Enabling discovery-based learning in construction using telepresent augmented reality

Amir H. Behzadan a,⁎, Vineet R. Kamat b

a Department of Civil, Environmental, and Construction Engineering, University of Central Florida, Orlando, FL 32816-2450, United States
b Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor 48109-2125, United States

A R T I C L E   I N F O

Article history:
Accepted 9 September 2012
Available online 3 October 2012

Keywords:
Augmented reality
Visualization
Construction engineering
Education
Learning

A B S T R A C T

Construction engineering students often complain about the lack of engagement and interaction with the learning environment. Notwithstanding, many instructors still rely on traditional teaching methods which include the use of chalkboard, handouts, and computer presentations that are often filled with many words and few visual elements. Research shows that these teaching techniques are considered almost obsolete by a many students specially those who are visual learners or team workers. Also, the influence of visual and social media has changed student perceptions and how they expect the instructional materials to be presented in a classroom setting. This paper presents an innovative pedagogical tool that uses remote videotaping, augmented reality (AR), and ultra-wide band (UWB) locationing to bring live videos of remote construction jobsites to the classroom, create an intuitive interface for students to interact with the objects in the video scenes, and visually deliver location-aware instructional materials to them.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

In a recent report published by the Association for American Colleges and Universities (AAC&U), the National Leadership Council for Liberal Education and America’s Promise identified “connecting knowledge with choices and action” as one of the seven principles of excellence [1]. Within engineering colleges and departments, this emphasis on creating a contextual link between knowledge and practice is even more prevalent. Although a large body of research has shown that specific teaching practices can improve student learning, engagement, and interest in engineering [2,3], and despite the fact that creativity and practicality are highly encouraged in academia, many engineering faculty have not been motivated to change their classroom practice and still rely on traditional methods to convey the theoretical knowledge to their students [4].

The curricula of these programs are heavily shaped around the concept of exposing students to basic science and engineering courses, and are often inadequate in preparing them for real life problem solving and critical thinking [5]. While engineering students need to pick up the social and technical skills (e.g. critical thinking, decision-making, collaboration, and leadership) they also need to be competent in the digital age [6]. Mills and Treagust [7] discussed that although most students are graduating with good knowledge of abstract engineering science and computer literacy, they do not know how to apply this knowledge in practice.

In the area of construction education, students have historically lacked a comprehensive knowledge of onsite construction tasks and the dynamics and complexities involved in a typical construction project [8]. This can be directly attributed to the fact that, to the most extent, existing instructional methods fall short in including guidance from and interaction with construction experts, and thus provide students with very limited access to hands-on experience. The classroom experience is often passive and deductive in nature as teachers communicate the fundamentals and students have to deduce derivations, examples, and applications in assignments [9]. Even site visits that ideally form an important component of teaching and learning in many aspects may not be always possible due to issues such as schedule conflicts, access difficulties, weather situations, and the overriding need for safety and liability [10].

Recent figures show that today's digital native students (who are highly engaged with the technology around them) are more likely to choose scientific and engineering fields that are more flexible and have already embraced the use of latest technologies [11,12]. Tobias [13] discussed that introductory science courses are often responsible for driving off many students who have an initial intention and the ability to earn science degrees but instead switch to nonscientific fields.

These and similar challenges highlight the role of new and innovative teaching techniques that use advanced computing and information technologies, simulation, and virtual learning environments to
complement engineering education [14]. Due to recent advances in the development of pedagogical concepts, applications and technology, and a simultaneous decline in hardware costs, the use of small-scale and mobile systems in education has received even more attention. Several researchers reviewed the effectiveness of technology in the classroom. Their findings indicated that when properly implemented, computer technology has a significant effect on student achievement, stimulated increased instructor–student interaction, encouraged co-operative learning, collaboration, problem-solving, and student inquiry skills [15,16].

