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Exploring the Potential

of Context-Aware Augmented Reality

in Construction Engineering Education

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Introduction

The new generation of students is to a large extent technology savvy, loves to interact on social media, and extensively uses the Internet as the main source of collecting information. Yet many civil and construction engineering instructors, especially those teaching traditional courses such as statics, equipment, construction methods, and building materials, rely heavily on traditional teaching methods. These include the use of chalkboard, handouts, and old-style presentations that are often filled with too many words and take advantage of too little technology. Consequently, many engineering students often complain about the lack of engagement and interaction with the learning environment. In the absence of clear strategies and examples on how to enrich existing teaching methods with the latest and the greatest technology advancements, long term problems such as decreasing enrollment trends and low student retention are inevitable.

This paper reports on a recent effort by the authors to design and implement an innovative learning tool that uses remote videotaping, augmented reality (AR), and ultra-wide band (UWB) locationing technologies to bring live videos of a remote construction jobsite 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. The ultimate goal of this exploratory project is to set an example of how the latest technology trends can help instructors deliver course materials in a more efficient manner where discovery-based and collaborative learning are the cornerstones of the teaching process.

Augmented Reality

Augmented Reality (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 (Behzadan & Kamat, 2005). 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.

Augmented Reality is different from Virtual Reality (VR), a visualization technology that has been around for several decades. Unlike VR, Augmented Reality 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 (Azuma, 1997).

As shown in Figure 1, the real advantage of Augmented Reality is that the view of the real world is used as a ready-made backdrop for displaying superimposed graphics or information. This allows Augmented Reality users to create and overlay only the information that needs to be augmented onto the real world view. As a result, recreating the whole surrounding environment, which may prove to be a time consuming and computing intensive task, is no longer a concern. In addition, the very fact that a human observer of an Augmented Reality scene is part of the real surrounding world enables the creation of immersive augmented environments where the observer can essentially interact with both real and virtual objects. Collaborative Augmented Reality takes this one step further by allowing multiple users to access a shared space populated by virtual objects (Kaufmann & Schmalstieg, 2003).

Figure 1
In Augmented Reality, Real World Views Are Used as a Background When Superimposing Virtual Graphics or Information

Johnson, Levine, Smith, and Stone (2010) predicted that the use of Augmented Reality in education will be widespread in a few years. Augmented Reality 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 Augmented Reality, 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.

- Augmented Reality 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.

During the past few decades, Augmented Reality has been used for training purposes, especially in potentially hazardous environments where real world experience is necessary but the actual presence of people in such an environment would incur an unacceptably high level of risk (Kerawalla, Luckin, Seljeflot, & Woolard, 2006). For example, the risk of using a real limb when experiencing its resistance against a biopsy needle is a high-risk task and so, overlaying an artificial limb with an ultrasound image of a real limb is beneficial in training medics (Bajura, Fuchs, & Ohbuchi, 1992). Augmented Reality has also been used for training in manufacturing (Caudell & Mizell, 1992; Sims, 1994), and military training (Rosenblum, et al., 2002).

The application of Augmented Reality in engineering has been relatively limited to a few pilot studies. For example, in the field of civil and construction engineering, previous research has used Augmented Reality to develop a tool to visually overlay locations of subsurface utility lines onto real world views in order to help maintenance workers avoid buried infrastructure and structural elements (Roberts et al., 2002). Also, Augmented Reality has been used to study the extent of horizontal displacements sustained by structural elements due to extreme loading conditions (Kamat & El-Tawil, 2005), and to assist viewers for computer-aided drawing (Wang & Dunston, 2006).

More recently, the authors created ARVISCOPE, a general purpose 3D visualization environment capable of animating simulation models of dynamic engineering operations in outdoor Augmented Reality (Behzadan & Kamat, 2009). ARVISCOPE supports real time communications with Global Positioning System (GPS) and motion tracking devices in order to create and constantly update live Augmented Reality animations of an engineering operation displayed to a mobile observer.

A snapshot of an augmented reality animated scene generated by ARVISCOPE is shown in Figure 2. In this Figure, 3D virtual models of an excavator and a truck involved in a simulated earthmoving operation are superimposed on top of a real world background, and displayed to a mobile user in real time as s/he navigates inside the real world.

Figure 2
Sample AR Animated Scene of an Earthmoving Operation Created in ARVISCOPE

Main Research Motivations

Construction operations consist of human interactions with machinery and equipment in dynamic environments. That is the main reason why compared to other industries, construction has the highest accident and fatality rate in the nation (Carliner, 2001; Pollack & Chowdhury, 2001). Research shows that inexperience and lack of knowledge among young and unskilled project personnel account for the highest number of work injuries and fatalities (Abdelhamid & Everett, 2000; Toole, 2002). This inevitable risk together with the high cost of accident recovery has been the major impediment to the involvement and recruitment of students and youngsters in construction projects.

