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EVALUATING THE PERFORMANCE OF UNMANNED AERIAL VEHICLES FOR SAFETY INSPECTION

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ABSTRACT

The potential use of Unmanned Aerial Vehicles (UAS) has come to the attention of the construction industry. However, its use still demands investigations for a better understanding of how this technology can be fitted to construction management tasks. This paper aims to evaluate the application of UAS for safety inspection on site, focus on its utility, equipment performance and risks associated with the use of that technology. For this, two case studies were performed in Brazil. Data was collected from flight tests on site for visual assets gathering and regular meetings with project personnel for feedback were held. The safety inspection analysis was based on the visualization of the safety requirements in the visual assets collected. Document analysis and interviews with project personnel and workers were performed for supporting the performance evaluation. As a result, the application of UAV could provide the visualization of 87.2% (Project A) and 58% (Project B) of the safety inspections items selected, providing detailed information for safety monitoring on jobsites. Barriers such as meteorological factors and pilot training influence the technology use for safety inspection. Further studies are under development in order to evaluate the impact of the safety inspection with the support of UAV in a systematic way.

KEYWORDS

Unmanned Aerial Vehicles/Systems (UAV/UAS); Safety inspection; Visual assets; Construction management.

INTRODUCTION

Unmanned Aerial Vehicles/Systems (UAVs/UASs) are defined as any aircraft that works without a human pilot onboard (Puri, 2005). Initially, UAVs were used in military applications, but more recently, the potential use of UAS in engineering environments has gained significant attention in domains such as Remote Sensing systems, field monitoring,

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infrastructure projects, urban planning, road inspections, jobsite management (Puri 2005, Irizarry et al. 2012, Themistocleous et al. 2014, Wen and Kang 2014).

In Brazil, commercial aviation activities are regulated and monitored by the National Agency for Civil Aviation (ANAC). The experimental operation using UAV requires authorization from the ANAC and its legal operation varies according to the classification of the Remote Pilot Aircraft (RPA), based on its Maximum Take-Off Weight (MTOW), the purpose of operation (experimental, commercial or corporate) and the visual grading criteria (Visual Line of Sight or Beyond Visual Line of Sight) (ANAC, 2015).

In construction projects, safety is a very important managerial task. In Lean terminology, poor safety is a form of waste, since injuries are costly not only in terms of human suffering but also in terms of worker compensation costs, lost time, lost productivity, and higher employee turnover (Nahmens and Ikuma 2009). Safety inspection, which is part of the safety management, has the role for hazard detection and correction of unsafe conditions (Irizarry et al. 2012; Woodcock, 2013; Lin et al. 2014). However, it is possible to identify some failures in process, especially related to non-standardization of inspection routine, difficulties to access jobsites in remote areas and real time management (Lin et al. 2014, Saurin et al. 2002).

Some emerging technologies have been used for accident prevention in construction jobsites, such as Technology of Information and Communication (TIC); Building Information Modeling (BIM), Global Positioning System (GPS), Geographic Information System (GIS), Radio-Frequency Identification (RFID) and Virtual Reality (VR) (Han et al. 2009, Lin et al. 2014, Jaselskin et al. 2015). For example, Teizer (2008) shows that construction safety can be improved by using emerging technologies such as 3D Range Imaging Cameras to improve safety in heavy equipment operation. Golparvar-Fard et al. (2011) state that the interactive zooming ability allows cases to be remotely analyzed by safety inspectors and can potentially lessen the frequency of on-site safety inspections.

The application of UAS for safety inspection and some other managerial tasks on jobsites has been the focus of exploratory studies as well (Irizarry et al. 2012; Wen and Kang 2014; Irizarry et al. 2015; Kim and Irizarry 2015; Irizarry and Costa 2016; Ham et al. 2016). Studies in other engineering areas show that UAV application can resolve the need for visual information and real time monitoring (Zhang 2008; Themistocleous et al. 2014). In addition, UAS potential can be related to low cost, high mobility, safety support, high speed visual assets acquisition and data transfer (Kim and Irizarry, 2015).

