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HUMAN FACTORS CONSIDERATIONS OF FIRST PERSON VIEW (FPV) OPERATION OF UNMANNED AIRCRAFT SYSTEMS (UAS) IN INFRASTRUCTURE CONSTRUCTION AND INSPECTION ENVIRONMENTS

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Abstract: This paper aims to discuss the most critical human factors and usability aspects involved in First Person View (FPV) operation of Unmanned Aircraft Systems (UAS) in infrastructure construction and inspection environments. The paper starts with the discussion of usability and safety issues, addressing how and to what extent FPV devices enable UAS control beyond visual line of sight (VLOS). The second part discusses the extent to which FPV devices can provide optical and perceptual enhancements as well as improve Situation Awareness (SA) in the context of construction inspection. Whether FPV operation of UAS would improve the processes of capturing and processing of relevant information is the bedrock of this discussion. In order to investigate the User Interface (UI) usability issues from a construction manager standpoint, the authors performed a Heuristic Evaluation (HE), which procedures and results are presented here. At the end, this paper presents a framework of an experimental approach for further study of the aforementioned implications.

1. Introduction

Different types of vehicles have been successfully operated by remote control for the past century. The field of teleoperation of robots has been specially concerned with enabling the remote control of those vehicles over large distances. Space and military agencies have been conducting extensive studies on these platforms (LaValle 2017), particularly on unmanned aircrafts.

The Federal Aviation Administration (FAA) officially defines the terminology "Unmanned Aircraft System (UAS)" instead of "Unmanned Aerial Vehicle (UAV)" – commonly known as "Drone" – because an Unmanned Aircraft (UA) does not carry an onboard crew (FAA 2017a). FAA also issues the mandatory authorizations and regulates the operation of UAS (both for commercial and public purposes) within the United States National Airspace System (USNAS) (FAA Modernization and Reform Act Public Law 112-95 2012; FAA 2013).

A UAS requires three main components to operate remotely: a) human resources including Pilot-in-Command (PIC) and Visual Observer (VO); b) one or multiple platforms (UAs) and c) communication sensors (Wi-Fi signal, cameras, GPS, etc.). During the pre-flight phase, the PIC should decide the type of flight to be conducted among manual, semi-autonomous or fully autonomous. The PIC should also be in charge of all controls of the UAS at the Ground Control Station (GCS) regardless of the flight type. In addition, at least one VO must maintain Visual Line of Sight (VLOS) of the aircraft during its flight. The aircraft communicates with the PIC through the communication sensors and, since it is usually equipped with high-resolution camera, it is capable of sharing visual assets such as still photos and real-time videos during flight.

Most UAS applications have been focusing on military missions (Dalamagkidis et al. 2008) but, recently, this technology has attracted researchers and practitioners from various domains, including from the construction industry. UAS has been used in different fields of civil engineering, including for traffic monitoring (Coifman et al. 2006; Puri et al. 2007), bridge inspection (Gillins et al. 2016; Khan et al. 2015), and construction inspection (Irizarry and Costa 2016; Liu et al. 2016).

Per LaValle (2017), remote operation of robots is often difficult by the need of handling the controller relying on a third person viewing. To overcome this issue, many robots have been equipped with First Person View (FPV) technology. To allow for FPV operation of UAS, the aircraft is equipped with wireless cameras that feed the ground control station with real-time imagery, which can be displayed through a smartphone, tablet or Head Mounted Display (HMD), providing the operator with first person viewing. The HMD is a display device worn by the human operator on his/her head. It is equipped with two inner small displays, one for each eye (binocular HMD), and may also comprise a head movement sensor.

Providing the operator with the awareness of the environment in which the robot navigates (not the human operator itself) would represent the shift from using these platforms for simple data collection towards using them for virtually transporting the human operator into the actual situation. Per LaValle (2017) this is a critical step toward telepresence in the sense that first person viewing would allow operators to see through the “robot’s eyes”, increasing their feeling of “being there”, where the robot is. The feeling of being there, also called “sense of presence”, is the bedrock of any truly immersive experience (Steuer 1992).

