Interactive Holographic Scenes for Teaching Wireless Sensing in Construction Engineering and Management

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Abstract

The proliferation of ubiquitous technologies coupled with the demands for delivering safer, less intrusive and more resilient building and civil infrastructure projects are pushing modern construction industries into investing in various types of sensing technologies such as laser scanners, drones, radio frequency identification systems and global positioning systems. Sadly, there is a shortfall of graduating construction engineering and management engineers or existing workforce equipped with the required knowledge and skills for developing and implementing sustainable solutions to the nation's infrastructure issues with these technologies. To prepare students for this future of construction, a few number of university engineering and construction programs have begun offering courses that include sensing technology content. However, owing to the hands-on learning requirement of the technologies, students have limited access to construction sites to collaboratively try-out or examine the potentials of these sensing systems in addressing project risks. These experiences are usually difficult to provide because of the hazardous nature of construction sites and constraints such as limited access, schedule, and weather. One approach to providing this experience is to project interactive platforms, in the form of holographic scenes and objects, a concept of mixed reality, of construction sites into the classroom environment, so that students can explore strategies for implementing sensing technologies. Using these augmented three-dimensional objects, students can visualize and interact with digital representations of construction sites and sensing technologies in the physical classroom environment. Students can feel present on construction site environments by enabling them to move naturally and explore in three dimensions, the spatial distribution, boundaries, dependencies and interaction between tasks. This paper presents the development of the interactive holographic scenes and objects, and preliminary studies exploring the extent to which this pedagogical tool can be used to provide students with a learning environment that enables them to gain hands-on experience with the use of the sensing technologies. A descriptive account of how the interactive holographic scenes can be used to provide hands-on experience in an educational environment is provided.

Keywords: Augmented Reality, Sensing, Holographic Scenes, Education and Construction

1. Introduction

Over the past five years, the rate of adoption of sensing technologies in the construction industry has grown exponentially (Dixon, Connaughton, & Green, 2018). There have been multiple reports of how construction companies are deploying sensing systems for tracking real-time performance and physical states of construction workers (Ball, 2016; Group, 2008; Team, 2014). Specifically, there has also been increasing reports of the use of vision-based systems (e.g. drones and laser scanners) for site inspection, work measurement and safety management. This advancement and diffusion of sensing systems in the construction industry, has triggered the demand for candidates/workforce with computing skills. However, there is a shortfall of graduating construction engineering and management (CEM) engineers equipped with the required knowledge and skills for developing and implementing sustainable solutions with sensing technologies. Some of the inhibitors to equipping CEM students with these competencies are: (a) limited access to construction sites where students can collaboratively try-out different sensing systems; and (b) owing to the cost of these technologies, some institutions struggle to provide experience and training to the students. These and similar challenges have prompted increased interest in the exploration of virtual resources for creating analogous learning environments where students can explore the potentials of sensing technologies.

In recent years, there has been an increased interest in the exploration of virtual environments for classroom instruction (Dib & Adamo-Villani, 2013), conducting experiments and interactive simulations (Alexander, Brunyé, Sidman, & Weil, 2005; Goulding, Nadim, Petridis, & Alshawi, 2012; Li, Chan, & Skitmore, 2012). Virtual environments have been known to enhance cognitive learning in engineering education (Balamuralithara & Woods, 2009; Ieronutti & Chittaro, 2007; Kollöffel & de Jong, 2013; Nikolic, Jaruhar, & Messner, 2011; Sampaio, Henriques, & Martins, 2010). By projecting interactive platforms (in the form of holograms and holographic scenes, a concept of augmented and mixed reality) of construction sites into the classroom environment, students can explore strategies for implementing the technologies for developing solutions to industry problems. In the context of this study, holographic scenes refer to augmented reality that appears to the user as holograms or three dimensional (3D) objects existing in the physical world. Using these augmented 3D objects in the form of holograms (Fig. 1), students can visualize and interact with digital representations of construction sites and sensing technologies in the physical classroom environment. Students can feel present on construction site environments by enabling them to move naturally and explore in three dimensions, the spatial distribution, boundaries, dependencies and interaction between tasks. In addition, students can perform selective analysis of construction tasks, operations and resources. Using the HoloLens, a head mounted display popularized by Microsoft, the holograms are produced in the form of AR that appear as 3D objects existing in the physical space. These holograms respond to gaze, gestures and voice commands. With the HoloLens, construction sites can be projected in front of a student or group of students (Fig. 1); they can touch and tag resources (e.g. equipment), position sensors (e.g. laser scanners, drones and real-time location sensors) and observe ergonomic exposures of construction workers. Furthermore, students can collaboratively navigate a construction site and within buildings to observe indoor and outdoor activities, with each student having different points of view.

