A Multi-user Virtual 3D Training Environment to Advance Collaboration Among Crane Operator and Ground Personnel in Blind Lifts

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ABSTRACT

As one of the most expensive and frequently used resources, cranes play an essential role in the operation of activities on construction sites. They require certified operators whose knowledge of codes and regulations is essential for safe and productive lift tasks. Blind spots pose a significant issue for crane operators as they limit the crane operator's field-of-view that potentially slows down execution of such tasks. Often collaboration between crane operators and ground personnel is limited and requires advanced communication techniques, such as radios, to resolve the limited visibility issue. Although visualization technology has been widely adopted in practice to enhance visibility, education and training programs related to cranes lack multi-user collaboration environments. This paper presents an approach towards developing a virtual training environment that allows multiple subjects to participate in lifting operations cooperatively. Through a 3D real-time immersive user visualization interface users are able to perform hands-on tasks such as operating cranes and directing blind lifts. In addition, geometry constraints and safety hazards are introduced to augment the simulation-fidelity of the virtual training environment. A test involving two users was conducted and the results show that the proposed approach can effectively simulate collaborative tasks in crane lifting operations. This study has potential to enhance the productivity and safety of crane lifting operations.

INTRODUCTION

Cranes are essential construction equipment to complete work tasks. They play an important role on almost every new construction site. Around 125,000 cranes are in operation every day in the construction industry and are responsible for major portions of lifting activities. However, cranes are also a major source for construction accidents and fatalities. A well-known internet website that keeps track of crane-related accidents (craneaccidents.com) reported 526 accidents and 269 fatalities from 2000 to 2002 worldwide. A report (McCann and Gittleman 2009) from the Center for

Construction Research and Training (CPWR) states that there were 632 crane-related deaths from 610 incidents in construction from 1992 to 2006. These numbers relate to 43 deaths on average per year. Among them, collisions and spatial conflicts have been identified as a major cause. They are responsible for 380 deaths. Similarly, as reported by the Occupational Safety and Health Administration (OSHA), 40% of the deaths involving cranes on construction sites from 1984 to 1994 were related to spatial conflicts. Among all factors lead to crane-related accidents, the proficiency of the crane operator is a major key in accident prevention. Neitzel et al. (2001) pointed out that crane operators have the most direct influence on the safety of crane lifting operations, and thus they must have the technical and performance proficiency in operating cranes. In an assessment conducted by Shapira and Lyachin (2009) with 19 construction equipment and safety experts, operator proficiency scored as the highest degree of influence among 21 factors that affect crane safety.

However, crane lifting operations are typically collaborative tasks that involve not only crane operators, but also other participants such as signal people and riggers. Crane operators often experience partial view obstruction of the workspace (pick up/drop off locations, hook travel path) on almost all projects and particularly in high-rise construction. When the operator has no line-of-sight with the load, they completely rely on instructions from signal people, who are always referred to as “the operator’s eyes and ears”, or on vision camera technology that supplements their own field-of-view. Although signal people fulfill a critical function, they are usually under-trained and have little experience in collaborating with crane operators in particular lifting tasks. In case of any technology, most cranes are not equipped with it as only the latest models come with cameras that have a camera pointed downwards the crane load. Situations like workers being directly below a crane load increase the chances of accidents in general. Such conditions bear even greater risks in blind lifts where the operator has to rely exclusively on the signal of the other people.

In blind lifting operations, signal people need to be familiar with the lifting plan and be aware of the hazards associated to the task. Moreover, they need to instruct crane operators in a concise and accurate manner. For crane operators, they need to maintain good communication with signal people and correctly execute their instructions. Despite the importance of collaboration in efficiency and safety of crane lifting operations, very few training programs emphasize collaboration training. To enhance the collaboration of crane operators and signal people in blind lift tasks, this paper explored a virtual training approach and implemented it in an actual construction site. Challenges and requirements in applying virtual technology in collaboration training of blind lift tasks were identified. The results of a pilot test show that the proposed approach can effectively simulate a collaborative work scenario for collaborative training and thus potentially enhance the efficiency and safety in collaborations in crane lifting operations.

