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USABILITY ASSESSMENT OF DRONE TECHNOLOGY AS SAFETY INSPECTION TOOLS

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SUMMARY: *The construction industry lags behind many others in the rate of adoption of cutting edge technologies. In the area of safety management this is more so. Many advances in information technology could provide great benefits to this important aspect of construction operations. Innovative use of these tools could result in safer jobsites. This paper discusses initial application of drone technology in the construction industry. In this study, a small-scale aerial drone was used as a tool for exploring potential benefits to safety managers within the construction jobsite. This drone is an aerial quadricopter that can be piloted remotely using a smart phone, tablet device or a computer. Since the drone is equipped with video cameras, it can provide safety managers with fast access to images as well as real time videos from a range of locations around the jobsite. An expert analysis (heuristic evaluation) as well as a user participation analysis were performed on said quadricopter to determine the features of an ideal safety inspection drone. The heuristic evaluation uncovered some of the user interface problems of the drone interface considering the context of the safety inspection. The user participation evaluation was performed following a simulated task of counting the number of hardhats viewed through the display of a mobile device in the controlled environment of the lab. Considering the task and the controlled variables, this experimental approach revealed that using the drone together with a large-size interface (e.g. iPad) would be as accurate as having the safety manager with plain view of the jobsite. The results of these two evaluations together with previous experience of the authors in the area of safety inspection and drone technology led to recommendations for the required features of an Ideal Safety Inspection Drone. Autonomous navigation, vocal interaction, high-resolution cameras, and collaborative user-interface environment are some examples of those features. This innovative application of the aerial drone has the potential to improve construction practices and in this case facilitate jobsite safety inspections.*

KEYWORDS: *drone, safety inspection, usability evaluation.*

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1 INTRODUCTION

In 2010, the construction industry contributed 3.4% of the United States total Gross Domestic Product (GDP) (Gilmore et al. 2011). One of the main concerns in such a financially important industry is related to safety issues. Technological advances in areas such as personal protective equipment, safety conscious design, focused safety training, and others have improved worker safety. However, even with such improvements, construction continues to be one of the most dangerous industries in the U.S. economy (Irizarry & Abraham 2005). According to preliminary results of the most recent census data from the U.S. Bureau of Labor Statistics (BLS 2011), 4547 work-related fatalities were reported in 2010. Of these, 751 or 16.5% occurred on construction sites. The fatality rate (9.5 per 100,000 full-time equivalent worker) ranked fourth highest among various industries (BLS 2011). Construction workers are still prone to accidents that lead to material losses, temporary or permanent disabilities, and to fatalities.

Both researchers and practitioners have addressed accident prevention. There are many different procedures that should be followed in order to reduce the number of accidents and move towards safe and zero-accident jobsites. One of the most important procedures is conducting periodical inspections of the whole construction jobsite. This means safety managers should conduct daily, weekly, and monthly inspections on the jobsite (consistent safety management) to evaluate site conditions based on safety criteria. To achieve this goal, safety managers perform walkthroughs of the jobsite and check the current safety situation of the workers, materials, and equipment, while having direct interaction with the workers. Providing safety managers with a communication tool that can enable them to be present at any time in all different areas of the construction jobsite and to provide the workers with real time feedback would be extremely beneficial. In this study, an aerial drone quadrotor helicopter (AR.Drone quadricopter) was used as an early prototype of a safety manager's assistant drone. An ideal safety manager assistant drone should be able to fly all around the construction jobsite and provide the safety managers with real time information about what is happening on the jobsite. Also safety managers should be able to have direct interaction with workers through the communication tools (video and voice transmitters) that would be provided on the ideal drone.

The following section will describe the task analysis of safety inspection as one of the responsibilities of safety managers. Then for facilitating safety managers' performance of this task, the AR.Drone quadricopter was recommended as a prototype of an ideal inspection tool. A usability evaluation of the quadricopter was performed using (1) an expert analysis - Heuristic Evaluation (HE) and (2) a user participation analysis. These usability evaluations provide an understanding of what the level of applicability of this drone in construction safety inspection is and how it can be improved. Finally, the features of an ideal inspection drone are discussed.

1.1 Safety Inspection

The Occupational Safety and Health Administration (OSHA) specifically requires that employers such as contractors are responsible for providing workers a safe place at which to work (Koehn 1996). Safety managers have many different responsibilities related to achieving this goal. The focus of the present research project is on safety inspections, which is one of the main responsibilities of a safety manager.

Toole (2002) suggested that all construction accidents result from eight root causes: lack of proper training; deficient enforcement of safety; safe equipment not provided; unsafe methods or sequencing; unsafe site conditions; not using provided safety equipment; poor attitude toward safety; and isolated, sudden deviation from prescribed behavior. One of the keywords that have been used by Toole (2002) to define the factors needed to prevent root causes of construction accidents is "Observation". The safety manager should observe employees, actual methods and sequencing, and actual site condition on a frequent basis (Toole 2002). Therefore, the safety managers' task of observation can be defined as frequently walking around the jobsite and getting real time data through direct observation and interaction with workers. This data would be used as the input in the safety manager's decision-making process.

Based on this definition, observation in the construction safety inspection process has three main characteristics: (1) being frequent; (2) direct observation; (3) direct interaction with workers. Below is the narrative sequence the user will follow to complete the task of safety inspection.

Frequent walking and observation: One of the main responsibilities of safety managers is their daily walking and observation of the whole construction jobsite. They should walk around to check workers, material, and equipment based on safety criteria. This frequent observation would usually occur on a daily basis and when there is only one safety manager who is responsible for a large construction jobsite, the observation can take more time and becomes complex.

Direct observation: The essence of safety inspections is direct observation on a construction jobsite. Safety mangers should be able to go in person to all different areas of the construction jobsite. This direct observation is a part of their daily inspection task. Direct observation would require the safety manager's presence in a short time to get real-time data at any specific location. Those locations can range from the bottom of excavation trenches to the top of the roof structures. This may happen either when the usual construction activities are happening or when an accident has stopped work activity. Safety managers should be able to be present at those locations to observe and provide feedback.