Hence, this paper presents findings of an ongoing research aimed at creating and assessing a pedagogical framework based on holographic scenes for equipping CEM students with the competencies required for deploying data sensing technologies on construction projects. This paper describes the theoretical framework guiding the development of the interactive holographic scenes. The development and a descriptive account of the implementation of the interactive holographic scenes is presented.

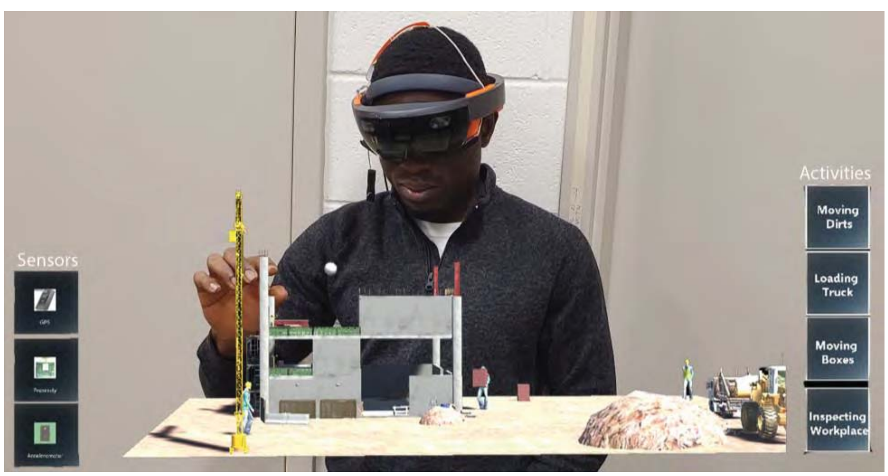


Figure 1: Example of a Hologram

2. Background

The potential of AR technologies in educational practices is recently gaining attraction. Cuendet, Bonnard, Do-Lenh, Dillenbourg, and Education (2013) designed an AR tool for classroom instruction. The authors demonstrated the adequacy of the tool for enhancing learning and engagement in the classroom. Kaufmann, Schmalstieg, Wagner, and technologies (2000) created a 3D construction tool using an immersive AR environment. The tool allows student and instructors to construct geometric shapes with head-mounted displays. Behzadan and Kamat (2013) developed a learning tool to enable students interact with remote construction job sites in the classroom. With the aid of the tool, students were able to view and retrieve relevant information regarding an object of interest from a video of a job site. Fjeld, Juchli, and Voegtli (2003) designed an augmented chemistry application which helps in teaching abstract organic chemistry concepts. To help engineering students develop spatial skills Martín-Gutiérrez et al. (2010) designed an augmented book which the students can use to visualize virtual objects. Despite the benefit of these technologies, the navigability of these tools is limited to the size and position of the markers. In addition to the fact that existing studies have not explored the applications of AR to the use of sensing systems, there have also been limited opportunities to truly explore interactivity of the AR environment – this is critical for promoting constructive learning. Although, holographic tools have been around for a while, there has been limited exploration of this technologies for enhancing engagement and learning. Some of the few notable studies include the following: In the medical industry, (Tres3D) developed a tool that enables students to view 3D holographic medical animations. Lee (2013) argued the use of 3D holographic technology for testing operations of real-world systems. Liarokapis et al. (2004) identified that integrating holographic technology with interactivity can provide students with learning experiences that are otherwise difficult to obtain. By surveying over 400 teachers in the United Kingdom, Ghuloum (2010) concluded that the holographic technology can function as an effective teaching and learning tool. With the advent of technologies such as the HoloLens capable of projecting interactive augmented 3D objects as holograms, opportunities exist to apply this concept to CEM education. Specifically, the ability to project interactive construction sites into the classroom environment can enhance situated and constructed learning experiences.

