Working Safely with Drones: A Virtual Training Strategy for Workers on Heights

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ABSTRACT

The use of drones in construction grew exponentially over the last few years, making the construction industry one of the fastest commercial adopters of drones. Drones are widely used in the construction industry for applications such as aerial mapping, safety and quality inspection, job site logistics, and progress monitoring. The integration of drones in construction job sites raises novel occupational safety and health issues for construction workers. Workers on heights are particularly exposed to the health and safety risks posed by drones. This work-in-progress paper presents the analysis and development phases of the study aimed at developing and evaluating training content for construction workers on heights. The objective is to train workers about drones in their environment and the associated health and safety risks. The training content includes Virtual Reality (VR) simulations, audio-visual instructions, and a VR game consisting of virtual drones to train workers in an effective, realistic, and safe environment. The learning objectives of the training are to (1) train workers about the basic operation and uses of different types of drones used on construction sites; (2) train workers about the health and safety risks associated with drones, including physical risks, attentional costs, and psychological impacts; and (3) train workers to work safely with drones.

INTRODUCTION

Construction is the oldest and one of the largest industries in the world and according to the Global Construction Perspectives and Oxford Economics (2015), it is expected to grow faster than the Gross Domestic Product (GDP) of the United States over the present decade. The introduction of the new materials and techniques resulted in a major change in the construction industry when the first generation of skyscrapers appeared. In the following century, the second industrial revolution provided new machines, equipment, materials, and power sources that allowed the construction of sky-high structures. This significant transformation also added a major hazard to the construction industry, the fall from heights. Along with this substantial hazard, low productivity has consistently been a concern in the construction industry. Since then, the industry has been struggling to find solutions to improve productivity and safety performance.

Throughout the last decade, research has focused on providing strategies for efficient hazard prevention and recognition, especially for work on heights. However, according to the Occupational Safety and Health Administration (OSHA 2015) data, fall from heights is still the most common cause of serious work-related injuries and deaths in the construction industry. Although the construction industry is still labour-intensive, robotic systems are growing fast and becoming common in the domain, as a potential solution for the two major concerns in this industry: safety and productivity. Among others, one of the most popular technologies being implemented in construction jobsites is the use of Unmanned Aerial Vehicles (UAVs), also known as drones. Drones are widely used in the construction industry for aerial mapping of the site, safety and quality monitoring, job site logistics, inspecting construction sites to assess structural integrity and damage, maintenance assessments etc. The global commercial market size of these aerial platforms was valued at $5.8 Billion in 2016 and is anticipated to reach $130 Billion by 2025 (Grand View Research, 2019). In just one year, the use of drones in construction grew by more than 200%, making the construction industry the fastest commercial adopter of drones (Drone Deploy, 2018). This indicates that drones are expected to become more frequent on job sites, subsequently increasing the interaction between human workers and drones. The integration of drones in construction jobsites, while beneficial raises new occupational safety and health issues for construction workers. Workers on heights (roofs, scaffolds, and ladders) are particularly exposed to the health and safety risks posed by drones. As a result, it is very important to educate workers about these new machines that will share their work environment and train them to work safely and effectively with their robotic partners on heights. As there are currently no specific OSHA standards or guidelines regarding drones on construction sites, training workers about this technology is even more critical since the shared work environment between workers and robots is already a reality.

Virtual Reality (VR) based training techniques are ideal for developing such training since VR-based simulations: (1) offer workers at heights the ability to interact with robots (i.e., drones) safely, repeatably, and in controlled environments; (2) allow them to envision, in realistic virtual settings, what future construction jobsites will look like and how the presence of robots (i.e., drones) will be adopted in such environments. Not only is accomplishing such type of training in real-world conditions impossible, but it also exposes workers to additional robot-associated unsafe situations that further exacerbate their safety performance.

BACKGROUND

Safety Challenges of Working on Heights

Construction is one of the most hazardous industries in terms of occupational injuries and fatalities (Martinez et al. 2021a). Causes behind these fatal and non-fatal injuries include the nature of the jobsite environments, which is characterized as loud, complex, dynamic, and challenging. Such characteristics, combined with the nature of tasks (e.g., working outdoors and at elevated areas and platforms) and other interrelated factors (e.g., risky activities, site conditions, organizational characteristics, and weather conditions), increase the likelihood of workers being exposed to hazardous situations (Hu et al. 2011; Nadhim et al. 2016). Among others, fall accidents are a huge concern for the construction industry, and the industry is looking for more effective approaches to reduce these tragic numbers. For example, Gambatese et al (2008) studied the association between architectural design and jobsite safety and found that