LITERATURE REVIEW

With the rapid development of computer graphics and interactive hardware, virtual reality technology provides a new opportunity to expedite learning process and enhance learning effectiveness. Many efforts have been invested in the application of information technology especially of advanced virtual reality (VR) technologies in construction training and education (Issa et al. 1999, Bouchlaghem et al. 2002). Through a thorough review of application of interactive technology in construction training, Dickinson et al. (2011) stated that serious games offer an engaging and innovative medium for delivering training to students who are more comfortable with hands-on learning for a hands-on trade. As an early effort in employing VR in construction heavy equipment operator training, Wakefield et al. (1996) developed an interactive VR excavator simulator for operator training. Similarly, Keskinen et al. (2000) developed a training system for accurate boom maneuvers of a hydraulic elevating platform. With a trainee in a physical elevating platform, the training experience is augmented by live physical stimuli. Taking advantage of the Internet as a communication tool, Bernold et al. (2003) developed a training system named the Internet-Based Backhoe Operator Trainer (IBOT) that allows a trainee to practice with a stationary backhoe at remote training location.

In the field of crane operator training particularly, Wilson et al. (1998) developed a Virtual Environment Crane Training Simulator (VECTS) for overhead crane operator training. It provides trainees with a 3D virtual environment for learning and practicing the skills needed for productive crane operations in the indoor factory environment. Kang and Miranda (2004) constructed a physics-based model of tower crane to simulate their dynamic behaviors, which they proposed can be further developed for training program for crane operators or course material for university students. Rezazadeh et al. (2012) took one step further in advancing human-machine interaction for virtual training by extracting control commands from facial gestures to manipulate the virtual crane. Despite extensive efforts has been made to explore the benefits of VR technology in construction education and training, very little focuses collaboration training in the operation level. As an effort towards this direction, Guo et al. (2012) proposed a training platform that allows multiple users collaborate with each other and interact with the virtual world to practice the tower crane dismantling tasks using Wii controllers.

DEVELOP APPROACH FOR COLLABORATION TRAINING SYSTEM

Collaboration between crane operators and signal people are crucial to the proficiency and safety of lifting operations because in many cases, especially in blind lifts, operators heavily rely on instructions from signal people on the ground for accurate placement of loads and timely avoidance of hazards. To enhance the collaboration between crane operators and signal people, this study proposes a virtual training approach that allows multiple users conducting a simulated virtual blind lifting task collaboratively on remote computers.

To construct such a training system, the first step is to identify the training task. Since the virtual environment is supposed to simulate actual lifting tasks, information such as crane type and specification, pick-up and drop-off locations, and potential obstructions on the lifting path need to be collected and accurately modeled in a virtual environment. These information can be acquired from lifting plan, site drawings, and building information models if exists. The next step is to model the identified lifting task in a virtual environment. A suitable platform for collaborative virtual training should (1) provide good graphics and physics, (2) support external controlling devices, and (3) support connection between multiple computers. Controlling devices need to be selected and configured to realistically simulate cranes maneuvers. For cranes, game pads with two joysticks can effectively simulate cranes maneuvers while minimize the cost. As the last step in developing the system, monitoring and assessing the performance of users are crucial to understand their training outcomes and evaluate their eligibility of a certain blind lifting task. Three types of measurements are chosen to reflect the efficiency and safety performance: (1) the accuracy of load placement, (2) the length of the lifting path and time taken, and (3) the occurrence of safety incidents. Figure 1 presents the framework of developing a collaborative virtual training system.