FPV operation of UAS might seem useful for construction inspection tasks at first, but the main issue that requires further investigation is whether and the extent to which this technology would be usable as an inspection assistant for construction managers while conducting inspection at the jobsite. More importantly, and considering the future context of application of this system, it should also be able to improve the manager’s Situation Awareness (SA) and his/her ability to make better and faster decisions within shorter periods of time. In this context, this study adopts a user-centered approach to access the system’s usability from the user standpoint, i.e., the extent to which the technology is usable considering the user’s demands in the context of construction inspections.

2. Construction Inspection with UAS

Construction inspection is one of many activities in construction management, usually conducted by construction managers and assistants. It relies mostly on periodical visits to the jobsite such that managers can verify if construction activities adhere to the planned schedule, costs and quality standards. To accomplish that, construction managers walk through the jobsite checking for the quality of ongoing and/or completed construction components, such as structural elements and finishes.

The activity of construction inspection strongly relies on the manager’s ability to diagnose a given situation, draw coherent conclusions from this analysis and suggest appropriate counter-solutions if needed. Making good decisions is, therefore, a critical aspect in construction inspection. In turn, good decisions would rely on the appropriateness and relevance of information about that specific problem or situation. Performing any kind of inspection at the jobsite requires high levels of attention and awareness of the surroundings and of several important details of the construction components being built. In contexts where information cannot be automatically generated or managed such as in the construction environment, reasoning on the quality of Situation Awareness (SA) becomes crucial. Providing construction managers with a communication tool that would allow them to be present at any time in all different areas of the jobsite and to make more informed decisions based on real-time data would be extremely beneficial to construction.

To the extent that only some information captured from a given environment is relevant for a specific purpose, the construction inspection process would benefit from the adoption of user-centered systems able to improve the inspector’s SA. Per Endsley (1995), SA is the process of realizing the surroundings to make decisions based on the assimilated information. It also means having access to relevant and sufficient information to make the right decision towards a predetermined goal. Endsley (1995) precisely defines SA as *“the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.”*

The study performed by Irizarry et al. (2012) revealed that the UAS is a suitable safety inspection tool with a performance subject to the screen size of the user interface (UI), i.e., the display size seems to have an impact on user performance in the inspection task using the UAS. Small-sized displays such as of smartphones would not be very appropriate, whereas large-sized tablet devices would be the best option in terms of usability in inspection tasks. In addition, an appropriate UAS platform for construction inspection purposes must have real-time video streaming function and a reasonably good battery life, of at least 20 minutes of operational duration (Irizarry et al. 2012). The employment of tablets or smartphones is indeed an inexpensive alternative for FPV operation of UAS. In turn, HMDs are a similarly accessible and easy to use technology, with the promise of allowing for a more immersive visualization.

For a construction firm to receive the authorization to operate UAS for commercial purposes, it is mandatory that the company be in accordance to FAA regulations. FAA established two types of UAS flights: a) public operations and b) commercial operations. Each operation requires the Certificate of Waiver or Authorization (COA) (FAA 2017b) and Section 333 Exemption (FAA 2017c) for safe and effective flight within the USNAS. FAA developed the final act (14CFR Part 107) for operation and certification of Small UAS (SUAS) on June 2016, and this rule was effective as of August 29, 2016. This act defines common operational limitations, PIC’s responsibilities, and aircraft requirements, as well as important rules for SUAS operations, such as: a) the platform (SUAS) must be less than 55 pounds (25kg) including payload; b) the platform should not be operated at speed exceeding 87 knots (100 mph); c) the platform should remain within VLOS of the operator; d) daylight operation only; e) no more than 400 feet above ground level (AGL) or remaining within 400 feet of a structure; f) operating within 5 nautical miles of an Airport Reference Point (ARP) and g) if the UAS loses communication or its GPS signal, the platform must return to a predetermined location within the private or controlled-access property (FAA 2016).