Studies on particular types of technology use are still being conducted. For example, a recent study on the impact of electronic field trips conducted by Maryland Public Television and the Johns Hopkins University Center for Technology in Education, found that participating students exhibited significantly higher levels of knowledge on three social studies units than students who had not participated. Participating students also demonstrated greater improvement in reading comprehension skills [17].

More recently, the introduction of computer technologies such as computer-aided design (CAD) and building information modeling (BIM) has aimed to improve the quality of learning in construction education. In a recent study, more than 60% of the students agreed that they had a better understanding on building structure after learning BIM [18]. Messner et al. [19] presented the results of a project aimed to improve construction education through the use of virtual reality (VR) and 4D CAD modeling. In particular, they integrated a 4D CAD visualization application into their undergraduate architectural engineering program, and experienced the use of a VR tool that allowed construction engineering students to interactively generate a construction sequence for a project in an immersive environment. The results of these experiments suggested that students can (1) understand construction projects and plans much better when advanced visualization tools are used, and (2) very quickly gain experience by developing and critiquing construction schedules in a full-scale virtual environment. These and similar studies indicate that the integration of advanced interactive 3D visualization into the curriculum can significantly assist students to relate their abstract (and mostly theoretical) knowledge to real practical problems in the field. At the same time, it is imperative that accumulating adequate skills and training to operate equipment and conduct engineering tasks through traditional training methods takes significant time and has proven to be costly and inefficient [20]. Thus, the overarching goal of this project is to provide a timely and effective education to the students through integrating technology into core curricula and implementing it in a classroom setting, rather than only providing devices and software [21].

At the same time, professional development and collaboration between students and instructors need to be encouraged and new forms of pedagogy and assessment must be accordingly created. What is essential is to make technology a ubiquitous resource in the learning process, personalize it based on students’ individual needs and learning styles, and then ask instructors to mentor and facilitate the use of technology while students learn, direct, and collaborate in a technology-rich environment. Integrating technology into the curriculum in today’s schools should not mean finding ways that computers can help instructors teach the same old topics in the same old ways. Instead, instructors must have the opportunity to combine technology with emerging models of teaching and learning to transform education. In an attempt to implement this philosophy, this paper presents the latest findings of an ongoing work which aims to explore the extent to which collaborative augmented reality (AR) can be effectively used as a transformative learning tool to improve the quality of education in engineering and science. The authors use construction education as a test bed by enabling students to learn the basics of equipment, processes, and operational safety in a learning environment that supports real time interaction with a remote job site.

2. Importance of research to construction education

Construction operations consist of human-machine interactions and high levels of exposure to equipment and tools in harsh environments. Although many construction firms have implemented strict jobsite safety measures and training, compared to other industries, construction still has the highest accident and fatality rate in the nation [22,23]. Research shows that inexperience and lack of knowledge among young and unskilled project personnel account for the highest number of work injuries and fatalities [24,25]. Although worker safety and health issues have been previously discussed at length by researchers [26], the inevitable risks associated with such projects, as well as the high costs of accident recovery especially compared to relatively lower pay scale in construction [27] have been traditionally an impediment to the involvement and recruitment of students and youngsters in construction projects.

On the other hand, the construction industry has been constantly facing increased national and international competition, and stringent governmental and environmental regulations while encountering issues such as organized labor, challenges of new technologies and new materials, and construction of complex projects [28]. These forces emphasize the importance of a steady supply of competitive and strong workforce to the industry and as a result, attracting talented students and imparting the best possible education are critical to the future of the U.S. construction industry [12]. In reality, many construction programs fail to provide students with an environment where they can acquire the skills and experience necessary to be successful at professional practice and onsite performance. In a study conducted by the U.K. Institution of Structural Engineers, it was revealed that civil engineering education fails to include practicality and feel for construction engineering [29,30]. Most engineers need to spend many years in the field in order to assimilate an adequate knowledge about actual construction performance.