design is only one of the factors that can affect job safety. research by Huang and Hinze (2003) investigated fall accidents using the OSHA data from January 1990 through October 2001 focusing on the last five years of this time interval. The research revealed that, despite the efforts of various researchers to find measures to improve fall prevention, some of those measures do not work as well as expected. One example was the increased proportion of accidents caused by falls even after the OSHA regulation on Personal Protective Equipment (PPE) for fall prevention was instituted in 1996. Kang et al (2017) conducted a similar study using the OSHA database, with a focus on the years 1997 to 2012. That research examined the frequency and trend of fall accidents and revealed a substantial increase in the number of fall accidents, especially from heights less than 9.1 m (30 ft). It is important to mention that OSHA considers all construction activities (residential, commercial, or industrial) present in a job site above 1.8 m (6 ft) as potential fall hazards. As such, fall protection is mandatory for such activities. Even with this strict regulation, OSHA`s data show that falls from heights is still one of the most common causes of fatalities and serious injuries in the construction industry (BLS 2014). More data from Construction Fatality Maps created by CPWR — The Center for Construction Research and Training (CPWR 2020), show similar records.

Considering the evidence, the construction industry needs to find a different and balanced way to guarantee the implementation of basic safety principles for each sector. Although more accurate data and studies were produced in the last few years, combined with new technologies, the study by Kang et al. (2017) concluded that the number of fall accidents has continued to increase. The same study showed that falls from 3.0 to 6.1 m (10 to 20 ft) which are usually related to small projects, have increased significantly. Haslam et al. (2004) indicated that jobsite conditions (e.g., site layout, housekeeping) account for around 50% of jobsite accidents. Organizational characteristics (e.g., company sizes, funding availability) could also play an important role in jobsite safety: smaller companies with limited funding do not have enough resources to train construction workers and provide them with the necessary personal protective equipment and fall arrest systems, jeopardizing their safety performance (Nadhim et al. 2016). Dong et al. (2013) highlighted the importance of adequate training, fall prevention programs, and adequate protective equipment. The research by Kang et al. (2017) found that in 70.7% of fall accidents workers were not using any fall protection equipment.

It is impossible to completely avoid fall hazards on a construction jobsite. Therefore, safety precautions must be adopted from the design phase to the substantial completion to prevent workers' exposure to fall hazards. However, to achieve expected results, safety controls, training programs, feasible requirements and appropriate PPEs are equally important. New technologies can be explored to improve the detection of hazardous situations (E.g., using real-time videos). Despite the adoption of multiple protection measures such as personal protective equipment and personal fall arrest systems to mitigate the safety risks, these attempts have not been enough to eliminate worker injuries and fatalities on jobsites. Therefore, it is critical to train construction personnel about the safest and most efficient construction practices.

Drones and workers on heights

We have already seen a tremendous increase in the deployment of drones in construction. With the predicted increase in construction activities, it is expected that there will be more interaction between human workers and these autonomous agents. Drones are an ideal technology for several applications in the Architecture, Engineering and Construction (AEC)

industry as they can access spaces that are unsafe, hard-to-reach or inaccessible by human workers (Albeaino 2019). The application of this new technology is still in its early phases but drone deployment in construction is rising rapidly. With these changes coming so quickly, it is essential to consider the new risks that this transformation of the workplace might bring in. Gheisari and Esmaeili (2017) revealed that the concerns and safety challenges presented by drones are significant obstacles to improving safety management on job sites. Research by Irizarry (2012) showed similar challenges associated with drones in the construction industry, such as the distraction that this type of equipment can create for the workers as well as the risk of people being hit by drones.

Over the last decade, several companies have started using drones to collect real-time data from projects to track the workflow progress, conduct building inspection, assist in earthmoving calculations, safety management, security surveillance, and site communication. There have been few exploratory applications of drones in material handling and aerial construction, which are expected to be more common in future. Although drones can provide substantial assistance in construction management, these also present new risks to the construction workers. These risks might arise from physical contact between drones and human workers or due to the distraction caused by drones. Drones (or their parts and/or payloads) can strike a worker directly or fall on the workers working below their flight path. Besides, drones can distract workers, which can affect their ability to work safely putting them or their co-workers at risk. Workers on heights are particularly exposed to the health and safety risks posed by drones because 1) drones fly closer to their work environment, as such have a stronger influence and, 2) workers on heights already have the highest fatality rates and drones can aggravate their already risky environment and increase the likelihood of falls. Considering this new hazard, it is crucial to train workers on heights to make them more familiar with the drones and work safely with them.