Direct interaction: Safety managers not only need to see what is happening in different areas of the construction jobsite, but also they should be able to have interaction with the workers. According to Rasmussen et al. (1994), effective safety feedback mechanisms should be established to promote safe work practices that alert workers of deviations from prescribed practices, entry into unsafe work zones, and failure of standard controls. Safety managers would provide real time feedback (e.g. reminding a worker to wear his hardhat or alerting a welder about his unsafe location/situation) through a direct interaction. Safety managers should be able to observe a situation and then, after an internal decision-making process, provide appropriate feedback. However, it is difficult to find safety feedback mechanisms that are implemented in construction, and no technology or process is currently being used in construction that can provide feedback in real-time (Shell Safety Committee, 1987). So any technology that can improve safety management by facilitating the analysis and communication of safety issues would have potential benefits (Hallowell et al. 2010).

This study proposes that a drone can be used to fly frequently over the construction jobsite and provide the safety managers with real time information about what is happening on the jobsite (frequent and direct observation). Also, through the communication tools (video and voice transmitters) embedded in the drone, safety managers would be able to interact directly with workers (direct interaction).

1.2 UAVs and the AR.Drone Quadricopter

Drones are Unmanned Aerial Vehicles (UAVs) that would operate under remote/autonomous control without any pilot onboard. This operation relies mostly on human involvement. The very first application of this device was within military missions and now they have their permanent position in the military arsenal (Nisser and Westin 2006). Some peaceful applications of these devices are in border patrol; search, rescue and damage investigations during/after disaster (e.g. hurricane, katrina or earthquake); locating forest fires or frost conditions in farmlands; monitor criminal activities; mining; advertising; scientific surveys and secure pipelines and offshore oil platforms (Nisser & Westin 2006, and Anand 2007)

One of the recent cases of using these devices for civilian applications is when a tsunami struck the Fukushima nuclear power plant in Japan on the 11th of March 2011. During that disaster, due to very unsafe conditions at the plant, Tokyo Electric Power (TEPCO) used a US-made micro aerial vehicle called Honeywell T-Hawk™ to photograph the nuclear plant from above. This flying robot had already been used by the US military to find roadside bombs in Iraq (Honig 2011).

There are several companies developing a variety of commercial drones. These drones usually provide an aerial photography and video platform for different applications in the industry or government. Table 1 lists some of the popular drones in the market and important information about them.

TABLE 1 Some examples of commercial drones in the market

Drone name	Developed by	Cost ($)	Weight (gr)	Operational Duration (Min.)	Camera
Scout	Aeryon Labs Inc.	30,000 to 50,000	1,300	25	1080p HD
Draganflyer X8	Draganfly Innovation Inc.	25,000 to 30,000	1,700	20	1080p HD
MD4-1000	Microdrone GmbH	Starts from 50,000	1,800	88	720p HD
AR.Drone	Parrot	300	420	15	640x480 pixels VGA

The first three drones in the table (Scout by Aeryon Labs Inc., Draganflyer X8 by Draganfly Innovation Inc., and MD4-1000 by Microdrone GmbH) are sophisticated commercial drones that have been recommend to be used for different applications from aerial photography and video to real state inspection. These drones have applicable features such as onboard GPS and HD cameras but the two important features which were used as the research group's main filters for choosing an appropriate drone platform were (1) the capability of streaming real-time video to an appropriate and not complicated user interface and (2) the low cost. For safety inspection purposes, the drone should be capable of providing real-time video of the current situation at the construction jobsite. Only under such an environment a safety manager would be able to provide immediate feedback and interact with the workers in real-time visually as well as via audio communication. Moreover using the current infrastructure (the user's own tablet or smartphone) for controlling the drone and receiving its real-time feed would be less expensive and more applicable for users. These three drones were not developed to be controlled by a mobile tablet computer or smartphone or stream real-time video to an interface. Scout can be controlled using its own complicated command center interface but is capable of streaming the real-time feed to tablets or smartphones. Draganflyer X8 is also controlled using its own command center interface, which does not provide real-time video on it, but high-resolution video glasses that can be connected to it to provide real-time streaming for the user. MD4-1000 also can be controlled using its own control joystick and does not provide a real-time feed directly on the control interface.

The limitations of not being able to provide a simple interface for both controlling and providing real-time feed together with the very high cost ($25,000 to $50,000) resulted in the selection of the AR.Drone, developed by the company Parrot™, as a drone platform for this research (Figure 1). It is the first quadricopter that can be controlled by an iPhone/ iPodTouch/ iPad device through its onboard Wi-Fi system (AR.Drone website). It was initially designed for the Apple iOS platform but now it can also be controlled with any Android device or even a computer and a joystick. Besides its affordable price, this consumer grade drone has some features that qualified it as a prototype of an ideal safety assistant drone. A major feature that is very useful in this research is real time video streaming. Dual cameras are embedded, one on the front and one underneath facing the ground, which help the operator to control the drone through the Wi-Fi connection. As an applied example, some engineers in New Zealand used this quadricopter to examine and film the front of the Roman Catholic Cathedral in Christchurch that was damaged in the 22nd of February 2011 earthquake (Zibreg 2011). Krajnik et al. (2011) has declared that many universities and research institutions have started using this device as an experimental platform in different researches such as autonomous surveillance/navigation (Faigl et al. 2010), human-machine interaction (Ng and Sharlin 2011), and even as a sport assistant by providing athletes with external imagery of their actions (Higuchi et al. 2011). The relevant specifications of the AR.Drone are listed in Table 2.

FIG 1. AR.Drone Quadricopter (Parrot, 2011)

TABLE 2: AR.Drone specifications (Adopted from Brandon 2010, Krajnik et al. 2011 and Parrot, 2011)

Specifications	Comment
Weight: 420g (0.9lbs)	A carbon-fiber frame and Styrofoam hulls for light weight and resiliency against impact
Dimension (With hull): 52.5x51.5cm (20.7 inches x 20.3 inches)	Dimension (Without hull): 45x29cm (17.7 inches x 11.4 inches)
Front video camera: 640×480 pixel color image and 75°×60° field of view	Camera streams real-time feed directly to screen
Bottom video camera: 176×144 pixel color image and 45°×30° field of view	Camera is used for calculating speed and position
An ultrasonic altimeter	
Onboard lithium-ion batteries	Batteries provide enough power for 15 minutes of flying time
A microelectromechanical (MEMS) inertial guidance system	This system includes (1) a three-axis accelerometer, (2) a two-axis gyroscope, and (3) a single-axis precision gyroscope for yaw.