Hence, given the high demand for skilled workforce in the construction industry, the high level of risk associated with equipment operations on site, and the fact that appropriate operational and safety skills take long time to accumulate, this research explores an innovative approach that integrates advanced technology into the teaching and learning experience. The authors have investigated visualization and sensing techniques to study, design, implement, and evaluate a potentially transformative pedagogical paradigm for engineering process education to impart the required training while providing flexibility, mobility, and ease of use. At the same time, these enhancements provide a more exciting and vivid experience for students and instructors while increasing the quality of learning through hands-on interaction with construction equipment, tools, and processes.

3. Methodology

In this section, first a comprehensive review of the enabling technology is conducted, and then a more detailed description of the developed methodology will be presented.

3.1. Enabling technology: augmented reality (AR)

The presented research aims to enhance the learning process by implementing AR visualization in an interactive learning environment. AR is the superimposition of computer-generated information over a user’s view of the real world. By presenting contextual information in textual or graphical format, the user’s view of the real world is enhanced or augmented beyond the normal experience [31]. The addition of such contextual computer-generated information spatially located relative to the user can assist in the performance of several scientific and engineering tasks. For this reason, AR enabling technologies have been researched in an increasing number of studies during the recent years.
AR is different from VR, a visualization technology that has been around for several decades. Unlike VR, AR does not completely replace the real world, rather the real world is supplemented with relevant synthetic information, and thus real and virtual objects coexist in an augmented space [32]. As shown in Fig. 1, the real advantage of AR is that the view of the real world is used as a readymade backdrop for displaying superimposed information (e.g. graphics, sound, diagrams) of interest. This feature enables AR users to create and overlay only the information that needs to be augmented onto the real world view and as a result, recreating the surrounding environment is not a concern. At the same time, by bringing the real world into the visualization, the user (as a real object in the real world) will become part of the AR experience and hence, can interact with both real and virtual objects in an intuitive manner. Collaborative AR takes this even further as it allows multiple users to access a shared space populated by virtual objects [33].

AR has been used by researchers in several fields of science and engineering. For example, visualization of medical information projected onto a patient’s body is one of the established applications of AR technology [34]. AR has also been used in military applications. For instance, the Battlefield Augmented Reality System (BARS) is an AR system that can network multiple dismounted war fighters together with a command center and supports information gathering and human navigation for situation awareness in urban settings [35]. Previous studies have also explored AR for a number of architecture and construction applications. For example, previous research have used AR to overlay locations of subsurface utility lines onto real world views in order to demonstrate the potential of AR in helping maintenance workers avoid buried infrastructure and structural elements [36]. Also, AR has been used to study the extent of horizontal displacements sustained by structural elements due to extreme loading conditions [37], and to assist viewers for computer-aided drawing [38].

More recently, the authors designed and implemented ARVISCOPE, a general purpose 3D visualization environment capable of animating simulation models of dynamic engineering operations in outdoor AR [39]. ARVISCOPE supports real time communications with Global Positioning System (GPS) and motion tracking devices in order to create and constantly update live AR animations of an engineering operation displayed to a mobile observer. Another major outcome of this research was ROVER, a mobile computing apparatus designed to address the problem of geo-referenced registration which historically has been a major research challenge in outdoor AR [40]. A proper registration results in objects in the real world and superimposed virtual objects precisely aligned in the global coordinate system (i.e., longitude, latitude, and altitude) with respect to each other. When used together, ARVISCOPE and ROVER can create interactive AR animations of any length and complexity. The designed framework is compatible with commonly accepted data transfer protocols [41].

