled operator in a specific operator training scenario of ARTS.

9. LIMITATIONS

To develop the AR training system, there are several limitations in both technological and social aspects that must be addressed. First, there is no repository of databases to utilize as information sources that could be readily used by AR systems because designers and constructors are not motivated to create them. AR systems may require access to a detailed database of the operating environment. For example, there are no ready samples of three-dimensional virtual buried utility designs or as-builts which could be used for trenching and pipelaying training scenarios. Even if such examples exist, the data may not be grouped to segregate the parts of the model that represent one type of buried plant or conduit from another. Thus, a significant modeling effort may be required and should be taken into consideration when building an AR application. Secondly, technological limitations remain the major obstacle for AR systems. For instance, AR requires highly accurate trackers because even tiny tracker errors can cause noticeable misalignments (poor registration) between real and virtual objects. The biggest obstacle to building effective AR systems is the requirement of accurate, long-range sensors and trackers that report the locations of the user and the surrounding objects in the environment. No tracker currently provides high accuracy at long ranges in real time (Azuma, 1997). Another example is occlusion detection. With little or no prior knowledge about the surrounding real world, occlusion detection becomes a very tricky art in Augmented Reality because the need for a digital representation of a virtual object to be partially hidden by a real object is difficult to recognize. Occlusion errors easily ruin the feeling of an integrated environment that the user might otherwise experience. Thirdly, because of the technology development that is yet needed, there is a lack of motivation for AR technology transfer. AR technology adoption is arguably a tremendous leap for late adopters of technology as the construction industry is known to be. Whether AR can be realized as a truly a cost-effective solution in its proposed applications has yet to be determined. There are many research and development questions to be explored to prove to and educate AEC practitioners about the feasibility and profitability of applying AR systems. Finally, social concerns should not be ignored during attempts to move AR out of the research lab and into the hands of real users (Azuma, 1997). For example, if workers perceive lasers to be a health risk, they may refuse to use an AR system with laser-based trackers, even if those lasers are certified as eye safe. Another important factor is whether or not the technology is perceived as a threat to jobs, as an eliminator of workers. However, this concern should not be a critical problem for AR because it is intended as a tool to augment the user's awareness of how to perform, rather than something that eliminates the need for a skill position**.**

10. CONCLUSIONS

Current practice for heavy equipment operator training is predominantly limited to 1) off-site training programs that give a novice a limited opportunity to experience real working conditions and 2) on-the-job operator training which is not only costly but is often not possible, requiring specialized equipment and an on-the-job trainer. The authors observe that Augmented Reality technology is suitable for information-intensive tasks, i.e., a focus on human decisions and subsequent actions, such as construction equipment operator training. This suitability is contrasted with that of machinery automation for the physically intensive tasks that convert information directly from paper-based plans to actual work, A thorough observation of the Augmented Reality projects for other industrial training also revealed that AR technology can expand the potential of “embedded” training in the field to provide training anytime, anywhere, and integrated into experiences in real world environments.

Motivated by such vision, an Augmented Reality-based real-world Training System (ARTS) was conceptually developed based on the evaluation of current state-of-the-art of training methods and the technological advance of AR components. ARTS is conceived to train the novice operator in a real worksite environment populated with virtual materials and instructions. From the analysis of the conceptual design of ARTS including mechanisms/strategies and application scenarios, the following propositions are identified:

- ARTS could be especially valuable where training in real-world situations would be impractical because a real field scenario may be unduly expensive, logistically difficult, dangerous, or too difficult to control.
- Because the ARTS scheme involves a human participant functioning with some aspects of a simulated interaction environment, the operator may experience a realistic sense of presence and interactivity with virtual objects via visual, auditory or force displays.
- ARTS could facilitate the delivery of equipment operator training during inclement weather conditions and novices have much more time to practice their skills without the pressure of high costs.
- Compared to exercises in a real environment, ARTS could provide unlimited training conditions/scenarios (structured tutorials and practice sessions).
- ARTS could eliminate environmental concerns such as noise, dust, etc.
- ARTS offers the means to rehearse future heavy construction equipment operations for actual construction sites.
- ARTS could facilitate progress along a steep learning curve.

The acknowledged limitations of Augmented Reality technology for construction applications include a lack of data resource, immaturity of technology, lack of motivation for technology transfer, and negative social attitudes. Critical considerations regarding AR applications for construction training are threefold: (1) construction firms can save time, money, and effort with effective use of AR technology for training programs; (2) a well-organized equipment information database should be developed to be available for AR use; and (3) as technology matures, standards are developed, and hardware costs decrease, AR technology will gain in significance to the construction industry and many of its operations.

It was also believed that a resulting usable ARTS system for field testing could only be realized by collaborative efforts between construction operations experts and the computer science/engineering experts. Future work includes refining the design of ARTS and prototypically developing a prototype system for certain selected application scenarios, and evaluating the effectiveness of ARTS against current training methods.

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