Drone Control (version 1.6.1) by Kammerer (2011), AR.PowerFlight (version 1.2) by Baeumle (2010), Drone Master (version 1.2) by Logic Consulting LLC (2011), Drone Captain (version 1.5) by New Wave Industries Inc. (2011), Flight Record (version 1.6.2) by All About Jake LLC (2011) and Free Flight (1.9.1) by Parrot (2011) are among the various applications developed for controlling the AR.Drone through iPhone/iPad devices. Of these applications, Free Flight was the first application created for the Parrot AR.Drone (AR.Drone website). Since this application was not capable of video recording or taking still pictures, and these features were required for performing the evaluations, another application called Flight Record, which did not have those limitations about video recording and taking images, was used in this research.

1.3 Usability and User-Centered Systems

Systems have traditionally been designed and developed through a technology-center perspective (Endsley et al. 2003). In such a perspective the designers would accept the technology as is and would try to apply the very same technology in different domains without considering the very important element of the ultimate end-user (human). In a technology-centered perspective, the end user and all its requirements would be considered improperly identical in different domains. In this research, a user-centered approach was employed. Unlike the technology-centered approach, the very first issue that should be resolved in a user-center perspective is whether the technology is usable considering the real users' experience and their own requirements in a specific domain. This user-centered usability-based step would provide a grounded base for understanding the requirements for practical application of the technology in a domain. Having the drone technology might seem very useful for safety inspection practices but the very first issue that should be resolved is whether this technology would be usable for both safety managers and construction workers. A usable system should be easy to use and learn to work with while having the least number of design errors that makes it efficient enough to be ideally used.

As Figure 2 illustrates and already discussed in section 1.1, within the current construction environment the safety managers usually have direct face-to-face and vocal interaction with construction workers. But using the drone technology would change this direct interaction between workers and safety managers by adding the two elements of aerial drone and the user interface to the interaction process (Figure 3). The aerial drone part of the drone system would usually fly as a safety assistant over the jobsite and would provide a real-time view of the jobsite on the safety manager's mobile handheld device (user interface).

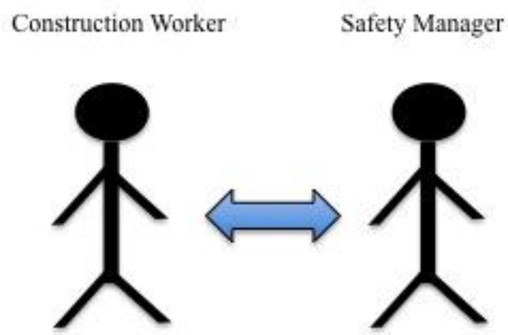


FIG 2. Construction worker and safety manager direct interaction

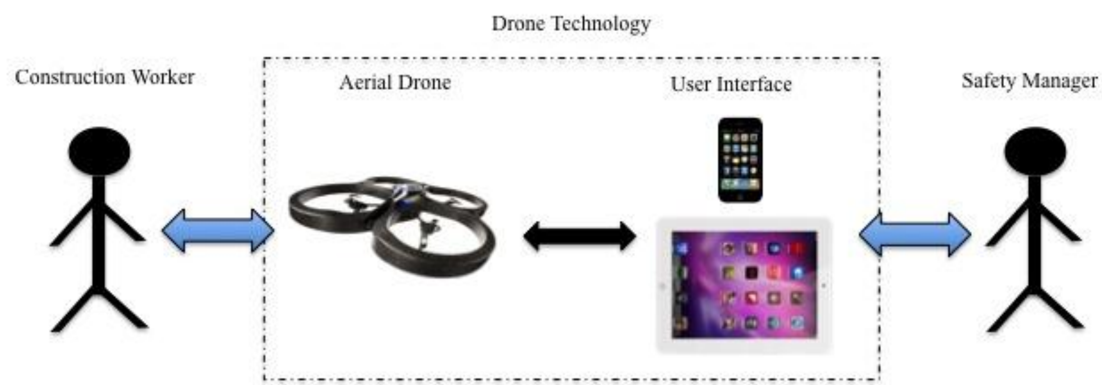


FIG 3. Construction worker and safety manager indirect interaction through drone technology

In such new condition, workers would see the drones flying around the jobsite and they would have to interact with them as they would interact with a safety manager. At the same time, the safety manager would get a real-time view of the jobsite and workers on the interface of the drone system. This interactive window of the jobsite would be a safety manager's center for interaction with workers and performing inspection tasks. Having the drone technology for construction safety practices embeds two parts, the aerial drone and the user interface. The construction workers usually interact with the aerial drone part of the drone technology while the safety managers would mostly interact with the user interface part. The focus of this research is on the safety inspection part and how a drone can play the role of a safety inspection assistant. In such environment, where approximately all the safety manager's interaction with the drone technology would happen within the interactive physical interface of the system, concentrating on the user interface is justified. The user-centered approach together with the usability assessment scope of this research led to two different usability assessments and safety manager's user experience measurement while performing a safety related task using the system.

1.4 Overview of the Research

As illustrated in Figure 4, the first step of this research was performing a Heuristic Evaluation (HE) of the AR.Drone interface that is considered as a prototype of a fully functioning safety inspection aerial drone. This expert analysis evaluation did uncover issues and problems with the interface, as well as leading to some recommendations to enhance it. Then a within-subjects experiment was designed to test the AR.Drone with real subjects while performing a safety-manager-related-task under different conditions. In this experiment, the subjects would count the number of hardhats they could see in different images of the construction jobsite under three different conditions; (1) plain view, (2) using iPad, and (3) using iPhone. Georgia Tech's Institutional Review Board (IRB) evaluated and approved the study protocol. After performing the experiment, a repeated measures analysis of variance (ANOVA) was performed to test the hypotheses that: (1) the quadcopter would serve as a suitable inspection tool; and (2) the accuracy of the user in identifying safety-relevant features in a scene has a direct relationship with the size of the screen that displays the scene image. After the statistical analysis and results, the features of an ideal safety inspection drone are discussed.