On the other hand, the U.S. construction industry has been constantly dealing with increased competition and stringent governmental and environmental regulations while facing issues such as labor strikes, challenges of new technologies and new materials, and construction of complex projects (Sawhney, Mund, & Koczenasz, 2001). 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 is critical to the future of this industry (Nehdi, 2001). 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. As a result, most engineers need to spend many years in the field in order to assimilate an adequate level of knowledge necessary to perform the job.

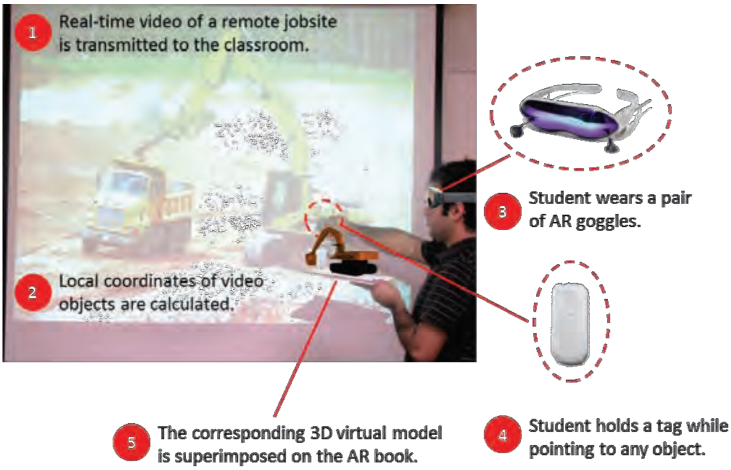
In summary, this project was motivated by the continuous demand for skilled workforce in the construction industry, the high level of risk associated with equipment operations, and the fact that appropriate operational and safety skills take lengthy work experience.

The goal of this research is 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.

Developed Methodology

Figure 3 shows the framework developed by the authors to deliver visual information from a remote jobsite to students in a classroom. As shown in this Figure, each student is equipped with an Augmented Reality 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.

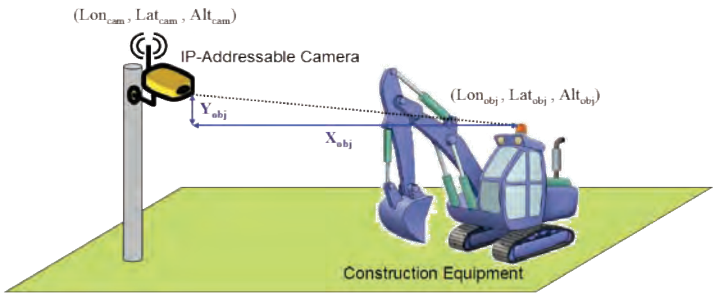
Figure 3
Creating an Augmented Reality Learning Experience in the Classroom



Using the envisioned framework, real time video streams of a remote construction jobsite captured by an IP-addressable camera are first transmitted via the Internet to the classroom, and displayed on a large projection screen. The global position of the onsite camera (in terms of longitude, latitude, and altitude) is also obtained using a GPS device mounted on top of the camera as it moves in the construction jobsite. In order to identify an object in the video (e.g. crane, excavator, hauler), it is essential to geo-reference that object by capturing the object's global position using a GPS device. Many modern heavy construction equipment such as graders or dozers have 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 for which the position needs to be geo-referenced in the video.

Positional information is constantly sent to a computer. As shown in Figure 4, taking into account the global positions of the camera (viewpoint) and any given object, the 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 calculated using existing geo-referencing methods such as the algorithm introduced in Vincenty (1975).

Figure 4
Global Position of Construction Objects Is Transformed to the Local 2D Coordinate of the Projection Screen



For example, if a 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), using the formulation developed by Vincenty (1975), the planar distance and azimuth between the camera and the object will be 96 meters and 343.84º, respectively. 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,

$$Z = 96 \times \cos(360° - 343.84°) = 92.21 \text{ meters}$$

$$X = 96 \times \sin(360° - 343.84°) = 26.72 \text{ meters}$$

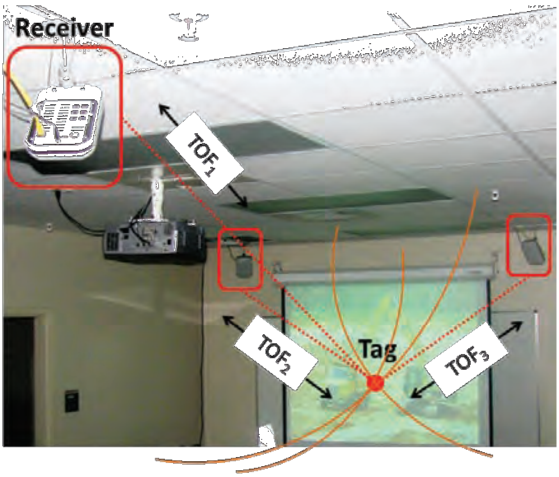
$$Y = 28.00 - 26.00 = 2.00 \text{ meters}$$

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.