Several State Departments of Transportation (DOT) in the United States have been working on UAS implementation on their primary tasks. The Arkansas DOT has explored the use of UAS for real-time traffic monitoring (Frierson 2013); the Minnesota DOT has evaluated the capacity of UAS for automated bridge inspection (Zink and Lovelace 2015); the Utah DOT has investigated the performance of UAS on highway monitoring and assessment (Barfuss et al. 2012). Finally, the authors of this article have been investigating the economical and operational benefits of UAS within Georgia DOT (Irizarry and Johnson 2014) and developing the field-test based guideline for safe and effective use of UAS on GDOT’s operations.

3. FPV Operation of UAS

As discussed before, equipping the aircraft with a camera and the human operator with a visualization device such as a smartphone or tablet (to receive and display the images) would enable FPV operation of UAS. However, when referring to FPV devices, these are mainly comprised by Head Mounted Displays (HMDs), and for that reason FPV operation of UAS is considered in this study as the use of a HMD to operate UAS. FPV operation of UAS (using HMDs) has been widely explored and adopted by hobbyists for aerial sports (in “drone racings”) and military agencies (Hayakawa et al. 2015; Morphew et al. 2004).

Evidence shows that FPV operation of UAS may improve target identification in search and inspection tasks in comparison to using a conventional computer monitor. By providing the user with a full field of view, HMDs may offer increased spatial and situation awareness due to the immersive aspect of the viewing experience offered by them. On the other hand, there is also evidence suggesting that due to side effects of motion sickness, disorientation and increased visual workload, the use of HMD may jeopardize subjects’ ability to identify a target of interest (targeting accuracy) (Morphew et al. 2004).

There are two major ways of coupling FPV devices with UAS. In both situations, the FPV goggles are connected to the remote controller, but with different subjects wearing them. These situations are described below.

1. PIC (controller + FPV) – VO: In the first situation, the PIC flies the UA with a remote controller in his/her hands and wears the FPV goggles at the same time, whereas the VO remains in charge of maintaining VLOS. The tablet device may still be coupled with the controller, but would not participate in the controlling or visualization processes. This configuration ensures that the VO maintains VLOS.

2. PIC (controller + tablet) – VO (FPV): The second situation is having the PIC using the remote controller with a tablet connected to it, which displays the real-time video imagery captured by the UA camera. In this case, the FPV goggles are also connected to the remote controller but are used by the VO, which becomes more like a passenger. Obviously, the VO misses the ability to keep VLOS, being unable to track the aircraft in the sky and let the PIC know in case of any obstacle or hazard situation.

Figure 1 illustrates both situations. The employment of FPV operation of UAS adds two components to the process of construction inspection in the jobsite. Interaction with construction environment is not direct anymore, but intermediated by the FPV-UAS platform (and corresponding user interface).