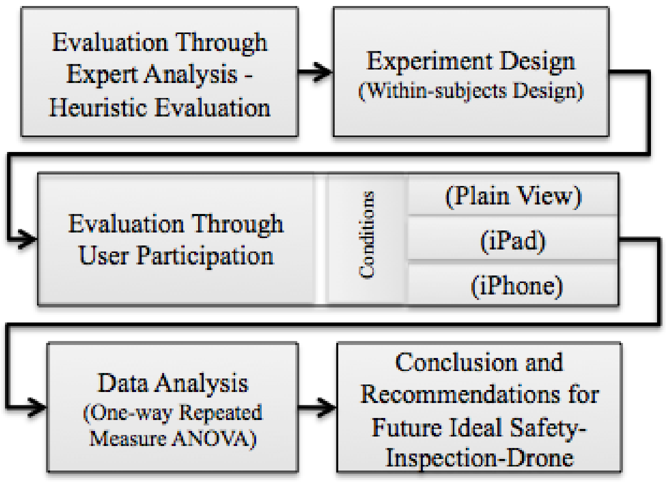


FIG 4. Research Methodology

2 STUDY 1: EXPERT HEURISTIC EVALUATION

A Heuristic Evaluation (HE) was used as the first step in evaluating the AR.Drone system. HE is a very popular and inexpensive method of systematic inspection of a user interface for usability purposes. Having the drone technology would not require the safety managers' presence in most of the jobsite. In such a situation, all the focus of the safety manager would be on the interface of an IT tool to get all the required data from the jobsite and interact with the workers. All the data and interactions should happen in the user interface used by the safety manager. Making this interface as usable as possible and investigating its usability issues from a safety manager perspective is extremely critical. HE, developed by Jackob Nielsen and Rolf Molich in 1990, is a "guideline or general principle or rule of thumb that can guide a design decision or be used to critique a decision that has already been made" (Dix et al., 2004). Nielsen, based on his experience, has indicated that for performing the HE, three to five evaluators are sufficient (Dix et al., 2004). Thus, three evaluators who are familiar with HE methodology and had previous understanding about safety inspection and the AR.Drone, completed the HE independently. To aid the evaluators in understanding the problems with the current design and how the system can be improved, Nielsen's ten heuristics were provided (Table 3).

TABLE 3: Nielsen's Heuristics for Expert Evaluation (Adopted from Dix et al., 2004)

#	Heuristic	Description
1	Visibility of system status	• Keep users informed about system status • Provide feedback about system status
2	Match between system and the real world	• Speak user's language • Follow real-word conventions • Make information appear in natural and logical order
3	User control and freedom	• Clearly marked "emergency exit" should be provided for a user who might choose a system function by mistake • Supports undo and redo
4	Consistency and standards	Follow platform conventions and accepted standards by having consistent meaning of words, situations or actions in different contexts
5	Error prevention	• Make it difficult to make mistakes • A careful design that prevents a problem from occurring in the first place is better than a good error message
6	Recognition rather than recall	• Make objects, actions and options visible • Reduce memory load

7	Flexibility and efficiency of use	• Allow users to tailor frequent actions • Provide shortcuts (accelerators) for performing frequent tasks would speed up the interaction that the system can cater to both novice and experienced user
8	Aesthetic and minimalist	Dialogs should not contain information that is irrelevant or rarely needed
9	Help users recognize, diagnose and recover from errors	Provide good error messages;(1) should be expressed in plain language (no codes), (2) precisely indicate the problem, and (3) constructively suggest a solution
10	Help and documentation	Provide help and documentation; (1) should be easy to search, (2) focus on the user's task, (3) list concrete steps to be carried out, and (4) not to be lengthy

Nielsen has suggested that these 10 heuristics should cover most of the common usability problems (Dix et al., 2004). After assessing the system and identifying usability issues, the evaluators assessed the severity of each usability problem based on the following scale of 0-4 (Table 4).

TABLE 4: Severity Rating (Adopted from Dix et al., 2004)

Scale	Severity Rating	Description
0	Not a problem	Not a usability problem at all
1	Cosmetic problem only	Need not to be fixed (unless extra time is available on project)
2	Minor usability problem	Low priority to be fixed
3	Major usability problem	High priority to be fixed
4	Usability catastrophe	Imperative to fix this before product can be released

The evaluators used the iPad for performing the HE since the display was large enough to facilitate the identification of usability deficiencies. For the purpose of the HE, the following defined order was used for flying the drone:

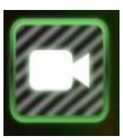
1. Connecting the iPad to the AR.Drone wireless through Wi-Fi
2. Starting the "Video Record" application
3. Drone take off
4. Turning the video camera on
5. Going forward for about 3 feet (From point A to point B)
6. Turning around
7. Going up for about 1 feet
8. Switching from front camera to bottom camera
9. Taking a picture
10. Going back from Point B to point A
11. Push the "emergency" button in the application for a quick landing

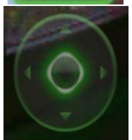
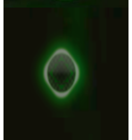
2.1 Resulting issues and recommendations from HE

Once the evaluators completed their separate assessments on the FlightRecord User Interface (Fig. 5), all of the problems and issues were collated, and the mean severity calculated. Table 5 shows the said problems as well as their importance and how addressing them can improve the AR.Drone's effectiveness in facilitating safety inspection activities. All of those issues were in the categories of minor usability problem (severity rating #2) or major usability problem (severity rating #3). The recommendations included in Table 5 are based on the safety context of this research and would be a good starting point for developing an ideal safety inspection assistant drone user interface.

FIG 5. FlightRecord User Interface (UI) on iPad while flying the drone

TABLE 5: Resulting issues and recommendations based on the HE of the UI

#	Component	Description	Issue	Violate HE #	Severity Rating	Recommendation
1		FlightRecord application logo	Not an appropriate logo and name for a construction safety inspection application	2	2	The elements of construction safety should be used in the design of the logo/name. This makes the application visually significant for the construction safety managers.
2		Switches between bottom and front cameras	Looks like a metaphor for video recording and not a switching bottom for bottom/front cameras	4, 5, & 6	3	Embedding the concepts of “switching” and “cameras” in its button design (reducing memory load & potential errors)
3		Drone’s forward speed (“+” is moving forward and “–” is moving backward)	A constant directional arrow which does not change with drone’s direction	2 & 5	2	The arrow should show the direction of the drone.
4		Battery bar & battery percentage	Provides redundant data	1& 5	2	Having only bar or percentage is adequate
5		Record/Pause the front video camera	Not a good metaphor for video recording. Also when the button is off, the word “off” is not readable	4, 5, & 6	3	Embedding the concepts of “video recording” and “on/off” in its button design (reducing memory load & potential errors)
6		User emergency reset would turn the drone’s motors off	The button is red while the drone is flying and would change into green in case of emergency	1, 2, & 4	3	The red and green colors of display should be switched (reducing memory load)