3. Theoretical framework and appropriate pedagogies for AR learning experience

The basis for employing AR for enhanced learning experiences is grounded in situated and constructivist learning theories. Situated and constructivist learning are purposefully been used to understand learning, knowing and doing as context-specific social processes by characterizing cognition as being socially shared (Lave, Wenger, & Wenger, 1991; Moore & Rocklin, 1998). These notions are rooted in both Vygotskian's understandings of higher mental processes as internalized social relationships (Newman & Holzman, 2006) and Dewey's early objections to stimulus-response theory (Clartcey, 2008). Because both situated, and constructivism hold many similarities, this study synergistically used both as framework to guide the development of the interactive holographic scenes. Using situated cognition and constructivism, strategies can be formulated for situating students' project work within an AR context, rich with its own material, social and educational dimensions. These project works are usually structured to involve real-life activities and challenges. Through learning from the process, also known as an experiential learning, students "take ownership" of the development of their new skills and knowledge (Kolb, 2014), by being actively involved in the process, reflecting and conceptualizing, and using new ideas gained from the experience for problem solving and decision making (Dewey, 1938). By including interactive platforms in the form of holographic scenes and objects of construction sites into the classroom environment, there will be more opportunities for student-centered active learning. In an effort to provide experiential learning experience, situated in real-life practices to all CEM students in the classroom, pedagogies of engagement will demand "project in context" AR learning scenario to provide students with authentic industry experiences and opportunities to reflect and conceptualize on what they learn. By utilizing project in the context of an

AR learning environment, the interactive holographic scene promises to reduce student's learning barriers with construction concepts and implementation of sensing systems.

4. Holographic Learning Environment

The main objective of designing the interactive holographic scene is to create environments that will enable students, through manipulation, to develop skills for problem/risk identification on construction projects and evaluate different sensing options/strategies for addressing the risks. The holographic learning environment shown in Fig. 2, provides a platform for students to explore the following: (1) investigate the characteristics of the jobsite; (2) selectively isolate the activities to investigate the suitability of different sensing systems; (3) implement the sensing systems; and (4) perform a cost-benefit analysis of the selected sensing solutions. The system architecture of the developed holographic learning environment is shown in Fig. 3. In general, the key elements of the module include development of animated GameObjects via Unity3D and holograms via the HoloLens. These are described as follows:

4.1 Animated GameObjects

Unity3D consists of GameObjects, services, and the Mixed Reality Toolkit (MRTK). Their functions are described as follows:

- *GameObjects:* The GameObjects are the construction site environment, resources, buttons and sensors. The site environment contains a partially completed building and temporary structures. The resources include construction workers, equipment (tower crane, trucks and loaders) and some materials. The buttons serve as control or initiation points for the activities, resources and sensors. With the sensor buttons, students can tag resources with the global positioning system (GPS), inertia measurement unit, radio frequency identification system, and proximity sensors. The activities button enables students to initiate construction tasks such as hauling materials and site inspection. With the resources button, students can select appropriate resources for implementing the tasks such as a truck, loader, material or laborer. Each of the button contains scripts that trigger specific behaviors when they are clicked on. When students gaze at any of these buttons, they are able to use the air-tap hand-based gesture in the HoloLens to select the button. For example, on clicking on the GPS tag, students are able to tag any of the outdoor construction resources. If a student gazes on and air taps any of the activity buttons, the gaming environment will isolate the selected activity and grey out other construction activities buttons. Furthermore, the resources associated with the activity will be displayed beside the clicked button. On selecting any of the resources, the resource will be tagged with the GPS tag.