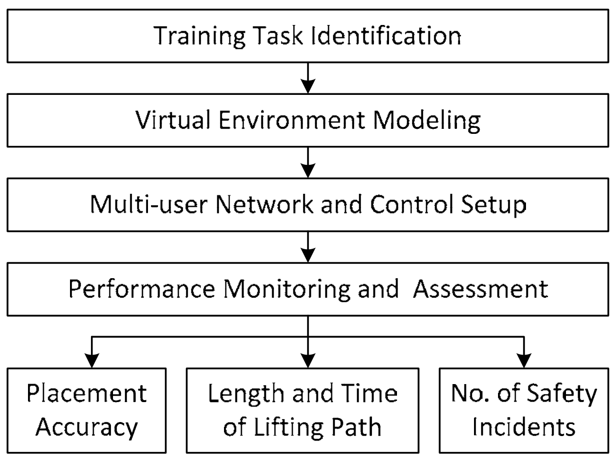

Figure 1. Framework of developing a collaborative virtual training system

Following the proposed procedures, a pilot system was developed for virtual collaborative training for blind lifting operations. The virtual environments on two computers were connected and synchronized through local area network so that the two users can work simultaneously in a single environment. Figure 2 shows the simulated construction site and user interface.

Figure 2. Simulated construction site and user interface

PILOT TEST AND RESULTS

In this test, a blind lift scenario in an actual construction project was created where a mobile crane operator is supposed to lift a rebar from a trailer and place it on the second floor of a building (Figure 3). The study followed methods explained in previous research (Cheng et al. 2013a and 2013b, Teizer et al. 2013). Models of a mobile crane and a worker avatar were downloaded from Trimble 3D warehouse, modified in Sketchup, and imported to the XYZ world in .3ds format. The building model was exported from the BIM model of the project and the model represented the actual structure condition at the point when the lifting job took place. The ground texture was extracted from Google Earth to reflect the as-is condition of the site.

As a common visibility problem for most lifting tasks involving mobile cranes, sitting in the cabin, the operator in this scenario cannot always see the load or the location they need to place the loads. Therefore, a second user was introduced in this scenario as a signal person. The signal person need to guide operator with proper oral instructions and warn him about potential hazards associated to the proximity to columns on the lifting path.

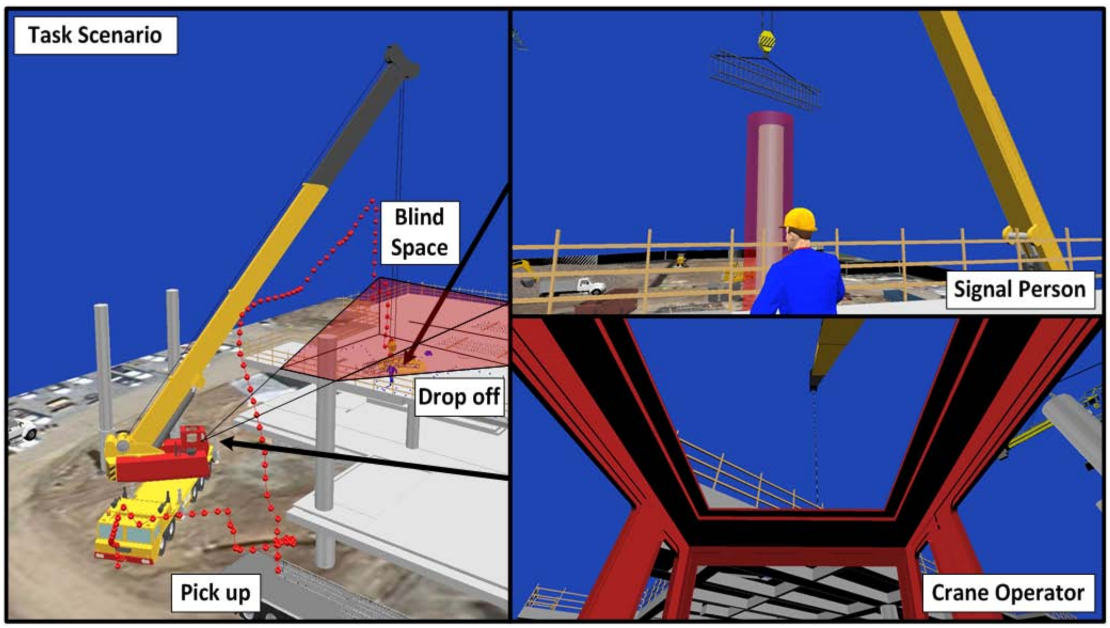

Figure 3. Lifting scenario and user perspectives

Two construction graduate students were involved in this test controlling the mobile crane and the avatar of the signal person in the developed virtual environment using gamepads with different configurations (Figure 4). To assess the performance of the lifting task, four parameters were measured during each iteration of the practice: (1) length of lifting path, (2) duration, (3) placement accuracy, and (4) number of unsafe incidents. Five iterations of the lifting task were conducted in the same virtual scenario.