7		Still Snapshot would take picture though front and rear cameras	Provides a shutter sound while taking a picture but there is no visual feedback to verify it	1	2	Provide visual feedback (e.g. changing the brightness of the interface right after pushing this button).
8		Joystick: makes the drone pivot to the right/left or climb/descend	Having these two buttons together would cause confusion (pivoting vs. directional movement)	1, 2, & 4	3	Controlling the drone with a single button would reduce the learning curve and would allow the user to have his/her other hand almost free. Right/left-handed option should also be provided in this case
9		Drone moves forward or backward by pressing + holding this button and tilting the iPhone				
10		Landing & takeoff	The button is not a good metaphor for landing/takeoff	1 & 5	3	Modify this button in a way to make the user easily find out drone is landing or taking off (e.g. color change).
11		Directional Gyroscope	Complicated and provides redundant information	1 & 2	2	Deleting this directional gyroscope and providing a small map with the current location of the drone in the construction jobsite while having geographical directions on the map
12		Artificial Horizon	Provides redundant information	8	2	There is no need for this component

3 STUDY 2: EVALUATION THROUGH USER PARTICIPATION

The heuristic evaluation concentrated on evaluating the interface of the system, as the most important part of the system for the safety manager, through analysis by the evaluators who are experts in both HE and safety inspection. But the expert analysis cannot be a replacement for the actual usability test with real subjects performing a safety related task. An experimental approach was employed to test the drone technology application the construction safety inspection practices. The experiment consisted of using the drone as a tool to inspect images from a typical worksite. The user's task was to count the number of hardhats present in 10 different construction-related images that had been projected on a flat non-reflective surface. Note that a hardhat is a personal protective equipment item used in many industries including construction, and determining whether workers are wearing their hardhat is an example of the many inspection tasks that safety managers must complete.

3.1 Study Design and Methods

A within-subjects experimental design was employed, in which each subject participated in three different image-viewing conditions. In the Control condition the subject sat in front of a board, on which the jobsite images were projected, and counted the number of hardhats in each picture (Figure 6).

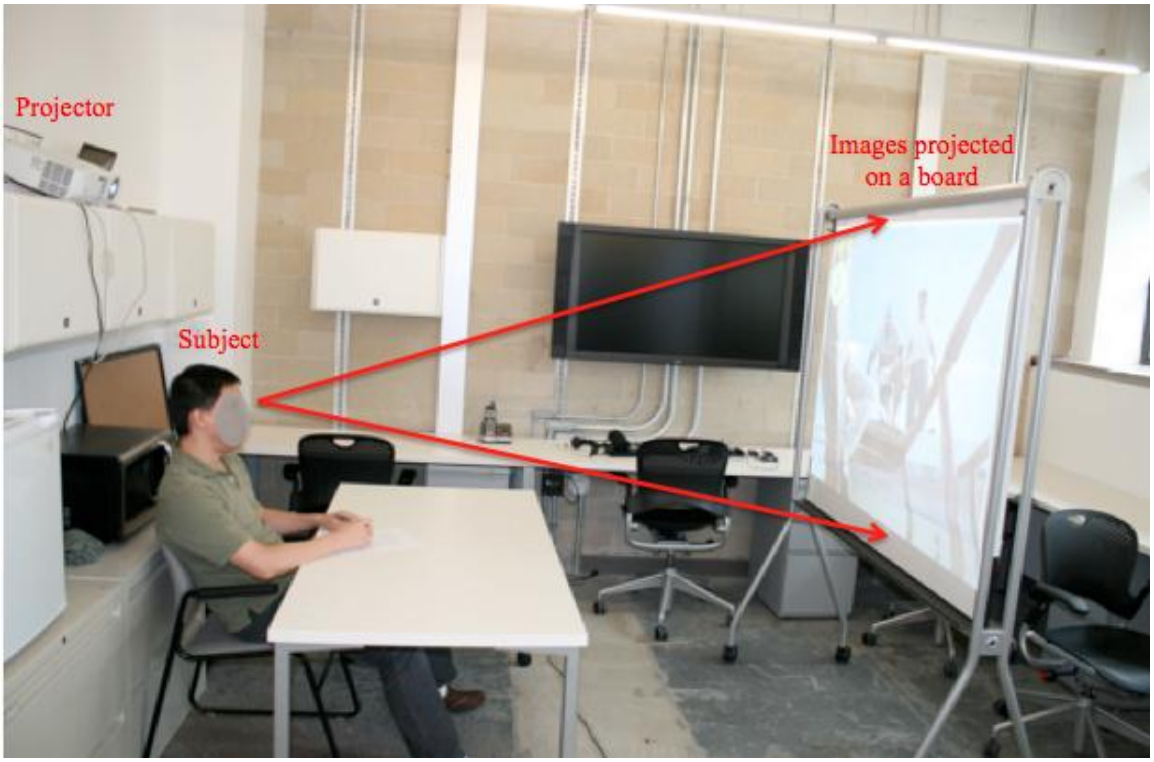
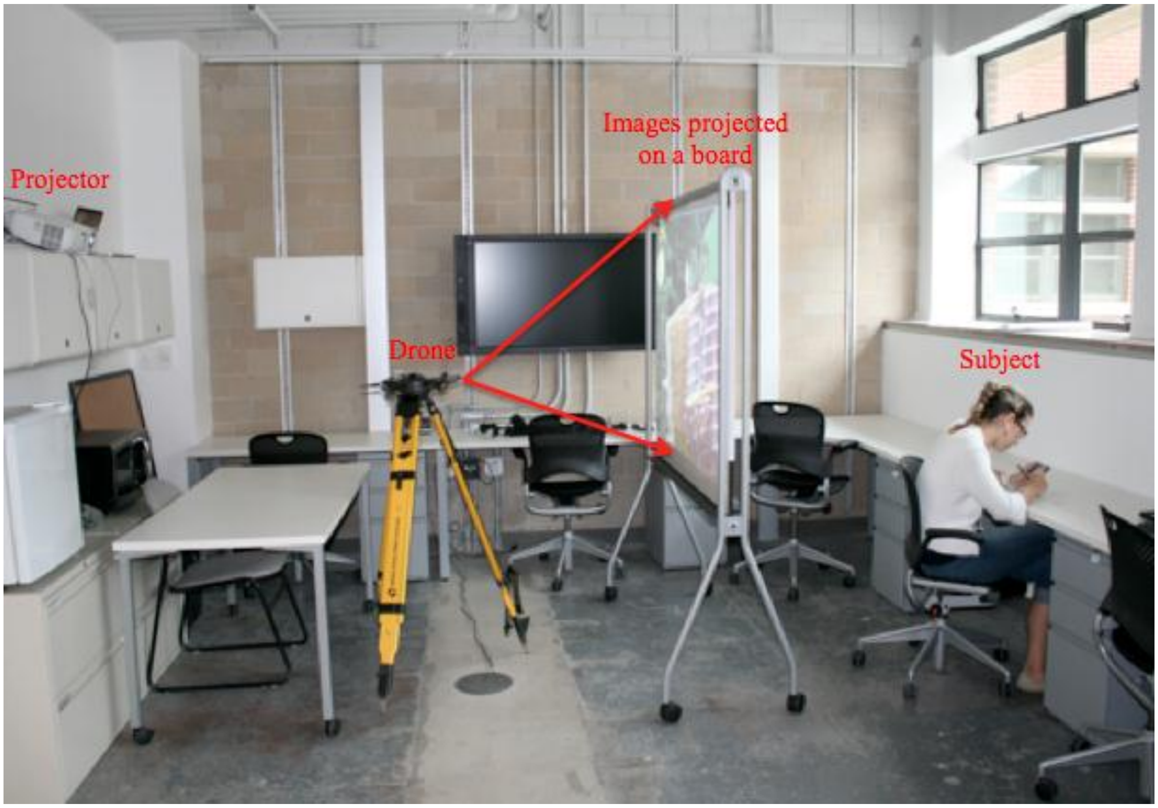


