A FRAMEWORK FOR UTILIZING CONTEXT-AWARE AUGMENTED REALITY VISUALIZATION IN ENGINEERING EDUCATION

Amir H. Behzadan
University of Central Florida, Orlando, FL, USA

Vineet R. Kamat
University of Michigan, Ann Arbor, MI, USA

ABSTRACT: A growing number of construction engineering students complain about the lack of engagement and interaction with the learning environment. A major factor contributing to this issue is that instructors in most construction and civil engineering programs still rely on traditional teaching methods including the use of chalkboard, printed handouts, and computer presentations that are often verbose but contain little visual information. This is despite the fact that according to a number of recent research studies these teaching techniques are considered outdated by a large group of new generation students who are visual learners or team workers. At the same time, the influence of interactive social media in every aspect of daily life has changed student perceptions and how they expect the instructional materials to be presented in a classroom setting. This paper presents an innovative learning tool that uses remote videotaping, augmented reality (AR), and ultra-wide band (UWB) localization to bring live videos of a real construction jobsite to the classroom, create an interactive interface for students to watch the streaming video and select objects in the scenes, and visually deliver location-aware instructional materials to students in real time. The objective of this research is to explore the extent to which these technologies can be used to provide students with a learning environment that enables them to develop an in-depth understanding of and gain hands-on experience with construction equipment and operational issues, while experiencing teamwork and critical thinking in a collaborative setting.

KEYWORDS: Augmented Reality, Visualization, Construction, Education, Collaborative Learning.

1. INTRODUCTION

Engineering systems are rapidly growing in complexity, size, uncertainty, and interdisciplinary characteristics. Construction and infrastructure systems are not exceptions as they mostly involve dynamic processes that occur in constantly evolving environments and continuously interact with one another. The circumstances in which these processes take place often become more complicated due to factors such as unforeseen site conditions, change orders, and project-related disputes. Despite this, figures show that many construction and civil engineering students have historically lacked a comprehensive knowledge of onsite construction tasks, and the dynamics and complexities involved in a typical construction project (Arditi and Polat 2010). Yet, the curricula of most construction and civil engineering programs do not fully convey the necessary knowledge and skills required to effectively face and resolve these challenges. Arguably, the major emphasis on traditional information delivery methods which include the use of chalkboard, handouts, and lecture-style presentations, coupled with focusing mainly on simplistic approaches and unrealistic assumptions to formulate and solve complicated engineering problems can potentially result in construction and civil engineering students falling behind in applying what they learn in the classroom to the practical scenarios in the field (Tener 1996). In particular, a major concern shared by many students is that little effort is made to educate them with the latest trends of emerging technologies and advanced problem-solving tools. Figure 1 shows the results of a recent survey of 63 junior-level students of civil and construction engineering. The results clearly indicated that a solid majority of students believed that compared to students in other engineering disciplines, they were exposed to less technology advancements in the classroom. While engineering students need to pick up the social and technical skills (e.g. critical thinking, decision-making, collaboration, and leadership) they need to be competent in the digital age (Bowie 2010). Mills and Treagust (2003) discussed that most students are graduating with descent knowledge of fundamental engineering science, but they don’t know how to apply that knowledge in practice. One of the fastest emerging technologies in engineering education is visualization. According to the same student survey (Figure 1), more than 90% of those responded indicated that they learn better when the instructor uses 3D representations or visualization to teach engineering concepts and theories. Although instructional methods that take advantage of visualization techniques have been around for several decades, many still rely on traditional media and tools. For example, students who take a course in construction planning may use drawings, scheduling bar charts, sand table models, and more recently, 3D CAD models. However, none of these techniques are capable of effectively conveying information on
every aspect of a project. For instance, 2D or 3D models do not reflect temporal progress, while scheduling bar charts do not demonstrate corresponding spatial layout.

At a broader level, previous work has highlighted the benefits of technological advances to the learning process. For example, Stratham and Torell (1996) 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 cooperative learning, collaboration, problem-solving, and student inquiry skills. 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. However, many students and new project personnel still fail to relate this abstract knowledge to real problems in the field. While the construction industry lacks a steady supply of skilled and experienced workforce, 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 (AbouRizk and Sawhney 1994). Thus, a main challenge is to provide a timely and effective education to the future workforce through integrating technology into core curricula and implementing it in a classroom setting, rather than only providing devices and software (Ash 2011). At the same time, professional development and collaboration between students and instructors needs 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.

To address the abovementioned challenges, this paper reports on the latest findings of an ongoing research being conducted by authors that aims to explore an innovative approach to integrate advanced visualization and location tracking technologies into the teaching and learning experience of engineering students. In particular, the authors have investigated the applicability of augmented reality (AR) 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. These enhancements will also 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.