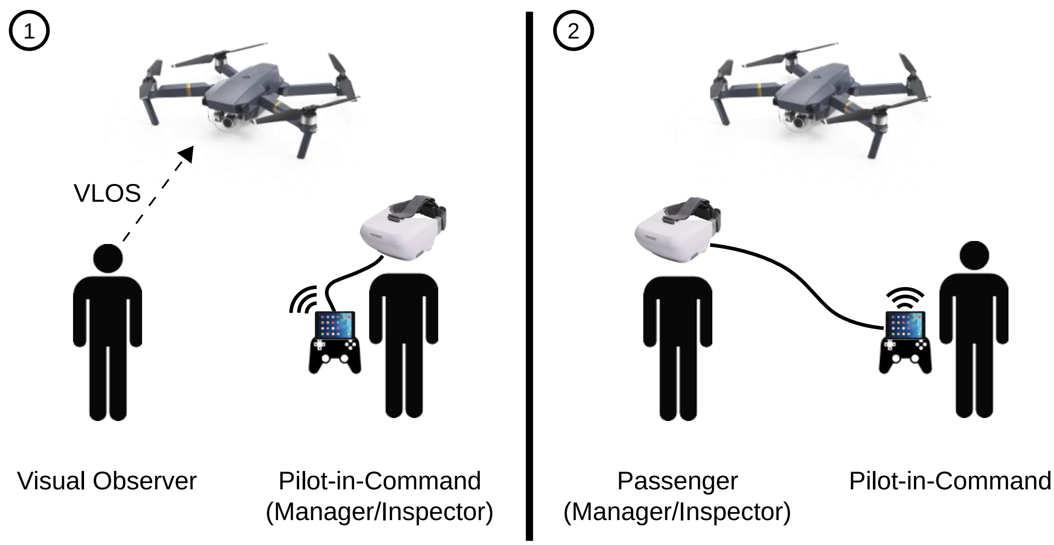


Figure 1: The two possible ways of combining FPV devices with UAS

The first alternative was chosen in this study, for both the Heuristic Evaluation (HE) and the development of the framework for the within-subjects experiment, because it is expected to be the best scenario in terms of usability, and also to keep this study within the recommendations of FAA (the presence of an VO, in this case). In the second alternative, a third person would be needed to be in charge of maintaining VLOS of the UA.

In this scenario, a critical aspect is the quality of PIC's visualization of the video input, which happens through the FPV HMD (the user interface of the system). The evaluation of this aspect is of major importance while in future FPV operations of UAV in construction inspection a construction manager/inspector would solely rely on data received through the system's UI, more specifically, on the visual data on display. Thus, concentrating on the implications from the adoption of this user interface is justified, and is the bedrock for the following tests and discussions.

4. Usability Tests

4.1 Heuristics Evaluation Experiment

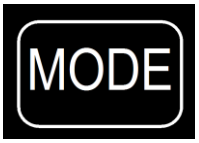
Investigating the performance of the user interface in the context of construction inspection tasks is one critical step in specifying the extent to which this technology would be efficient. In this study, a Heuristic Evaluation (HE) is used for a systematic inspection of the user interface (the HMD screen) of the FPV-UAS system, with the aim of revealing potential usability issues (Dix et al. 2004). More specifically, the goal is to investigate the extent to which the screen icons match the user information needs (the Pilot-in-Command). The inner screen of the HMD utilized in this study is shown in Figure 2 below. The HMD device is named SkyView, fabricated by Yuneec. It features a built-in 5-inch screen with 720p HD of resolution (720 x 1280), 75.5° of field of view and an aspect ratio of 16:9. Three evaluators with advanced knowledge on construction inspection as well as on UAS for construction applications were recruited, and completed the HE independently.

Figure 2: Inner screen of FPV HMD used in the study

The heuristics for expert evaluation presented by Nielsen and colleagues (Dix et al. 2004), also adopted by Irizarry et al. (2012), were expected to guide the evaluators through the assessment process. This set of heuristics works as a checklist of important points that must be reviewed over the evaluation procedure. Six of these heuristics are particularly critical for the present study considering that this analysis is focused on the display features and performance. These are: 1) visibility of system status (keep users informed about system status; provide feedback about system status; speak user's language), 2) match between system and real world (follow real world conventions; make information appear in natural and logical order), 3) consistency and standards (follow platform conventions and accepted standards by having consistent meaning of words, situations or actions in different contexts), 4) recognition rather than recall (make objects, actions and options visible; reduce memory load), 5) aesthetic and minimalist (relevant and needed information only) and 6) help and documentation (Dix et al. 2004).

Upon the system evaluation, the degree of importance (severity) of each identified usability problem is given based on a scale ranging from "0 = Not a problem" to "4 = Usability catastrophe" (Dix et al. 2004). The severity of each usability issue is established based on the investigated application, i.e., on the use of the platform for FPV operation of UAS in construction inspection. Results are shown in Table 1 below.