The 2010 Horizon Report, a joint report prepared by the New Media Consortium and EDUCAUSE [42], predicts that the use of AR in education will be widespread in two to three years. AR can enhance the traditional learning experience since:

- The ability to learn concepts and ideas through interacting with a scene and building one’s own knowledge (constructivism learning) facilitates the generation of knowledge and skills that otherwise would take too long to accumulate.
- Traditional methods of learning spatially-related content by viewing 2D diagrams or images create a cognitive filter. This filter exists even when working with 3D objects on a computer screen because the manipulation of the objects in space is done through mouse clicks. By using 3D immersive AR, a more direct cognitive path toward understanding the content can be made possible.
- Making mistakes during the learning process will have literally no real consequence for the educator whereas in traditional learning, failure to follow certain rules or precautions while operating machinery or handling a certain hazardous material would lead to serious safety and health related problems.
- AR supports discovery-based learning which refers to a learning technique in which students take control of their own learning process, acquire information, and use that information in order to experience scenarios which may not be feasible to construct in reality given the time and space constraints of a typical engineering project.
- One of the most important objectives of all academic curricula is to promote social interactions among educators and to teach them to listen, respect, influence, and act. By providing multiple students access to a shared augmented space populated with real and virtual objects, they are encouraged to become involved in teamwork and brainstorming activities in order to solve a problem which at the same time, helps them improve their communication skills.

There are two major categories of AR visualization technologies: marker-less, and marker-based. A marker is a 2D computer recognizable graphical pattern or symbol printed on a sheet of paper to which a piece of information (e.g. video, audio, text, diagram, or graphics) is assigned. In marker-less AR, markers are not used and the condition under which a virtual object is displayed is defined by the user. For example, the user can specify that a virtual object is always displayed at a certain 2D coordinate on an AR display. In marker-based AR, a virtual object is displayed only if its corresponding marker pattern is visible. A well-known example of marker-based AR is the Lego Digital Box technology used in Disney World. As shown in Fig. 2, kids can hold a Lego box in front of a camera and the animated 3D model of the completed Lego set is superimposed and displayed on top of the box when the box is visible to the camera.

In a more recent effort, the Public Broadcasting Station (PBS) used part of a $72 million grant from the U.S. Department of Education to test whether AR games and mobile devices can help young children
with skills such as sorting and measuring [43]. In this research, marker-based AR was used. In particular, marker patterns were printed on sheets of paper bound together to form an “AR Book”. Fig. 3 shows sample pages of GEN-1, a first generation AR Book designed by the authors for prototype development and validation experiments. More details about the development of GEN-1 are discussed in Section 4.

### 3.2. Visual information delivery using augmented reality

Fig. 4 shows the conceptual framework developed in the presented research to deliver visual information from a remote jobsite to students in a classroom. As shown in this figure, each student is equipped with an AR head-mounted display (HMD) which enables viewing of augmented information and graphics overlaid on the markers inside the AR Book. When a marker is visible through the HMD, the corresponding information is shown to the student. The following subsections describe the necessary steps that were taken to deliver visual information to a student.

#### 3.2.1. Capturing and transmission of remote scene information

Real time video streams of a remote construction jobsite captured by an IP-addressable camera are transmitted via the internet to the classroom, and displayed on a large projection screen. The global position of the camera (i.e. longitude, latitude, and altitude) is also obtained using a GPS device mounted on top of the camera. In order to identify an object in the video (e.g. crane, excavator, hauler), it is essential to geo-reference that object. This is done by capturing the object’s global position using a GPS device. Most modern construction equipment such as graders or dozers takes advantage of built-in GPS transmitters which can be used to obtain their position in the field. However, if necessary, site personnel can be asked to mount a GPS device on any object of interest the position of which needs to be geo-referenced in the video. The positional information is constantly sent to a computer.