2. AUGMENTED REALITY-BASED INFORMATION DELIVERY FRAMEWORK

In the past, several researchers have explored the feasibility of advanced visualization technologies in architecture, engineering, and construction (AEC) (Nikolic et al. 2010, Messner et al. 2003, Psotka 1995) as well as other scientific and engineering disciplines (Yair et al. 2001, Kaufmann et al. 2000, Ota et al. 1995). Most of the previous work in this area has used the capabilities of virtual reality (VR) visualization paradigm. In order to have realistic and convincing virtual scenes, it is necessary to first create 3D models of the facilities and equipment. These models will then need to be properly rendered inside a virtual environment and displayed to the user. The process of creating, rendering, and updating the computer generated graphics, which is often referred to as CAD model engineering (Brooks 1999) may turn into a tedious if not an impossible task especially when the size and complexity of the scene increase. An alternate approach to VR, is the AR visualization paradigm in which views of the real world objects are used as readymade backdrops of the visualized scenes and the modeler needs to only create and render those information that are necessary and of relevance to the user (Behzadan and Kamat 2005). In addition, since real and virtual worlds coexist in AR visualization, human users (from the real world) can more effectively interact with computer generated graphics (of the virtual world) on a 1:1 scale. Hence, in this research, AR was used as the main visualization technology to develop an interactive learning environment for engineering students. Figure 1 shows the components of the developed AR-based instructional information delivery framework.

![Fig. 2: Components of the augmented reality-based information delivery system developed in this research.](image)

In this framework, each student wears an AR head-mounted display (HMD) which enables viewing of augmented information and graphics overlaid on the fiducial markers inside an AR Book. A fiducial marker is simply a logo bounded by a thick black frame that is visually detectable by the camera mounted on the HMD and
can be mapped to certain 2D/3D graphics. When a marker is visible through the HMD, the corresponding information is shown to the student. When the application is launched, 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 camera is equipped with a global positioning system (GPS) that continuously transmits the position of the camera (i.e. longitude, latitude, and altitude). To track objects (e.g. crane, excavator, hauler) in the video, they must be as well geo-referenced. This is done by capturing each object’s global position using a GPS device. Most modern construction equipment such as graders or dozers takes advantage of onboard GPS units which can be used for this purpose. However, if necessary, additional GPS units can be mounted by site personnel 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 position of the camera (viewpoint) and any object in the video, local position of that object inside the coordinate frame of the projection screen (with the camera located at the center point of the screen) is then calculated using existing geo-referencing methods such as the algorithm introduced by Vincenty (1975) and used by Behzadan and Kamat (2007). For example, if the camera located at 81º 20' 59'' W and 28º 27' 57'' N (elevation 28 meters above mean sea level), is capturing views of an object (e.g. construction equipment) located at 81º 21' 00'' W and 28º 28' 00'' N (elevation 26 meters above mean sea level), the planar distance and azimuth between the camera and the object will be 96 meters and 343.84º, 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,

\[
\begin{align*}
Z & = 96 \times \cos(360º − 343.84º) = 92.21 \text{ meters} \\
X & = 96 \times \sin(360º − 343.84º) = 26.72 \text{ meters} \\
Y & = 28.00 − 26.00 = 2.00 \text{ meters}
\end{align*}
\]

The perspective viewing properties of the camera (e.g. horizontal and vertical fields of view, near and far planes) will then be used to construct a transformation matrix that converts the calculated coordinate values to orthogonal coordinates inside the 2D frame of the projection screen. This contextual knowledge is essential for real time detection and further interaction with the objects inside the live video streams. As this information is constantly updated as new GPS data is received by the system, students are able to walk up to the projection screen while carrying their AR Books and watch the video stream. As shown in Figure 2, each student wears a smart tag on his or her index finger to have the ability to interact with the video scene and retrieve information about the objects of interest. As this tagged finger moves across the screen, its local position inside the 2D coordinate frame of the projection screen is captured by a network of data receivers installed in the room at known positions. As shown in Figure 3, this calculation is based on the time-of-flight (TOF) concept. At least three data receivers are needed in order to precisely calculate the tagged finger position through 3D triangulation in the local coordinate of the projection screen. An additional (fourth) data receiver is also used to increase accuracy and eliminate any potential errors in locating the position of the tag on the projection screen.