Table 1: Display icons and correspondent evaluation

Item logo	Name	Description	Issue	Violated heuristic #	Severity rating	Comments
	Flight info	Indication of flight mode in effect (autonomous, manual, etc.)	Repre-senta-tion	1	2	Flight mode shown in text only. A graphic alternative could assist user.
	Satellite info	Satellite signal strength	Data	1	2	Number of satellites not shown.
	Controller info	Signal strength (UA to controller)	Data	1	2	Strength level (%) of connection not shown. This data is important to judge reliability of connection.
	Video info	Wi-Fi signal / transmission rate (UA to display)	Data	1	2	Strength level (%) of video signal not shown. This data is important to judge reliability of connection.
	Battery info	Battery life	Data	1	3	Battery level shown (%) but no indication given as to time of flight remaining with shown level.
	Horizon	Indication of horizon line	Data	1, 2, 3	0 for 1 2 for 2 2 for 3	Symbol represents what is expected but inclination angle value not show.
H: 0.0M	Height	Indication of UA's altitude / elevation	Data	1	1	Terms are abbreviated. Full term in smaller font could better present the term used.
D: N/A	Distance	Indication of UA's distance from controller (in plain view)	Data	1	1	Terms are abbreviated. Full term in smaller font could better present the term used.
Az: N/A	Azimuth	Indication of azimuth	Data	1	1	Terms are abbreviated. Full term in smaller font could better present the term used.
H.S: 0.0M/S	Horizontal Speed	Indication of horizontal speed in effect (m/s)	Data	1	1	Terms are abbreviated. Full term in smaller font could better present the term used.
V.S: 0.0M/S	Vertical Speed	Indication of vertical speed in effect (m/s)	Data	1	1	Terms are abbreviated. Full term in smaller font could better present the term used.

4.2 Framework for Within-Subjects Experiment

The proposed within-subjects experiment aims to investigate the performance of FPV operation of UAS in construction inspection environments. The framework was based on methods used and developed by Irizarry et al. (2012) and Morphew et al. (2004). In the study conducted by Morphew et al. (2004), the objective performance measurement was based on target detection accuracy, besides subjective measurements of workload, fatigue, SA (using the Situation Awareness Rating Technique – SART), and motion sickness in both experimental conditions. Subjects were asked to identify objects as targets, non-targets or distractors. In lieu of using video recordings, the researches opted for exposing subjects to a virtual simulation. Irizarry et al. (2012) conducted a usability analysis of UAS for jobsite safety inspection tasks, which was based on counting the number of hardhats in still pictures of the jobsite through three different display settings, including a large-sized tablet device and a smartphone.

The experiment consists in using the FPV-UAS system as a tool to inspect dynamic images (video recordings) from a typical jobsite. The user's task is to count the number of a specific construction element – a structural component such as a beam, for instance – present in the video take of the jobsite, thus simulating an inspection task, under two different conditions: tablet viewing *versus* FPV HMD viewing (independent variables), as illustrated in Figure 3 below. Note that to stipulate the number of a construction element is one of many inspection tasks usually performed by managers. The hypothesis is that the accuracy of the user in identifying the correct number of construction elements in the video would be higher by using the FPV HMD than with the tablet display. Data analysis consists in performing a quantitative comparison of subjects' performance in identifying and counting the construction components between those two different viewing situations. The main goal is to reveal which one would allow for a higher number of accurate responses (hits).