Therefore, despite those recent studies, the effective and systematic application of UAS for safety inspection still requires investigations that aim for a better understanding of how this technology can be fitted to construction management.

This paper presents an ongoing study which aims to evaluate the application of UAS for safety inspection on construction sites, focusing on the its utility for safety inspection, equipment performance and risks associated with the use of that technology. This research is part of a collaborative project between the Federal University of Bahia-Brazil and the Georgia Institute of Technology-USA, and the main outcome is the development of a set of guidelines for the application of UAS for safety inspection. This paper seeks to contribute to the identification of the role of UAS to support managerial tasks on site, especially concerning safety inspection, detection and correction, with the aim of preventing accidents, improving worker health, reducing costs, and increasing value.

RESEARCH METHOD

This work adopted a case study strategy, according to the following stages: (a) literature review on the use of UAS in engineering, monitoring and safety inspection and the Brazilian regulations for UAS flights, (b) case studies, and (c) UAS performance evaluation for safety inspection. These stages will be detailed below.

The location of the projects selected follows the criterion established by ANAC, allowing flights with a minimum radius distance of 5km from airports and heliports. Two residential projects were studied and Table 1 describes the main features of each project.

Table 1. Features of Project A and B

Project	Description	Safety inspection focus
Project A 	Residential low income housing project Land Area: 150,000m² Built Area: 91,000m² Total of 1880 units: 91 5-story buildings and 5 3-story buildings Construction time: 24 months 600 labor workers	Concrete pouring process, Roof process, Assembly and disassembly of steel form works, and Assembly and disassembly of safety pavement template works House keeping, temporary installation and wastes
Project B 	Residential high rise building Land Area: 2,500m² Built Area: 151,578m² Total of 104 units: 1 26-story building Construction time: 26 months 220 labor workers	Façade process Collective Protective Equipment and Individual Protective Equipment House keeping, temporary installation and wastes

The equipment used in the study was DJI Phantom 3 Advanced equipment, with Sony EXMOR camera ½.3", with 12.76 pixels, image size of 4000x3000, creating pictures in JPEG and DNG format and videos in MP4. A set of forms for the application of UAS for safety inspection was used based on Irizarry, Costa and Kim (2015), as following.

- **Planning Meeting Form**: form to determine information needed and workflow with project safety personnel and managers. The data is related to general project information, safety management process information, flight plan information.
- **UAS Mission Check List and Flight Log Data Form**: form used for pre-flight, during-flight, and pre-landing operations in order for an efficient flight, considering safety requirements and the appropriate use of the equipment.
- **Safety Checklist by Snapshot Types – Full version**: form used for identifying the safety requirements which might be visualized using the UAS technology. It was

adapted to the Brazilian Safety Regulation, called NR 18 Working and Environmental Conditions in the Construction Industry (Brasil, 2015). Initially, the NR 18 requirements which could be visually verified outside of the buildings were selected (a total of 60 items). These items could be associated with physical causes (e.g. scaffolding is not plumb and square), unsafe condition (e.g. unprotected workers from falling) and unsafe acts (e.g. workers not wearing protective equipment). The safety requirements were classified in three shot types: (a) **Overview**, including a general view of the site, focusing on organization and housekeeping, temporary installation and wastes, (b) **Medium Altitude View**, involving requirements related to Collective Protective Equipment and Individual Protective Equipment, and (c) **Close Up View**, which was established by processes, such as roof and waterproofing, concrete pouring and masonry, earthwork and foundation, equipment operation and façade.

- **Safety Checklist by Snapshot Types – for field**: form involves a summary of the safety requirements, with a total of 25 items, in order to guide the pilot and the observer during the data collection with the UAS.