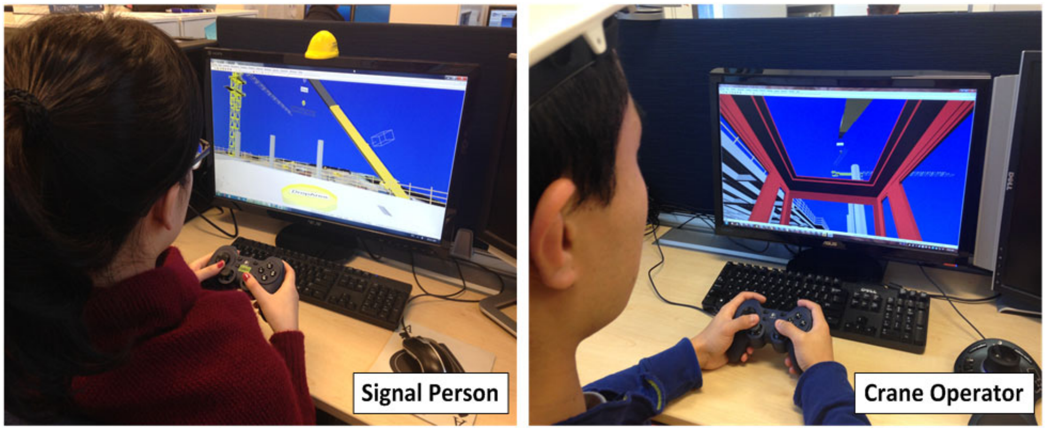

Figure 4. Test with two users

As presented in Table 1, as the pair of users got familiar with the task through five iterations of practice, time needed for the lifting task decreased and the accuracy of load placement increased. This indicates that practicing the lifting task in the developed virtual environment is able to enhance the collaboration between crane operators and signal people and thus improvement the efficiency and safety of lifting operations. It should also be noted that the length of lifting path did not obviously reduce consequently as lifting time and placement accuracy did. This fact indicates that in such blind lift task, the selection of lifting path has little room for improvement because of spatial constrains and blind space. In the aspect of safety performance, no incidents were detected in all five iterations which means adequate attention was paid to the proximity hazards between the crane load and columns already built in the (virtual) construction site. Further tests are necessary involving potentially experienced vs. inexperienced crane operators and personnel on ground. The complexity of the lifting operation as well as many other factors that built the virtual environment may change to adequately reflect the construction environment as realistically as possible.

Table 1. Results of multi-user collaboration test

Iteration #	Length	Time	Placement Offset	No. of Incidents
1	114.1 m	137.3 s	2.33 m	0
2	126.1 m	112.8 s	2.20 m	0
3	110.1 m	107.5 s	1.53 m	0
4	115.8 m	83.2 s	0.90 m	0
5	110.5 m	93.7 s	0.77 m	0

CONCLUSION AND FUTURE WORK

This paper presents a virtual training approach to enhance the collaboration between crane operators and signal people in blind lifting operations. Collaborative training was realized through the construction of virtual lifting scenarios and the setup of network and interactive controlling system. A test scenario was developed based on an actual blind lifting task. Two users, one acting as a crane operator and one as a signal person, conducted the blind lifting task through two computers in the same virtual environment. An increase of lifting efficiency and accuracy was observed with more iteration of practices. The results indicate that the proposed approach for virtual collaboration training is able to effectively simulate blind lifting tasks and potentially enhance the efficiency and safety through repeated practice.

This study provides exploratory efforts towards using virtual training approach to enhance the efficiency and safety in collaborations in crane blind lifting operations. Although the pilot test indicated promising outcomes, implementations and validations of such training system in various construction conditions need to be carried out to certify the practical impacts and contribution of crane lifting operations.

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