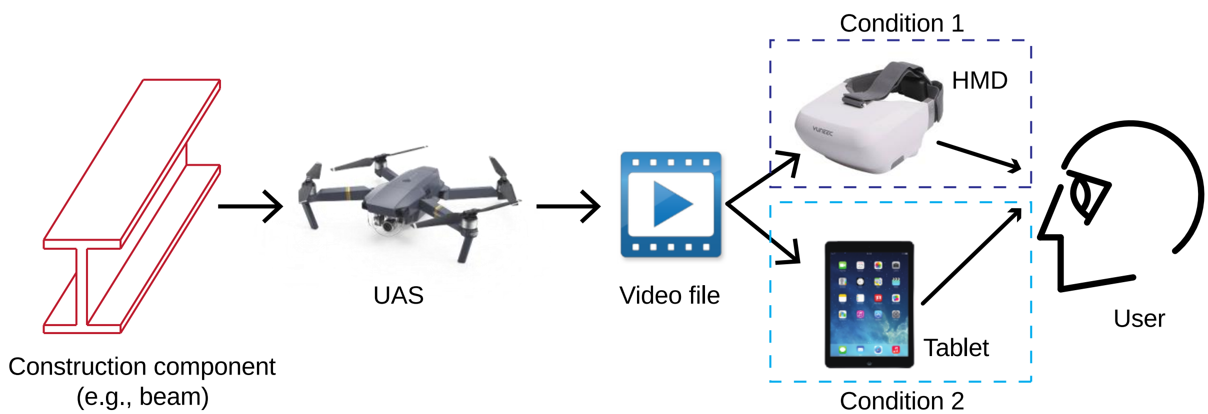


Figure 3: Comparison schema between two viewing conditions

To control the conditions of the experiment and while the goal is to analyze the performance in the identification task rather than of flight capabilities, the flight itself does not need to be performed during the experiment. The entire experiment might be performed inside the controlled environment of a laboratory, using video images of a flight conducted previously. Whether a given user interface – tablet or FPV device – would offer better piloting conditions is a topic for further research, which may include usability testing of the actual task of piloting the aircraft.

In both situations, a video of a flight over a construction jobsite will be presented to participants. Naturally, an actual flight should be performed prior to the experiment so that the images can be collected. This flight should follow a pre-establish flight plan comprising the coordinates in which the UA would stop, stand in front of, and focus on the aimed construction elements to record the video. The goal is to simulate the way an UAS would be used to perform inspection in an actual jobsite. In the first situation, the user will watch the video wearing the HMD, whereas in the second condition the participant will watch the video through the tablet display (not necessarily coupled with the remote controller).

As stated previously, the task consists in counting the number of “a given construction element” (to be determined) while watching a video of a construction jobsite. The video length should not exceed one minute. When the video displaying is over, the subjects should write down their responses in the data collection form provided, which should comprise subjective statements about the viewing experience with each interface, besides the objective questions regarding the number of elements identified. The participants should rate the subjective statements per a 7-point Likert scale. These scores are called Subjective Rating Scores. Using a Likert scale (1=Strongly Disagree to 7=Strongly Agree), participants are asked to rate approximately ten different subjective statements right after they finish the counting task in each situation. It is recommended to use different participants for each interface condition, i.e., subjects who perform the inspection task using the tablet should be different from those who use the HMD in order to avoid any bias effect.

The last step is to perform the statistical analysis on the participants’ accuracy in identifying the construction elements, named the Accuracy Score. This score is obtained by dividing the number of identified elements by the total number of elements shown in the video images times 100, i.e., calculating the percentage of identified elements or hits (dependent variable). A repeated measures analysis of variance (ANOVA) is recommended to establish the significance of the difference between the average percentages of each condition (the average of the individual percentages within each group), and validate the hypotheses that the performance of the user is better when using the FPV HMD in comparison to using the tablet display. The overall framework of the experiment design comprising the usability testing and other components is illustrated in Figure 4 below.