A total of 23 flight tests were performed with an average time of 9 minutes each, and the number of pictures, video recording and flight parameters were catalogued (Table 2). For all flights, at least three members of the research team were involved: the pilot, the observer who guided the pilot for the safety inspection data collection, and a second observer to focus on the safety of flight (aircraft and surrounding area, such as airplanes, and birds). It is important to note that each flight had a purpose stated before takeoff, defined together with project personnel (use of Planning Meeting Form). Examples of this include flight for safety inspection based on the checklist, flight for examining the construction process in detail for safety purpose and flight for data collection for 3D modeling generation. This last item is not the focus of this paper. For the flight tests with the UAS the Pre- Flight Checklist and Safety Checklist by Snapshot Types – four field forms were used. After the flights, a feedback meeting with project personnel for the immediate assessment was organized.

Table 2. Visual assets data collection

Project	Period	Number of visits	Number of Flights	Number of Pictures	Time of Video recording	Maximum Distance(m)	Maximum Altitude(m)	Total Flight Duration(h)
A	Oct/15 tc Mar/16	4	14	579	39:02	734.0	120.0	2:07:43
B	Nov/15 t Mar/16	3	9	722	09:48	173.5	76.8	1:15:43

At Lab, the data was fully processed based on the Safety Checklist by Snapshot Types Full Version. Due to the exploratory nature of this study, statistical analysis concerning visual assets sample size used for Safety Checklist were not performed. The analysis consisted of verifying if each safety item of the checklist could be visualized using any of the visual asset collected. A data base of safety inspection items and visual assets was created. A total of 7 Safety Checklist by Snapshot Types was applied, with 4 for Project A and 3 for Project B.

Additional data was collected during the studies aiming to gather the user's perception in terms of the utility and the risks associated with the UAV technology. A questionnaire for evaluating the degree of importance of the safety requirements used in the Safety Checklist by Snapshot Types Form was applied to 12 project personnel in Project A and B (2 Project Managers, 1 Field Engineer, 1 Trainee 3 Safety Personnel, and 5 Safety Trainees). The answers of the questionnaire were analyzed using the Relative Importance Index (RII), according to Ferreira and Brito (2015).

$$\text{Formula 1. (RII)} = \frac{\Sigma W}{AxN}$$

Where:

W is the weight given by the participant for each element using Likert Scale in 5 levels (1 - Very Low up to 5 - Very High);
A is the highest level, in this study it is 5;
N is the sample size (12 participants).

In addition, interviews to gather the manager's user perception concerning the utility of the visual assets to support decision making related to safety inspection were conducted for a total of 10 interviewees in Project A and B (1 Director, 1 Safety Director, 3 Project Managers, 2 Field Engineers, 1 Trainee, and 2 Safety Personnel). Finally, a questionnaire aiming to collect worker's perception concerning the interference of the UAV in their tasks during the flight, the privacy and the perception about the risks, such as falling, was given to a total of 18 workers from Project A and B who had the experience of working during a UAS flight. The evaluation of the UAS performance was based on the constructs, variables and sources of evidence presented in Table 3.

Table 3. Definition of Constructs, Variable and Source of evidence

Constructs	Definition	Variables	Sources of evidence
Utility	Means to evaluate to what extent the information provided using UAS technology supports safety management users	Meeting the information needs for safety inspection Applicability for safety inspection	Level of Importance Questionnaire Safety Check list data collection and visual assets from UAS
Equipment Performance	Means to evaluate to what extent the UAS specifications adopted are applied for safety inspection	Flight autonomy Device stability System reliability Easy use for users	Feedback meetings with project personnel and Interviews with project personnel Document analysis
Risks associated with technology use	Means to evaluate to what extent the risks associated with the technology might influence the application for safety inspection	Interferences in project activities Acceptability from workers Hazards such as falling and collisions	Direct and participant observation Mission check list data Visual Assets from UAS Flight log and note data Interviews with project personnel Workers' Questionnaire

RESULTS AND DISCUSSION

This section presents the results related to the utility of the UAS for safety inspection, equipment performance, and risks associated with the use of UAS technology.