Next, students walk up to the projection screen while carrying their Augmented Reality Books and watch the video stream. As shown in Figure 3, each student holds a positioning tag while pointing to the objects inside the video scene. As the student moves his or her finger on the screen, the local position of the tag is captured by a network of data receivers installed in predetermined positions. At least three data receivers are needed in order to precisely calculate the tagged finger position through triangulation in the local coordinate of the projection screen. An additional (fourth) data receiver can also be used to increase accuracy and eliminate any potential errors in locating the position of the tag on the projection screen.

Figure 5 illustrates the process of triangulation in which the concept of time-of-flight (TOF) is used to determine the 3D position of a mobile tag inside the space surrounded by a network of wireless receivers. As shown in this Figure, knowing the wireless signal speed and the TOF between a receiver and the tag, the location space of the tag relative to each receiver is approximated. The intersection of all three location spaces determines the exact 3D position of a tag at any given time.

Figure 5
3D Triangulation Is Used to Determine the Exact Position of a Mobile Tag in Real Time



When a student's tagged finger moves close to an object in the video, relevant data (e.g. 2D or 3D models, manufacturer's data, loading charts, work schedule) in form of virtual information is displayed to the student through the HMD on the Augmented Reality Book. Students can also move their Augmented Reality 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.

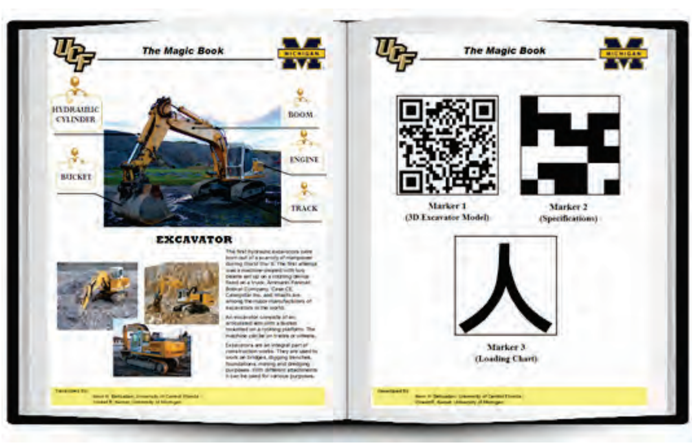
Preliminary Results

The authors have successfully created a first generation Augmented Reality Book called GEN-1 in order to test whether contextual graphical information can be effectively presented to students in real time. GEN-1 is a simple prototype of an Augmented Reality-enhanced book that was completely implemented in Visual Studio .NET, using Augmented Reality Toolkit and osgART libraries. Using GEN-1, students can gain a better understanding of construction equipment by looking at overlaid 3D models of construction machinery on Augmented Reality markers (Behzadan, Iqbal, & Kamat, 2011).

As shown in Figure 6, 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 pieces 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 a fiducial 2D marker pattern. Figure 6 also shows snapshots of two validation experiments.

Figure 6

Snapshots of Preliminary Experiments Conducted Using GEN-1 AR Book Prototype



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 Augmented Reality 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 fiducial marker patterns are designed in a way that they are detectable by the designed Augmented Reality 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 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 Augmented Reality 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 Augmented Reality displays and see the virtual models superimposed over the book pages from their own viewpoint. 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 Augmented Reality 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 (Billinghurst, Kato, & Poupyrev, 2001).

Future Work

The next phases of this work 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 second generation prototype is being developed to test the functionality of the presented methodology in a classroom setting. We will use several direct and indirect measures such as performance on assignments, end-of-course student assessments, pre- and post- surveys, and interviews to collect and analyze data about the impact of the newly developed tool on students' perception and quality of learning.

Summary and Conclusions

Unlike several other scientific and engineering programs, the construction and civil engineering curricula in many schools still rely heavily on traditional instructional methods and fall behind in terms of the use of novel technological advancements to deliver instructional materials in the classroom. This paper reported on the latest results of an ongoing project which aims to investigate the requirements and develop a real time interactive visual information delivery framework. 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 Augmented Reality 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 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 visual information are augmented on the Augmented Reality Book and displayed to the student.

Students can also move their Augmented Reality Books around the room to form groups, virtually manage a project, discuss specific planning scenarios, and explore alternative solutions in a collaborative setting. The ultimate results of this Augmented Reality approach to engineering education should be to increase interest in the field through student interaction, while increasing students' ability to experiment without increasing danger to themselves.

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