FIG 6. Experiment setup for the Control condition

In the other two conditions, a drone was mounted in front of the board, with the drone's front camera capturing the images of the jobsite (see Figure 7). These conditions simulate the way the drone would actually be used on the construction site. In the iPad condition, the participant viewed the projected images via the screen of an iPad tablet device. In the iPhone condition, the participant viewed the projected images via the screen of an iPhone smartphone. The iPhone and iPad were selected as representative phone-size and tablet-size mobile handheld devices respectively that might be used by safety managers on a daily basis to perform inspection-related practices. The new technologies that are built on current common infrastructure (e.g. iPhone or iPad) would not only have lower cost but also would be easier to work with due to users' previous experience of using similar devices on a regular basis. Having the most accurate and flawless user interface might also contribute to usability shortcoming when there is a small screen size. The safety manager would only need to have interaction with a user interface on a handheld device and all the real-time critical information about the safety status of the jobsite would be displayed on the interface. In such condition, the restricted screen space might lead to not accurate decisions that in the safety inspection practices might lead to catastrophes. The research team performed an experiment to not only measure the user experience while performing a safety inspection task but also to compare between the two most common handheld interface sizes to check which one would lead to more accurate response and satisfy user expectations.



(a) Experiment setup for the iPhone and iPad conditions

(b) Drone mounted on top of a tripod

(c) The subject looking through an iPhone (treatment condition)

(d) The subject looking through an iPad (treatment condition)

FIG 7. Treatment Conditions

For each participant, a Microsoft PowerPoint file was prepared which consisted of three parts. Each part had 10 images that were randomly chosen from a pool of 40 different pictures of construction jobsites. Participants completed the following steps in each part:

- The participant would see 10 different pictures, one at a time, of workers in a construction jobsite.
- The participant then had 5 seconds to inspect each picture and count the number of hardhats they saw in each image.

- After the 5 seconds of viewing, the picture would fade away and the subjects had 10 seconds to write down their response in the data collection form provided to them. After the 10 second response period, the next picture would appear on the display.
- After counting the number of hardhats in all 10 pictures under any specific condition, participants were asked to rate several subjective statements about the viewing condition using a 7-point Likert scale.

The experiment lasted approximately twenty-five minutes per participant. A statistical analysis was performed on the accuracy of the correct number of hardhats under any condition. The experiment hypothesis was that the accuracy of the user in identifying the correct number of hardhats in the pictures would have a direct relationship with the size of the screen used to view the jobsite image; the larger the screen size, the more accurate the user would be.

3.2 Participants

Given that this was a within-subjects study, ten adult participants (5 male and 5 female) were recruited from the Georgia Tech community. All reported normal or corrected to normal vision. None of the subjects had used the AR.Drone previously and only one of them had heard about it before the experiment. In the case of the touch screen devices, 8 subjects had already used iPhone, 5 had used iPad, 1 had used other devices and 2 had never used any touch screen devices.

3.3 Results of user participation experiment

Accuracy Scores. Figure 8 shows each participant’s accuracy scores in the three different conditions of the experiment. Accuracy was measured by dividing the reported number of pictures by the actual number of pictures in each condition. A Shapiro-Wilk test (appropriate for small sample sizes) with an alpha level of $p = .05$ was used to assess the normality of accuracy scores under three different conditions. The accuracy scores were normally distributed under plain view ($p = .112$), iPad ($p = .088$), and iPhone ($p = .500$). Accuracy was then analyzed with a one-way repeated measures ANOVA with Greenhouse-Geisser correction when necessary, and alpha level of $p = .05$. Planned comparisons were used to compare condition means.

There was an effect of viewing condition, $F(1.245, 11.208) = 8.143$, $p < 0.05$, indicating that accuracy depended on how the participant viewed the images. Accuracy was highest in the Control (plain view) condition (mean accuracy, $M = 78\%$), which was numerically higher than the accuracy in the iPad condition ($M = 57\%$), though this difference did not reach conventional levels of statistical significance, $p = .096$. Accuracy in the iPhone condition was lowest ($M = 43\%$); this was statistically different from the Control (plain view) condition, $p = .003$, and from the iPad condition, $p = .021$.