UTILITY OF UAS FOR SAFETY INSPECTION

Table 4 presents the results of the Relative Importance Index, representing to what degree the safety items selected meet the information needed for safety inspection according to the managers' viewpoint.

Table 4. Relative Importance Index for the Main Safety Inspection with UAS

	Overview	N	W	RII
1	Perimeter fencing	12	51	**0.85**
2	State of all equipment, material, and personnel traffic routes	12	50	**0.83**
3	Rebar and formwork pre assembly area	12	49	**0.82**
4	Material laydown areas	12	47	0.78
5	Parking and emergency evacuation routes	12	45	0.75
6	Waste containers provided	12	44	0.73
7	Erosion control	12	44	0.73
	Medium Altitude view			
8	Workers protected from falling	12	52	**0.87**
9	Safety nets or planked floors	12	51	**0.85**
10	Ramps or runways protected by guardrails and free of obstruction	12	51	**0.85**
11	Workers wearing protective equipment	12	45	0.75
12	Waste removed by chutes closed	12	44	0.73
	Close Up View			
13	Exposed pieces of reinforcing steel capped	12	52	**0.87**
14	Aerial work platform protected by guardrails	12	52	**0.87**
15	Assembly and disassembly of the forms	12	51	**0.85**
16	Area on refueling and maintenance of equipment	12	50	**0.83**
17	Scaffolding is plumb and square, and with cross bracing	12	49	**0.82**
18	Cargo handling area signaling	12	48	**0.80**
19	The stalls for sand, gravel are close to the concrete mixer and winch	12	47	0.78
20	Working areas free of waste and detritus	12	47	0.78
21	Lifting loads protected by fall	12	47	0.78
22	Stocks of materials are close to the winch or cranes	12	45	0.75
23	Isolation of the area of crane operation	12	43	0.72
24	Heavy equipment	12	43	0.72
25	Stocks of materials are protected from rain	12	40	0.67

From the users' viewpoint, the most important requirements of the Overview snap shot are perimeter fencing, state of all equipment, material, and personnel traffic routes and rebar and formwork pre assembly area. For Medium Altitude View snap shot, the most important requirements to monitor are workers protection from falling, safety nets or planked floors, and ramps and runways. From a close up view, the most important requirements for safety inspection are whether stocks of materials are close to the winch or cranes, assembly and disassembly of the forms, cargo handling area signaling, area for refueling and maintenance of equipment, scaffolding is plumb and square, and with cross bracing, and aerial work platform protected by guardrails. Analyzing the results obtained with the association of the visual assets collected with the UAS during site visits, 87% and 58% of the applied items of the Safety Checklist could be visualized in Project A and Project B, respectively (Figure 1).