  Each of the game objects have interactive components such as the animator, playable director and mesh collider. With these interactive components, animations were created for the game objects. The animator was used to generate individual animation clips for each game object e.g. a laborer carrying out lifting tasks or the trucks hauling materials. With the animator, movements were assigned to the GameObjects such as translation and rotation within the construction site. The playable director uses the animator component to assign the recorded animations to the GameObjects. The mesh collider component was added to enable interaction between students and the GameObjects.
- *Services:* The services are used for improving user experience while using the HoloLens. The game module uses the graphics device services to determine the appropriate graphics application programming interface to reduce and balance the load on the Holographic Processing Unit.
- *Mixed Reality Toolkit:* The MRTK is a third-party library package consisting of the cursor, the HoloLens camera, and gaze control. The gaze control uses the position and orientation of a learner's head to determine their gaze vector. The gaze control uses the cursor to shoot a laser into the students view or on any of the GameObjects. This gives learner's confidence in what

they are trying to interact with. Unlike traditional computer screen which displays 3D content on 2D screen, the HoloLens camera projects the GameObjects as holograms.

4.2 GameObjects as Holograms

To be able to view the animated GameObjects as holograms via the HoloLens, the developed game is loaded into the Microsoft HoloLens via the Holographic Remote application in Unity3D. To use this application, HoloLens is connected to the internet and the application is built using the Visual Studio Universal Windows Platform. On connecting the HoloLens to the internet, the Holographic Emulation uses the HoloLens Wi-Fi internet protocol address to stream the animated GameObjects from Unity3D. As the students interact with the holographic environment, their movements are captured and translated into a first-person avatar.