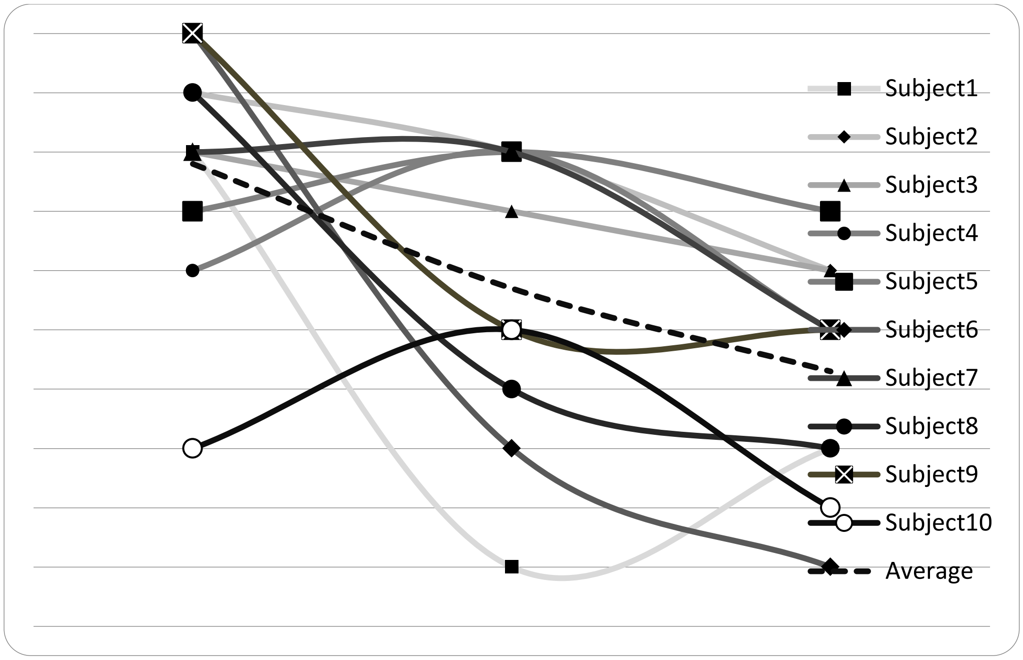


FIG 8. Subjects' accuracy scores

Subjective Rating Scores. Using a Likert scale (1=Strongly Disagree to 7=Strongly Agree), participants were asked to rate 10 different subjective statements right after they completed the hardhat counting task under each condition. Table 5 shows the average rating score of each statement under each condition.

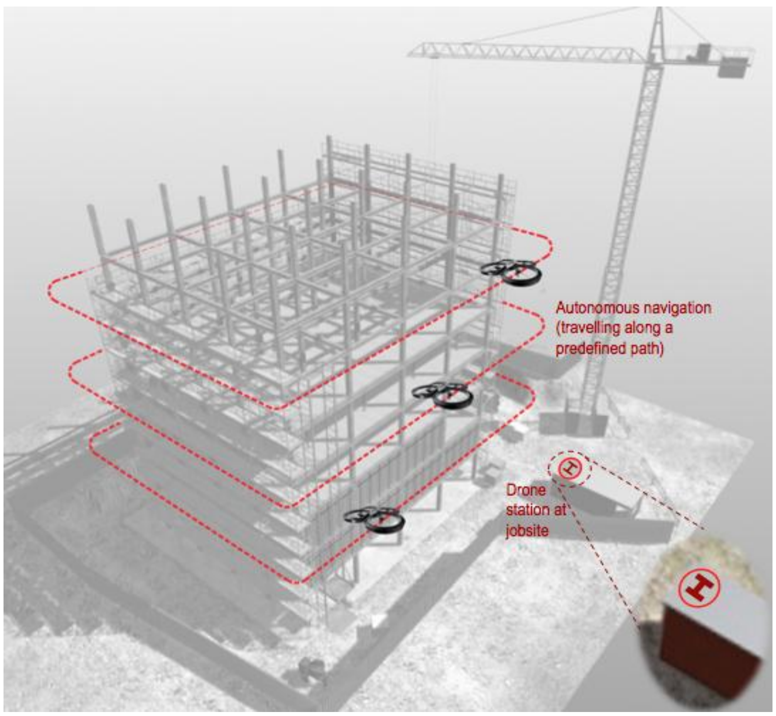
TABLE 6. Average score for each subjective statement for each viewing condition (1=Strongly Disagree to 7=Strongly Agree)

Subjective Statement	Average		(n=10)
	Plain View	iPad	iPhone
1. I can effectively complete this task using this system.	6.4	4.8	3.7
2. I am able to complete this task quickly using this system.	6.3	5.1	4.8
3. I am able to efficiently complete this task using this system.	6.2	4.4	3.7
4. I feel comfortable using this system.	6.3	4.5	3.7
5. The size of the picture was big enough to find out the number of hardhats.	6.7	5.1	3.1
6. The task was mentally demanding.	2.7	2.7	3
7. The task was physically demanding.	1.9	2.5	2.6
8. The pace of the task was hurried or rushed.	2.7	2.9	4.3
9. Overall, the image quality was good.	6.3	3.4	2.6
10. Overall, I am satisfied with the ease of completing this task.	6.4	4.6	3.5

Participants indicated that they were most able to complete the task (Question #1) using the plain view (mean response out of 7, M = 6.4), followed by the iPad (4.8) and then the iPhone (3.7), which parallels the accuracy results. The same pattern of results held for nearly all of the subjective responses (see Table 6). Overall, participants were very positive about their effectiveness, efficiency and comfort of performing the task with the plain view, and were also positive (albeit less positive than for plain view) while using the iPad. Using the iPhone to complete this safety inspection task was not rated positively (most average rating scores were lower than half of the scale). Note that for Question #8 regarding pace of the task, lower values indicate a higher rating. Screen size appears to have been a major factor in satisfaction and perceived effectiveness. The iPad's screen size was sufficient to be rated positively, whereas the iPhone screen was clearly too small for this task. Only plain view could satisfy the participants (6.3) in terms of the image quality.

4 IDEAL SAFETY INSPECTION ASSISTANT DRONE

In addition to real-time video streaming on the user interface, based on the results from experiment and usability evaluation as well as the authors' experience in the multidisciplinary area of safety inspection and drone technology, the following proposed features should be embedded in an ideal safety inspection assistant drone:



(a) Autonomous navigation using predefined paths or locations

(b) Voice interaction between workers and the drone

(c) Safety manager interacts with workers using the drone and through the iPad

FIG 9. Ideal safety inspection assistant drone

The following are considered the basic three required features for a safety inspection drone which are based on the authors' experience and understanding of the integrated domain of safety inspection and drone technology:

- *Autonomous navigation:* The safety managers should be able to manually control the device as well as using the autonomous navigation feature. Having predefined paths or locations that the drone can automatically use, with or without minimum user interference, would be an ideal feature. Figure 7a shows drone's station on jobsite and its use of autonomous navigation to fly along predefined paths or over specific locations
- *Voice interaction:* The safety managers should be able to talk through this tool with the workers in the jobsite (Figures 9a and 9b). Under critical circumstances, this feature will enable the safety managers to make required commands before physically arriving to, for example, the accident scene.
- *Improving the battery life:* The battery life of the AR-Drone provides up to 13 minutes of continues flight. This should be increased to allow longer flight time.