Knowing the global positions of the camera (viewpoint) and an object of interest, the local position of the object inside the coordinate frame of the projection screen with the camera located at the center point of the screen is calculated using existing geo-referencing methods such as the algorithm introduced in [44] and used by authors in [45]. For example, if the camera located at 81° 20′ 59″ W and 28° 27′ 57″ N (elevation 28 m above mean sea level), is capturing views of an object (e.g. construction equipment) located at 81° 21′ 00″ W and 28° 28′ 00″ N (elevation 26 m above mean sea level), using the formulation presented in [44], the planar distance and azimuth between the camera and the object will be 96 m and 343.84°, respectively. Hence, assuming that X values indicate points to the right (+) or to the left (−) of the camera’s lens, Y values show elevation difference (positive if the object is located above the camera’s lens elevation, and negative otherwise), and Z axis runs from the camera’s lens into the depth of the field, the local position of the object in the camera’s coordinate frame can be calculated as follows,

\[
Z = 96 \times \cos(360° - 343.84°) = 92.21 \, \text{m} \\
X = 96 \times \sin(360° - 343.84°) = 26.72 \, \text{m} \\
Y = 28.00 - 26.00 = 2.00 \, \text{m}
\]
These calculated coordinate values will be then converted to orthogonal coordinates and used to determine the position of the object inside the live streaming video projected on the 2D screen. This contextual knowledge enables further interaction with the objects as described in the following subsection.

3.2.2. Visual delivery of information

Students walk up to the projection screen while carrying their AR Books and watch the video stream. As shown in Fig. 5, each student wears a touch sensor (i.e. tag) on his or her index finger to have the ability to interact with the video scene and retrieve information.
4. Implementation and results

The authors have successfully created a first generation AR Book in order to test if contextual graphical information can be effectively presented to students in real time.

4.1. GEN-1: first generation AR Book prototype

The first generation AR Book developed in this research, GEN-1, is a prototype of an AR-enhanced book that was implemented in Visual Studio .NET, using the ARToolkit library. ARToolkit is one of the earliest object-oriented programming libraries that provide functionalities and methods to track fiducial markers. As shown in Fig. 6, a fiducial marker is a logo bounded by a thick black frame. The four corners of the frame are used to compute the camera pose, and the center logo is used to interpret the identity of the marker so it can be mapped to certain 2D/3D graphics. Because of its simplicity and fast tracking speed, ARToolkit has been popular for over a decade in numerous AR visualization applications.

Using the functionalities provided by ARToolkit, GEN-1 provides a fiducial marker-based AR interface for students and helps them gain a better understanding of construction equipment by overlaying 3D models of construction machinery on AR markers [46]. As shown in Fig. 3, GEN-1 consists of left hand pages each coupled with a corresponding right hand page. Each left hand page contains informative details and illustrations about a certain piece of construction equipment, which can include a wide range of information such as the details about various parts of the equipment, history of the equipment, major components, functions, and also its current manufacturers.

The corresponding right hand page contains one or more marker patterns. Fig. 7 shows snapshots of two validation experiments. As shown in this figure, GEN-1 uses a normal textbook as the main interface. Students can turn the pages of the book, look at the pictures, and read the text without any additional technology. However, when looking at the same pages through an AR display, students will see 3D virtual models of the equipment discussed on the left hand page on top of the marker depicted on the right hand page. The marker patterns are detectable by the designed AR visualization platform. Once a marker is detected, a virtual graphic model of construction equipment (previously assigned to that marker inside the AR application) is displayed on the marker. The output can be seen on a handheld display, through a HMD, or on the computer screen. The models appear to be attached to the real page so students can see the AR scene from any perspective by moving themselves or the book.

The virtual content can be static or animated. This interface design supports collaborative learning as several students can look at the same book through their AR displays and see the virtual models superimposed over the book pages from their own viewpoints. Since they can see each other and the real world at the same time as the virtual models they can easily communicate using normal face-to-face communication cues. All of the students using the AR Book interface have their own independent view of the content so any number of people can view and interact with a virtual model as easily as they could with a real object [47].