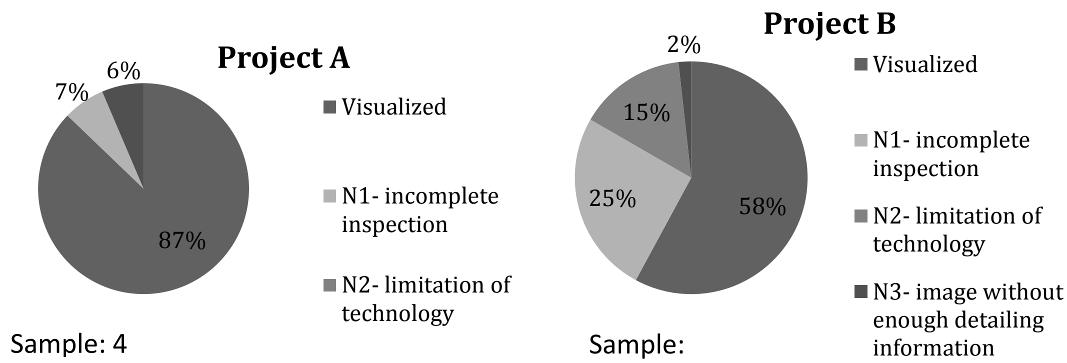

Figure 1. Results of the analysis of the cklist and visual assets

At Project A, the reason that 7% of the safety in ms were not visualized was due to a failure in the inspecting procedure, meaning that despite the fact that the item could be inspected, the information required was not collected during the flight (N1 - incomplete inspection). Examples of items which were not properly inspected during some of the 14 flights are the assembly and disassembly of the forms, lifting loads protected from falling, signaling and isolation of cargo handling area and the stalls for sand, gravel are close to the concrete mixer and winch. These failures happened due to the ample extension of the construction site (150,000m²) and the amount of tasks being developed simultaneously (structure activity cycle time is 10 apartments per day in this project). Also in 6%, the visual asset did not provide enough information for the inspection (N3 - image without enough detailing information), such as a ramps or runways protected by guardrails and free of obstruction, aerial work platform protected by guardrails and lifting loads protected from falling. These two findings indicate a need for a more accurate inspection during flights, including better pilot and observer training.

At Project B, due to the vertical characterization of the building and the focus on façade, 15% of the non-visualized safety inspection items, such as rebar and formwork pre assembly area, ramps or runways protected by guardrails and free of obstruction and stocks of materials, were related to the limitation of technology. Furthermore, 25% of the non visualized safety inspection items were related to incomplete inspection. Some examples of this problem are workers protected from falling (guardrails and toe board, lifeline and harness), workers wearing protective equipment especially in work at high elevation, waste removal by chutes and assembly and disassembly of the forms. Several factors contributed to those failures, as the fact that the protecting net along the façade was a barrier against detailing inspection, the limited altitude of 60m for urban area was a barrier to inspect the top of the 80m tall building, the constrained construction site as well as the strong winds in the location limited the use of the technology for safety reasons.

Analyzing the results of the Safety checklist by snapshot (Figure 2), 95.8% and 88% of the overview safety items applied for Project A and Project B, respectively, could be visualized, which include organization and housekeeping, temporary installation and wastes. For the items proposed for the medium altitude view, including Collective Protective Equipment and Individual Protective Equipment, 96.2% and 71% items applied for Project A and Project B, respectively, could be visualized. However, the inspection related to the close up view was a challenge, mainly for Project B, and it was only possible to inspect 42% of the items. The items 17, 18, 21 and 23 presented in Table 4 were especially difficult to inspect due to the short distance between the neighboring buildings and the building which was being inspected and the limited altitude of 60m for urban area contributed to the non-visualization of the items before mentioned.

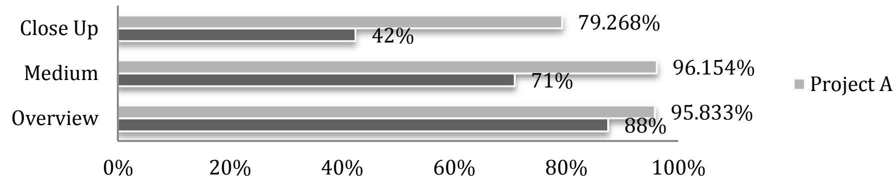

Figure 2: Percentage of safety inspection items visualized by snapshots

UAS EQUIPMENT PERFORMANCE

During the 23 flight tests in Project A and Project B, the average time was 09min08sec per flight, while the autonomy of the battery is between 15-18 minutes. However, for safety reasons, the research team used to start the landing process with 35% of the charge remaining, mainly when the aircraft was at a relatively high altitude or far from to the taking off location. The manufacturer recommends the return of the aircraft with 30% of battery charged. The average number of pictures taken per flight was 57. Depending on the purpose of the flight, more pictures or intense use of video recording were used. In general, the battery autonomy was not a constraint for data collection, since two or three batteries were used for each construction site visit, but the flight plan for each battery was essential to establish the point of interest for data collection. In the 23 flights in Project A and B any stability problem which could reduce the quality of visual assets was noted.