![Image](image-url)

Fig. 3: 3D triangulation is used to determine the exact position of a mobile tag in real time.
When the student’s tagged finger moves close to an object in the video (i.e. linear distance between the tagged finger and the position of a video object is less than a certain threshold), relevant visual information (e.g. 2D or 3D models, manufacturer’s data, loading charts, work schedule) will be displayed to the student through the HMD on AR Book markers. Students can also move their AR Books around the room to form groups, virtually manage a project, discuss a certain scenario, and explore alternative solutions in a collaborative setting, while learning basic concepts such as equipment operations, jobsite safety, resource utilization, work sequencing, and site layout.

3. IMPLEMENTATION AND PRELIMINARY 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. 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. 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. Figure 4 shows a sample GEN-1 lesson on excavators. As shown in this Figure, each left hand page contains informative details and illustrations about a certain piece of construction equipment (e.g. excavator), which can include a wide range of information such as details about various parts of the equipment, history of the equipment, major components, functions, and also its current manufacturers. Each left hand page is coupled with a corresponding right hand page that contains several marker patterns.

![Figure 4: Sample pages from GEN-1 AR Book. Each left hand page is accompanied by a corresponding right hand page which contains several marker patterns.](image)

Figure 5 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 markers depicted on the right hand page. The marker patterns are detectable by the designed AR visualization platform. Once a marker is detected, a virtual model of construction equipment (previously assigned to that marker inside the AR application) is displayed on the marker. The output can be either seen on a handheld display or a HMD or even on the computer screen. The models appear attached to the real page so students can see the AR scene from any perspective by moving themselves or the book. As stated earlier, the virtual content displayed to students 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 viewpoint. Since they can see each other, the real world, and the virtual models all at the same time 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.
Fig. 5: Snapshots of proof-of-concept experiments conducted using GEN-1 AR Book. 3D virtual models of construction equipment are displayed on right hand side pages.

Currently, the authors are working on the design and implementation of full-scale usability experiments in classroom settings. Table 1 lists the major hardware components used to develop this large-scale test environment.

Table 1: Major components used to develop a large-scale test environment.

<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>Locationing System</td>
<td>Ubisense Ultra-Wide Band (UWB) platform</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>

The experiments will be conducted to evaluate student learning in the context of the developed methodology. As part of these experiments, several direct and indirect measures such as performance on assignments, end-of-course student assessments, pre- and post- surveys, and interviews will be deployed to collect and analyze data about the impact of the newly developed tool on students’ perception and quality of learning. In order to track the position of tagged fingers on the projection screen, an UWB real time locationing system (RTLS) is used. The system includes 4 Series 7000 IP30 sensors (i.e. data receivers) and a number of smart tags that can be attached to student fingers. Table 2 shows manufacturer’s specification of the UWB tracking system used in this research.

Table 2: Manufacturer’s specifications of the UWB tracking system used in the large-scale test environment.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>3D accuracy up to 6 inches at 95% confidence level (depending on specific environment and system configuration)</td>
</tr>
<tr>
<td>Tag Update Rate</td>
<td>Variable from 10 per second to 1 every 10 minutes</td>
</tr>
<tr>
<td>Aggregate Cell Update Rate</td>
<td>40 updates per second (maximum)</td>
</tr>
<tr>
<td>UWB Radio Transmission</td>
<td>6.0 GHz – 8.5 GHz, -41.3 dBm/MHz, Center frequency: 7.02 GHz</td>
</tr>
<tr>
<td>Telemetry Radio Channel</td>
<td>2.4 GHz ISM band, Ubisense control protocol</td>
</tr>
<tr>
<td>Tag-Sensor Maximum Range</td>
<td>&gt; 160 meters at 40 updates per second in Open Field Measurement (optimally aligned Slim Tag)</td>
</tr>
<tr>
<td>Suggested Sensor Spacing</td>
<td>100 feet to 200 feet at 40 updates per second in an indoor open environment (e.g. warehouse)</td>
</tr>
</tbody>
</table>
4. SUMMARY AND CONCLUSIONS

The main motivation behind this research was the need to fundamentally revive the existing construction and civil engineering curricula that still heavily rely on traditional instructional methods and mostly fall behind in terms of integrating state-of-the-art information delivery technologies into the classroom. This paper reported on the latest results of an ongoing project aimed to investigate the requirements and develop a real time interactive visual information delivery framework for construction and civil engineering education. 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 any object in the video by pointing directly to that object. A network of wireless receivers captures the position of the student’s finger on the 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 visual information are augmented on the AR Book and displayed to the student. 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. Preliminary results and proof-of-concept experiments have illustrated the feasibility of this approach in visually imparting basic engineering knowledge about construction equipment to students. The authors are currently working on the design and implementation of classroom-scale experiments where multiple users can simultaneously interact with a live video stream and learn the concepts in a collaborative environment.

5. REFERENCES