4.2. Collaborative learning in a multi-user AR environment

Recent research by the authors has also led to the development of ARVITA, an AR-based 3D visualization environment in which multiple users can view and interact with modeled engineering processes from different perspectives. This framework is an expansion of a VR-based visualization platform called VITASCOPE, an open, loosely-coupled,
user-extensible 3D animation description language designed specifically for visualizing simulated construction processes and resulting products in 3D, and developing higher-level construction visualization tools [48]. By integrating computer detectable AR marker patterns and viewpoint tracking technology into VITASCOPE, the newly developed collaborative AR learning tool enables students to look at and immerse in dynamic animations of simulation-based construction scenarios displayed to them on top of the markers. Fig. 8 shows a snapshot of an experiment where two students are observing a simulated earthmoving operation from two different perspectives. In this experiment, a camera mounted in front of each user’s HMD sent a streaming video of the real world to the computer. The predefined AR marker pattern was then detected inside each video frame and viewpoint transformation parameters were accordingly calculated in real time. The 3D modeled earthmoving operation was then overlaid on top of the marker and displayed on a separate computer screen to each user.

5. Future work

This paper focused on describing the research motivation and the technical aspects of an AR-based pedagogical framework developed by the authors. The next phases of this research will comprise full-scale usability experiments in classroom settings aimed at evaluating student learning in the context of the developed methodology. Currently, a full scale prototype is being developed to test the functionality of the presented methodology in a classroom setting. The major peripheral components of this test bed are listed in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP-accessible camera</td>
<td>StarDot NetCam XL (wireless)</td>
<td>Capture and transmit real time videos of a remote location</td>
</tr>
<tr>
<td>Indoor locationing system</td>
<td>Ubisense ultra-wide band (UWB) platform (receivers and tags)</td>
<td>Locate the position of student tagged finger on the projection screen</td>
</tr>
<tr>
<td>Head mounted display (HMD)</td>
<td>eMagin Z800 3DVisor</td>
<td>Display graphical information to the student through a pair of AR goggles</td>
</tr>
<tr>
<td>HMD-mounted video camera</td>
<td>Microsoft LifeCam VX-5000</td>
<td>Capture views of student surroundings to be used as the backdrop of the AR visualization</td>
</tr>
</tbody>
</table>

6. Summary and conclusions

The main motivation behind this research was that unlike several other scientific and engineering fields, many construction and civil engineering programs still heavily rely on traditional instructional methods and fall behind in terms of integrating state-of-the-art information delivery technologies into the classroom. In this paper, the latest results of an ongoing project which aims to investigate the requirements and develop a real time interactive visual information delivery framework were presented.

In this framework, real time video streams of a remote construction jobsite are captured and transmitted via the internet to the classroom, and displayed on a large projection screen. Each student can walk up to the screen while carrying an AR Book and watch the video stream. Students have the ability to interact with the scene and retrieve information about objects by wearing smart tags on their fingers. As the student moves his or her finger on the screen, a network of motion sensors captures the position of the student’s finger on the projection screen and maps that position to the locations of objects in the video. When the student’s finger moves close to an object in the video, relevant information (e.g. 2D or 3D models, manufacturer’s data, loading charts) are augmented on the AR Book and displayed to the student. In order to see this overlaid information, each student is equipped with an AR HMD which enables viewing of augmented information and overlaid graphics. Students can also move their AR Books around the room to form groups, virtually manage a project, discuss specific planning scenarios, and explore alternative solutions in a collaborative setting.

Acknowledgments

The presented work is partially supported by a grant from the Office of Research and Commercialization (ORC) at the University of Central Florida (UCF). Activities that resulted in the development of GEN-1 and ARVITA were supported by the National Science Foundation (NSF) through grant CMS-0448762. The authors gratefully acknowledge the support from the UCF and the NSF. The authors would also like to thank Mr. Suyang Dong (Ph.D. Student at the University of Michigan) for his participation in the development of ARVITA, and Mr. Asif Iqbal (former Visiting Student Researcher at the University of Michigan) for his participation in the development of the first generation AR Book. Any opinions, findings, conclusions, and recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the UCF, NSF, or the individuals named above.

References