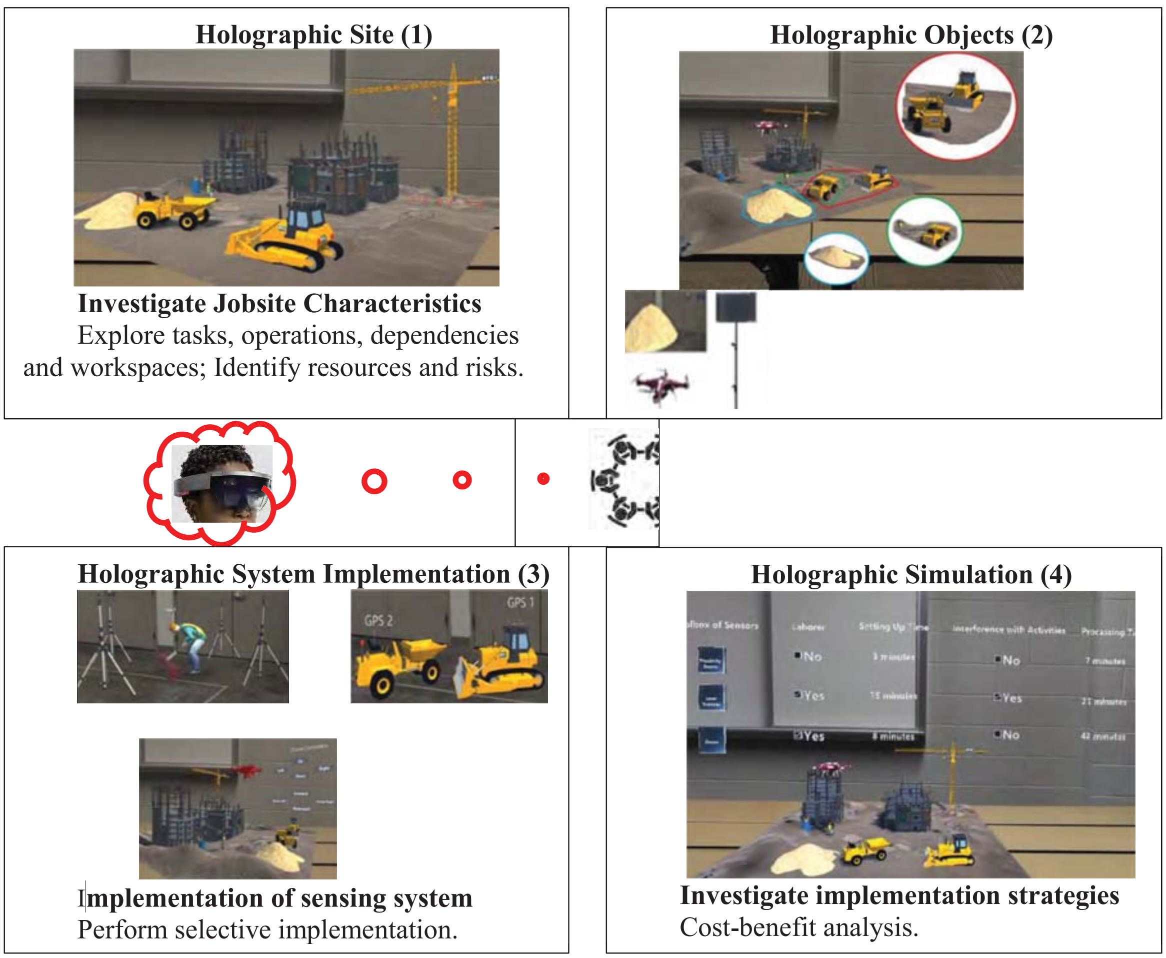


Figure 2: Holographic Environment for Learning Sensing Systems

5. Implementation and Preliminary Results

The working prototype provides a platform for facilitating classroom instruction and student project work. Students can interact with the virtual construction activities in the holographic learning environment. The learning activities in the holographic scenes are formulated based on realistic scenarios of construction activities. Students are able to work collaboratively by navigating the scenes to perform the following: (1) distinguish between construction activities; (2) identify dependencies and interaction between the resources; (3) define workspaces of activities; (4) identify potential risks (from each activity) to project performance; (5) select and try-out different sensing systems for addressing the project risks; (6) observe the data structures from each sensing system, and (7) determine suitable formats for presenting solutions for quick decision making. Depending on the selected activities, choice of sensing systems and placements, the holographic environment will show the suitability or appropriateness of the sensing plan for addressing the intended problems.

Using the HoloLens, which can project 3D augmented objects as holograms, students can easily navigate construction sites, isolate activities to observe the workings of resources, and implement different sensing technologies such as the real-time location sensors (Fig. 4a), IMU (Fig. 4b), laser scanner (Fig. 4c) and drones (Fig. 4d). Presently, only the GPS, IMU and proximity sensor objects are functional in the preliminary prototype. The preliminary prototype can be used to instruct students on how to use sensing systems for addressing construction related issues such as assessing ergonomic risks of workers, tracking productivity, identifying potential near-misses and close calls. For example, for construction ergonomics, students can select a task e.g., 'Moving Materials' task and the worker assigned to carry out this task is isolated in the game. A table of body parts which are usually prone to ergonomic risks (B. o. L. S. (BLS), 2018) for the worker are displayed and the student can select any of the body parts. For example, for a painter, the head, back, shoulder and lower arm are the subject to the greatest ergonomic risk (B. o. L. a. S. (BLS), 2016). The back is annotated to show the angle of bent from the neutral plane or standing position as shown in Fig. 4b. A postural ergonomic risk classification table as shown in Table 1 is displayed to the student (Chander & Cavatorta, 2017). This will help students form a mental image of the physical demand of construction work, how the body angles are measured, and the relationship between the angles and the risk.