VR-based Safety Training

Multiple studies have leveraged the use of VR-based simulations for construction training. For example, Sakib et al. (2020) developed a training method for drone operators using virtual reality. The study used VR to extract physiological markers, such as Mental workload (MWL), stress level, trait, and state anxiety from the drone operators during virtual flights. VR offers several advantages over traditional safety training approaches by simulating the high-risk interaction conditions without exposing trainees to real risks (Xie et al. 2006). Advantages of using VR-based training tools also include the ability to replicate real-world conditions in a repeatable, risk-free, and controlled manner. This is particularly advantageous for training construction personnel how to interact with robots in construction jobsites, which in the real-world can be unsafe, exposing workers to additional robot-associated unsafe situations. In addition, VR-based training environments allow for the simulation of future robot-dependent jobsite environments that would ultimately train and prepare construction workers for the future. This also allows them to recognize what future construction jobsites will look like and how the presence of drones will be adopted in such dynamic and challenging environments.

GOALS AND OBJECTIVES

The overall goal of this study is to develop and test a virtual training strategy for construction workers on heights to train them about drones in their environment and the associated health and

safety risks. This work in progress paper presents the development of a training strategy. More specifically, this study addresses the development of VR training content for workers at heights that simulates the construction environments prevalent with drones and demonstrates the potential safety challenges of working with drones. The training content also focuses on educating workers about safe working practices that they should follow when interacting directly or indirectly with drones. The VR training includes explanatory videos, virtual walkthroughs, animations etc. to achieve the following learning objectives:

1. Train workers about the basic operation and uses of different types of drones present on construction sites.
2. Train workers about the health and safety risks associated with drones, including physical risks, attentional costs, and psychological impacts.
3. Train workers to work safely with drones.

TRAINING STRATEGY

The accident reports collected by OSHA (OSHA 2018) and The Campaign to Prevent Falls (CPWR 2020) in construction over the last 5 years were studied to identify the common scenarios resulting in accidents for workers on heights. Based on the accident reports, falls from roofs, ladders, and scaffolds account for 56% of all fall-related accidents in construction. Therefore, in this training, we limit the scope to workers on roofs, ladders, and scaffolds (e.g., roofers, painters, electricians) as they already operate in high-risk work environments, which could be further exacerbated by the presence of drones. To develop the training strategy, we followed the five steps of the commonly accepted Instructional System Design (ISD) that includes: Analysis, Design, Development, Implementation, and Evaluation. In this work in progress paper, we will present the first three steps of the process.

Assessment:

In this task, we identified the most hazardous construction scenarios (figure 2), such as work on roofs, scaffolds, and ladders, and then evaluated various risks posed by the introduction of drones in these scenarios. The development first focused on CPWR's fatality maps and OSHA's Integrated Management Information System (IMIS) database for the last 5 years to identify the frequent construction tasks that resulted in falls and associated fatalities for each fall hazard category (i.e., fall from roof, fall from scaffold, and fall from ladder). The details provided in the investigation reports were used to identify the key characteristics associated with each accident.

Design:

The next step focused on designing the training content to achieve the learning objectives for this study. The training instructions leveraged current OSHA guidelines about fall prevention and struck by-incidents, and OSHA standards for safety training and education (1926.21, 1926.503), fall protection (1926.500 – 504 & 1926.760), protection against struck-by hazards such as personal protective and lifesaving equipment (29 CFR 1926 Subpart E), head protection (1926.100), eye and face protection (1926.102), and scaffolds (29 CFR 1926 Subpart L) and falling object protection (1926.451(h)).