Frequent walking and observation which is one of the safety managers main responsibility would require a drone to be capable of having long battery life to be able to fly around the jobsite for long periods every day. Also having autonomous navigation and predefined paths would be a very applicable option for frequent observation on the jobsites by not adding another task of controlling or piloting a drone to the safety manager's responsibilities. Direct interaction with the workers is also a responsibility of the construction safety managers. Vocal interaction is a very important option for an ideal safety inspection assistant drone that is aligned with the direct interaction responsibility of the safety manager.

The following features are based on the result from experimental part of the research:

- *Improving Cameras:* The video feedback is provided by a VGA camera (640x480 pixels) in front with a 93° wide angle diagonal lens and a high-speed camera in bottom with a 64° diagonal lens. These cameras should be improved to provide the safety managers with better picture and video resolution. This statement is supported by the negative responses of the subjects about the image quality while using iPad and iPhone in the experiment (3.4, 2.6, n=10). In addition to real time applications, high-resolution pictures and videos can be saved in the drone to be transferred to a computer for processing when the drone has landed. Furthermore the tool should be capable to take pictures and videos automatically or in predefined intervals. Also another disadvantage of the camera system is that both camera images cannot be obtained for the user simultaneously. The user should just have one of the bottom and forward cameras or choose two-picture-in-picture mode (Krajnik et al. 2011).
- *Having an iPad(tablet-size)-compatible-application:* Based on the questionnaires, the users would prefer to use the iPad compared to the iPhone. The larger interface did provide more accurate results in the experiment that also was supported by the qualitative statements (Table 5).

The following features are based on the comments provided by the users on the open-ended part of the subjective usability questions:

- *Multitasking:* Being able to have other info/applications available while using the drone. For example being able to email a picture, surf the web, view OSHA safety codes or call/Skype while using this application would be beneficial. But having multiple windows and how it may affect the productivity of the safety managers should be studied.
- *Optional audio/visual/vibrating emergency warnings:* Having different types of warning systems for various features (e.g. landing, battery low) would be ideal.
- *Collaborative User Interface Environment:* Other people involved in project (e.g. project manager or superintendent) should be able to use the drone or see the interface in their own device and even be able to provide comments or assist the safety manager under critical circumstances.
- *Environmental applicability:* Frequent jobsite observation would lead to considering climate and weather condition issues in developing an ideal safety inspection assistant drone. A construction project may start in any season and can last for a short or long time. Safety managers should be able to perform the jobsite inspection under hot/cold, rainy/snowy, and cloudy/clear conditions. Table 6 provides some climate and weather indicators that affect the inspection task of safety managers. These issues and their usability implications should be considered while designing the safety inspection assistant drone.

TABLE 6. Environmental (weather) indicators that affect the safety inspection task

Environmental Indicators	Usability Implications
Temperature	Perspiration when it is hot and wearing gloves in cold temperature should be considered
Precipitation/ Snowfall	Waterproofing of drone and control device
Wind	The stability of the drone
Cloud	The brightness and reflectivity of the display

5 CONCLUSION

In this study, a small-scale aerial drone was used as a tool for exploring potential benefits to safety managers within the construction jobsite safety inspection. Safety managers should perform walkthroughs of the jobsite and check the current safety situation of workers, materials, and equipment, while having direct interaction with workers. The authors believe that providing safety managers with a safety inspection assistant drone would be extremely beneficial and can enable them to achieve the goals of the safety inspection.

Using the AR.Drone, as an experimental platform for this research, usability evaluation was performed using (1) an expert heuristic evaluation (HE) and (2) a user participation study. These two studies provided an understanding of the applicability of this drone to construction safety inspection, and how it can be improved. The HE methodology uncovered some user interface (UI) issues about the AR.Drone application interface and some recommendations were provided to overcome those deficiencies considering Nielsen's heuristics and safety inspection context. Afterwards, the simple task of counting the number of hardhats in images of a jobsite was performed in the controlled environment of the lab under three different conditions (plain view, via iPad, and via iPhone). This experiment was designed to simulate the actual use of the drone in the construction jobsite while performing a simple task of a safety manager. The data revealed that accuracy score in the iPad condition is closer to plain view condition and on the other hand the iPhone elicits a statistically significant reduction in accuracy score compared to the plain view condition. This means iPad has closer accuracy scores to plain view in comparison to the iPhone. The findings were also supported by the results of the subjective survey done after each part of the experiment. Subjective questions included in the survey revealed that on average the participants agreed that the size of the picture on an iPad was big enough to determine the number of the hardhats; the iPhone screen was not large enough. Also participants felt that the pace of performing the task was hurried or rushed using the iPhone but they didn't have the same feeling under plain view or iPad conditions. Overall, participants were satisfied with the ease of completing the task under plain view and iPad conditions but they were not satisfied with the ease of performing this task using iPhone.

Afterwards, based on the literature review and the studies reported on here, some features were recommended for an ideal safety inspection assistant drone. Autonomous navigation, voice interaction, environmental applicability, high-resolution cameras, multitasking application, and collaborative user interface environment are some of those features.

In terms of the challenges of using drone in the construction industry, the main one is endangering the safety of the workers in the jobsite. Issues such as workers being distracted or even hit by drones should be studied (and obviously avoided in any deployed system). Also there is a social challenge of applying this technology in the construction jobsite that should be considered as well. The workers are used to having a safety manager who would walk through the construction jobsite to check the safety requirements. Having a safety assistant drone, which flies over the jobsite and sometimes allows safety managers to talk to workers remotely, might seem awkward or even under critical circumstances might not work appropriately. But considering all the challenges, this innovative application of the aerial drone has the potential to improve construction practices and in this case facilitate jobsite safety inspections. This research can be considered as an initial step of applying drone technology to the construction industry. For example, providing photos from upper angles can be used to cover blind spots that are currently a limitation in the photogrammetry of the structure and the jobsite (Ito et al. 2011). Providing real time videos, being able to fly to all different parts of the jobsite, and voice interaction are some features that would make the drone an appropriate technology to be used in other sectors of the construction industry.

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