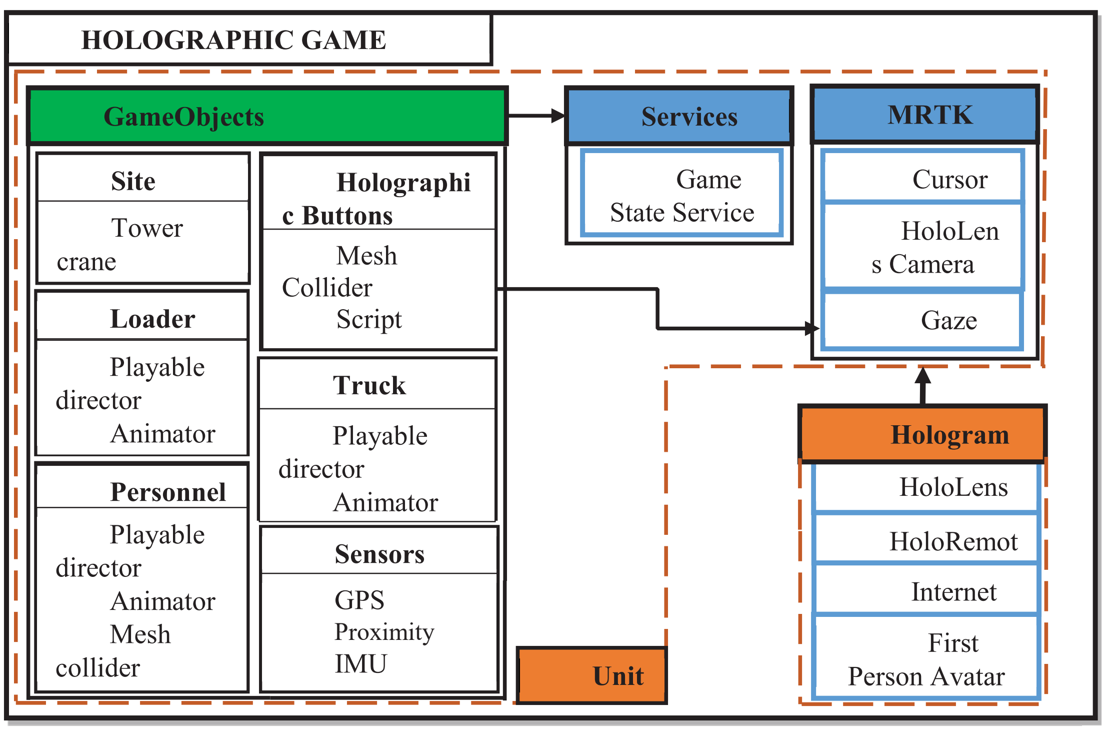
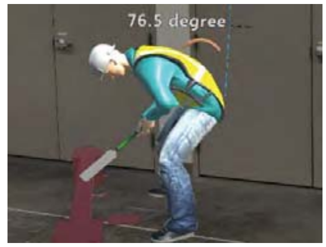


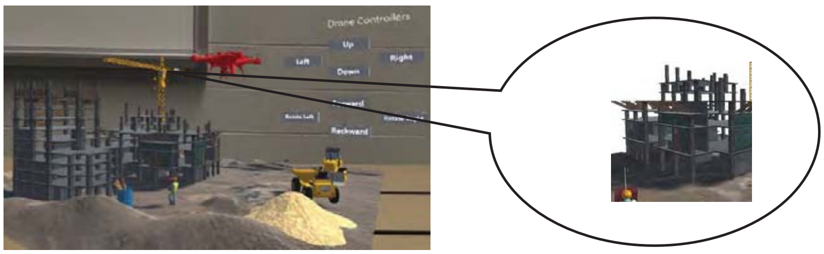
Figure 3: System Architecture of Holographic Learning Environment

(a) RFID-RTLS tagged worker



(b) IMU tagged worker

(c) Scanning stockpile



(d) Drone surveying site

Figure 4: Preliminary Proof of Concept of Holographic Scenes

Table 1: Risk Classification Chart

Body Part	No Risk	Low Risk	Medium Risk	High Risk
Trunk Flexion		0 – 20	21 – 60	>60
Trunk Lateral Flexion			0 – 10	>10
Shoulder Flexion		0 – 20	21 – 60	>60
Elbow Flexion		0 – 20	21 – 60	>60
Hip Flexion	0 – 30	31 – 60	61 – 90	>90

6. Conclusions and Future Work

As construction companies continue to adopt sensing systems, it is important to equip the future CEM workforce with the competencies required for utilizing these systems. Limited accessibility to jobsites and cost of these technologies are some of the factors that currently limits opportunities to provide these learning experiences to students. This paper presents the development of an interactive virtual construction environment in the form of holographic scenes, where students can closely observe construction activities, understand how to identify possible risks and investigate suitability of different sensing systems for addressing the risks. The holographic scenes consist of animated GameObjects which can be viewed and manipulated as holograms via the HoloLens. With the HoloLens, students can navigate, interact, and visualize the projected holographic scenes. The preliminary prototype currently includes functional GPS, IMU and proximity sensors. The prototype also enables productivity and safety assessments of construction activities. As part of future work, the GameObjects of the sensing systems shown in Figs. 4a, 4b, 4c and 4d will made functional. Usability studies will be conducted to improve the functionality of the prototype.

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