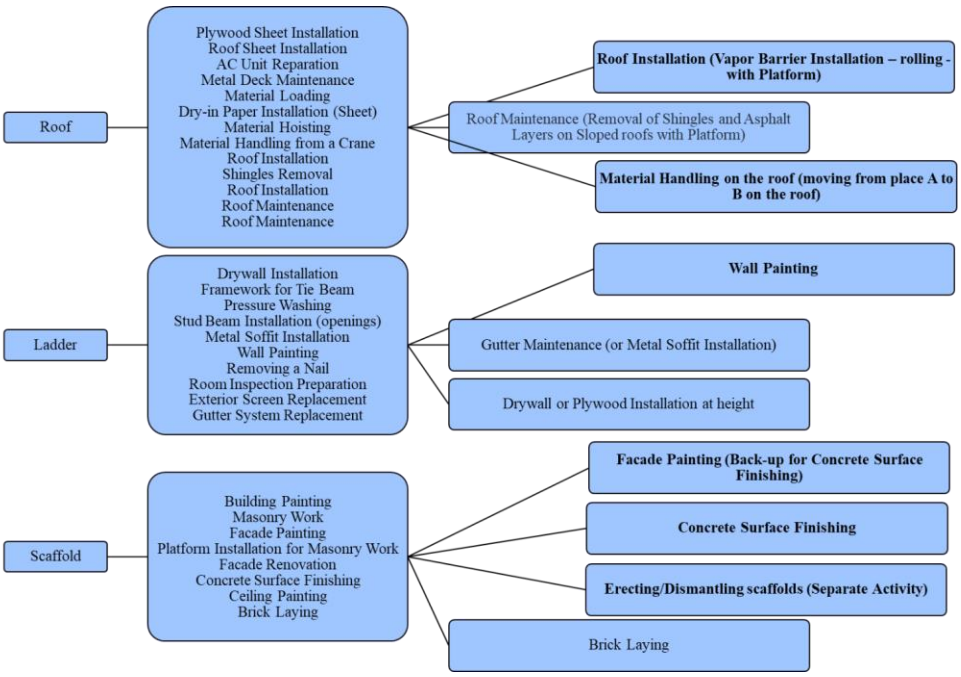

Figure 1: Common Fall Accident Scenarios and Tasks

The training content focused on instructions to educate trainees on different types of drones and their basic operation/ missions, and the risks posed by these drones. The first step to protect workers against hazards is to identify the potential hazards in the workplace and then assess the risk posed by the hazard correctly. Since drones do not have a continuous and regular presence in job sites, the potential hazards related to drones cannot be demonstrated to the workers in real life without putting them at serious risk. Therefore, the training content was designed to educate workers and help them understand drones' characteristics, types, use and risks associated with these flying machines. Finally, training content also focused on managing the risks and working safely with drones. The hazard control pyramid or hierarchy of hazard control (NIOSH 2021) was used to select appropriate strategies to manage each risk posed by drones in different scenarios.

Development:

This step included the development of a training video based on the content design above. First, a virtual -drone dominant construction site (Figure 2) was developed with virtual drones and virtual workers to simulate future construction sites with multiple drones. Relevant characteristics (identified above) were modelled in the environment to virtually create fall hazard scenarios. The virtual site was developed in Unity game engine that has design and scripting capabilities. The following types of drones were developed in the virtual site their main types and responsibilities will be:

- Inspector-drone: Progress Monitoring, Building Inspection, and Earthmoving
- Builder-drone: Aerial Construction and Site Communication
- Safety-drone: Safety Management, Security Surveillance, and Site Communication
- Delivery-drone: Material Handling and Site Communication

Fig 2: Top: Virtual Construction Site, Bottom: Different types of Virtual drones

The virtual site was used to produce a training video (Figure 3) consisting of a 45-minute audio- visual presentation that consists of three parts:

- Part 1 focuses on the basics of drones and their operation. The aim is to educate trainees to familiarize them with the drones that they might encounter at their sites. This part includes videos and animations for current and future drones (such as builder drones). The animations were be made in Unity 3D and Blender software using the 3D models of drones created in software like 3DS Max.
- Part 2 focuses on various types of risks associated with drones in construction. This part is based on findings from phase 1 and will educate trainees about physical contact risks of drones, distraction caused by sight, audio, and mere knowledge of drones, and psychological impacts of drones such as stress and anxiety caused by multiple drone sharing workers work environment.
- Part 3 focuses on educating workers on managing the risks created by drones in their environment and how to work safely on heights in drone dominant construction sites. The guidelines were identified in the previous phase. This part also includes several animations designed in Unity and blender software to demonstrate safe work practices. This part demonstrates safe ways of minimizing distraction from drones.

Figure 3: Snapshots from Training Video

CONCLUSION

According to OSHA guidelines, it is critical to perform a job hazard analysis to identify hazards before they occur for tasks with the following characteristics:

- Jobs with the highest injury or fatalities rates.
- Jobs in which one simple human error could lead to a severe accident or injury.
- Jobs with the potential to cause severe or disabling injuries.
- Jobs that are new to the operation
- Jobs are complex enough to require written instructions.

The introduction of UAVs in jobsites meet almost all the requisites mentioned and as such it is imperative to develop new strategies to reduce the risks to acceptable levels. The most effective strategy is to prepare the workforce for this inevitable integration of drones in their work environments. However, due to the uncontrollable or unpredictable nature of construction sites, and the real risks associated with drones and workers on heights, on-site training are not safe or practical. Therefore, this study aimed at developing a VR based training strategy to educate workers to better understand their flying partners and identify risks associated with working with or near drones. This work-in-progress paper presented the initial phases of development and the future papers will focus on the implementation and evaluation of the effectiveness of the training strategy through user experiments.

ACKNOWLEDGEMENT

This material was produced under the Susan Hardwood Grant from the US department of Labor. It does not necessarily reflect the views or policies of the DOL, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government. This material is also based upon work supported by the National Science Foundation under Grant No. 2024656.

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