Concerning the reliability of the equipment, during the 23 flight, 15 failures along the system were identified. 11 of these were related to signal loss during flight, and it necessary to use the Return to Home Bottom 6 times, but in the other situations, the system was recovered during the operation. The difficulty to identify GPS satellites before the taking off were noted in two flights in Project B, however soon after the take off, the minimum number of satellites for operation was identified by the UAS. Also, the wind speed (over 5.5m/s) was an impediment for two flights in Project B, despite the fact that the wind speed presented was below the manufacturer's recommendation for flight (10m/s). These two problems happened because the take off location was very constrained and surrounded by tall buildings.

RISKS ASSOCIATED WITH THE UAS TECHNOLOGY

Table 5 presents the users' perception concerning the risks associated with the technology and the influence of the application for safety inspection. According to the survey, for the workers, the degree of privacy invasion was relatively low (1.94), the distraction from working was relatively low (2.00) and the concern about the hazards of falling and collision was relatively low too (1.89). For the managers, the UAS seems easy to use (3.89), has low interference on the project site (1.44), as an example the stoppage of crane or heavy equipment is highly accepted by the workers (4.56) and caused low concern to the hazard of falling or collision. Furthermore, for these managers the adoption of UAS for safety inspection depends on the purchasing cost of equipment, the availability of technical support services nearby, pilot training or hiring a trained person for operation of the UAS and principally the interest and perception of cost benefit of the leadership for its adoption.

Table 5. Workers' and Managers' Perception concerning Risks associated with UAS

Workers' Perception During the flight, what is your degree of...	N	Average	Standard Deviation
Perception of privacy invasion	18	1.94	1.11
Distraction from working	18	2.00	0.69
Concern to hazards of falling or collisions	18	1.89	1.18
Managers' Perception During the flight, what is your degree of...	**N**	**Average**	**Standard Deviation**
Ease using of the UAS by the research team	9	3.89	1.05
Interferences of the UAS in project activities	9	1.44	1.01
Perception of acceptability of the UAS from workers	9	4.56	1.33
Concern to hazards of falling or collisions	9	2.22	0.97

Note: Likert Scale 1 - Very Low up to 5 - Very High.

CONCLUSIONS

The aim of this study was to evaluate the performance of UAV for safety monitoring based on visual assets obtained. A database of 1301 photos and 48min50sec of video recording was collected by flights at two active construction sites in Brazil.

The application of UAV could provide the visualization of 87.2% and 58% of the safety inspection items established in Project A and Project B, respectively, especially concerning organization and housekeeping, temporary installation and collective protective equipment, providing outside information which was not very clear beforehand and with high quality. Based on the visualization of the items, non-conformities related to unsafe conditions and unsafe acts could be identified, such as workers were not using PPE, inadequate guardrails and scaffoldings. Most of the safety inspection items established in this study was considered important by project personnel, with the average of the Relative Importance Index of 0.79, considering 25 safety items. The identification of the reasons for non-visualization of the safety items and the analysis of them by snapshot showed that the size of the site (constrained or wide), the location of the site (high or low population density area), meteorological factors (high wind speed) and pilot and observer training influence the application of the UAV for safety inspection and its accuracy up to this point.

The performance of the equipment during the 23 flight test in terms of flight autonomy, device stability, system reliability, and ease of use met the needs of the DJI Phantom 3 Advanced system for safety inspection according to the flight log data base developed. No major problems were identified during the flights which may cause damage to goods or people, and the application of UAV did not interfere significantly in the construction activities, except the need to stop the crane in Project B during a few flights. Concerns of privacy or risk of collision and falling were not highlighted by project personnel and workers.

The findings point out the potential of UAV application for safety inspection, providing real time information and allowing the visualization of safety issues in remote and difficult areas. There is an expectation that these results can contribute to the decision-making process and increase the effectiveness of the safety inspections, however these impacts have not been measured so far. Therefore, new studies are under development in order to evaluate the impact of the safety inspection with the support of UAV in a systematic way, focusing on fast feedback, allowing immediate corrective actions, reducing the safety inspection time and simplifying the safety inspection process.

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