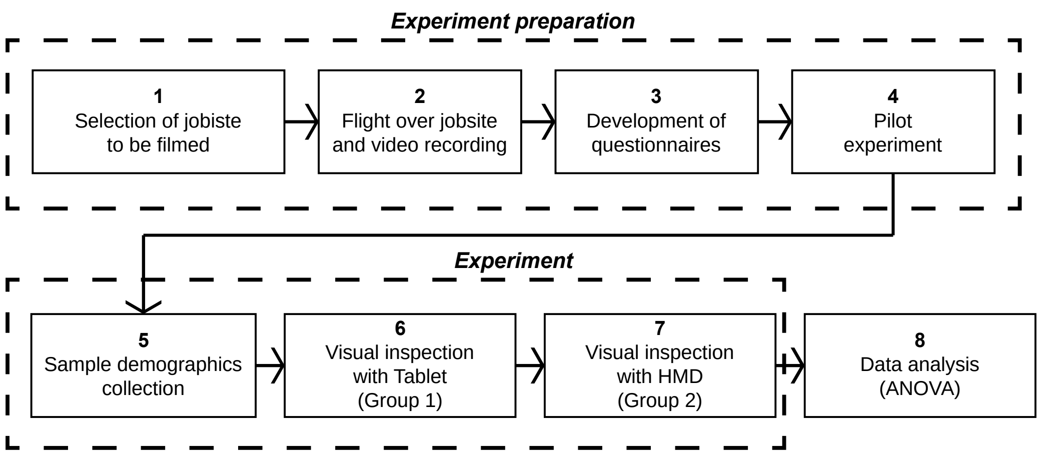


Figure 4: Framework of the proposed experiment design

5. Discussion on Potential Implications

The use of UAS in construction jobsites offers several benefits. For instance, it enables access to hard-to-reach locations on structures under construction, allowing for the inspection of construction elements that would be too complicated otherwise. However, in FPV operation of UAS, a critical issue is how to ensure safety of construction workers in the jobsite during flight. Issues such as workers being hit by the aircraft should be studied and obviously avoided in any deployed system. In the proposed setting of FPV operation of UAS, although the PIC wears the HMD, VLOS is still maintained by the VO. This setting also complies with FAA safety recommendations.

Nonetheless, the PIC might be able to control the aircraft beyond VLOS when wearing the HMD. The possibility of flying beyond VLOS might allow for PICs to stay indoors and/or at a different location. However, it poses several challenges, especially in regards to safety. To ensure safety and allow for better usability in these conditions, the HMD must display more accurate and detailed information of the UA’s location during flight. The heuristic evaluation revealed the lack of critical location information on the screen of the HMD. This information is decisive for enabling FPV operation of UAS in construction jobsites. Displaying the exact UA's location on a dynamic map (GPS positioning) would address this issue and let the PIC knows in real time the accurate UA's location at the jobsite.

The use of the HMD may result in a decrease of the PIC's situation awareness, i.e., he/she may lose SA of his/her local surroundings. When wearing the HMD, the PIC would be immediately transferred – at some level – to the UA's location and experience awareness of the environment that the UA is overflying. At some extent, the FPV HMD puts the operator right in the pilot seat of an aircraft. This loss of local SA and gain of remote awareness (of a remote location) is presumably what makes the experience more immersive. In turn, the increment of immersion in another environment (a stronger sense of *presence*, of "being there") would facilitate the access to relevant and sufficient information of the UA's surroundings, hence, improving the decision-making ability of PIC during construction inspection. In addition, the decrease of perception of noise in the PIC's location could also contribute to enhance attention and focus on the remote environment displayed on the HMD screen. However, the extent to which the increment of immersion provided by the use of the HMD benefits the inspection task in comparison to using conventional displays remains still unknown. The proposed within-subjects experiment aims to check for the existence and to measure the extent of this benefit. In other words, it aims to verify if it is true that the more immersive the experience, the more accurate the user/inspector would be.

Towards the development of more intuitive and interactive ways of FPV operation of UAS, it is expected that future platforms will incorporate additional/complementary immersive features, following the trend of virtual reality systems. Incorporating more intuitive and user-centered flight control mechanisms such as gesture tracking controllers, voice control, and support for Augmented Reality (AR) would significantly expand the range of applications of this platform in the construction industry.

6. Conclusions, Contributions and Future Work

This paper presented and discussed some major implications of FPV operation of UAS in construction inspection. The study looked into some positive aspects and deficiencies of this system, as well as needed safety measures that should be taken when combining these technologies at the jobsite. The heuristics evaluation revealed an overall lack of critical information that should be displayed on the inner screen of the HMD. The user interface issues and respective recommendations were drawn in the light of construction inspection practices. The experiment design framework is an important contribution and provides an adequate usability testing method that could verify the extent of the usefulness of this system in the context of construction processes. The knowledge of whether FPV operation of UAS represents significant improvements on PIC's SA is precisely what would justify the adoption of FPV HMD in construction inspection rather than using non-immersive conventional displays such as tablets or smartphones. Future works include conducting the experiment described in this paper.

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References

Barfuss, S. L., Jensen, A., and Clemens, S. 2012. *Evaluation and Development of Unmanned Aircraft (UAV) for UDOT Needs.* Utah State Department of Transportation.

Coifman, B., McCord, M., Mishalani, R. G., Iswalt, M., and Ji, Y. 2006. Roadway Traffic Monitoring from an Unmanned Aerial Vehicle. *IEE Proceedings - Intelligent Transport Systems*, IET, 11-20**.**

Dalamagkidis, K., Valavanis, K. P., and Piegl, L. A. 2008. Current Status and Future Perspectives for Unmanned Aircraft System Operations in the US. *Journal of Intelligent and Robotic Systems*, **52**(2): 313-329.

Dix, A., Finlay, J., Abowd, G., and Beale, R. 2004. *Human-computer interaction*, 3rd ed., Prentice Hall.

Endsley, M. R. 1995. Toward a Theory of Situation Awareness in Dynamic Systems, Human Factors. *The Journal of the Human Factors and Ergonomics Society,* **37**(1): 32-64. DOI: 10.1518/001872095779049543.

FAA. 2012. *FAA Modernization and Reform Act of 2012. Public Law 112-95,* U.S. Government Publishing Office, Washington, D.C.

FAA. 2013. *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap.* Washington, D.C.

FAA. 2016. *TITLE 14 CFR PART 107 - Small Unmanned Aircraft Systems.* U.S. Department of Transportation.

FAA. 2017a. “Unmanned Aircraft Systems (UAS)”. https://www.faa.gov/uas (accessed February 17, 2017).

FAA. 2017b. “Certificate of Waiver or Authorization (COA)”. https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/coa (accessed February 17, 2017).

FAA. 2017c. “Section 333”. https://www.faa.gov/uas/beyond_the_basics/section_333 (accessed February 17, 2017).

Frierson, T. 2013. *Use of Unmanned Aerial Vehicles for AHTD Applications: Studying Visual Aids to Assist in Corridor Analysis*. Arkansas State Highway and Transportation Department.

Gillins, M. N., Gillins, D. T., and Parrish, C. 2016. Cost-Effective Bridge Safety Inspections Using Unmanned Aircraft Systems (UAS). *Proceeding of Geotechnical and Structural Engineering Congress 2016*, 1931-1940.

Hayakawa, H., Fernando, C. L., Saraiji, MHD Y., Minamizawa, K., and Tachi, S. 2015. Telexistence UA: Design of a Flight Telexistence System for Immersive Aerial Sports Experience. *Proceedings of AH'15 - Augmented Human International Conference,* 171-172.

Irizarry, J., Gheisari, M., and Walker, B. 2012. Usability Assessment of Drone Technology as Safety Inspection Tools. *Journal of Information Technology in Construction (ITcon),* **17**: 194-212.

Irizarry, J., and Johnson, E. N. 2014. *Feasibility study to determine the economic and operational benefits of utilizing unmanned aerial vehicles (UAVs).* Georgia State Department of Transportation.

Irizarry, J., and Costa, D. B. 2016. Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks. *Journal of Management in Engineering*, **32**(3).

Khan, F., Ellenberg, A., Mazzotti, M., Kontsos, A., Moon, F., Pradhan, A., and Bartoli, I. 2015. Investigation on Bridge Assessment Using Unmanned Aerial Systems. *Proceeding of Structures Congress 2015*, 404-413.

LaValle, S. M. 2017. *Virtual Reality*, Cambridge University Press, University of Illinois, IL, USA.

Liu, J., Jennesse Jr, M., and Holley, P. 2016. Utilizing Light Unmanned Aerial Vehicles for the Inspection of Curtain Walls: A Case Study. *Proceeding of Construction Research Congress 2016*, 2651-2659.

Morphew, M. E., Shively, J. R., and Casey, D. 2004. Helmet Mounted Displays for Unmanned Aerial Vehicle Control. *Proceedings of SPIE - The International Society for Optical Engineering,* **5442**: 93-103. DOI: 10.1117/12.541031.

Puri, A., Valavanis, K., and Kontitsis, M. 2007. Statistical Profile Generation for Traffic Monitoring Using Real-time UAV based Video Data. *Proceeding of MED'07 - Mediterranean Conference on Control & Automation 2007*, IEEE, Athens, Greece, 1-6.

Steuer, J. 1992. Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication*, **42**(4): 73-93. DOI: 10.1111/j.1460-2466.1992.tb00812.x.

Zink, J., and Lovelace, B. 2015. *Unmanned Aerial Vehicle Bridge Inspection Demonstration Project*. Minnesota Department of Transportation, Research Services & Library.