Effect of Illumination on Human Drone Interaction Tasks: An Exploratory Study

Mustafa Ozkan Yerebakan, Shuai Hao, Kun Xu, Masoud Gheisari, Idris Jeelani, Boyi Hu
University of Florida

With recent changes by the Federal Aviation Administration (FAA) opening the possibility of more areas for drones to be used, such as delivery, there will be increasingly more interactions between humans and drones soon. Although current human drone interaction (HDI) investigate what factors are necessary for safe interactions, very few has focused on drone illumination. Therefore, in this study, we explored how illumination affects users' perception of the drone through a distance perception task. Data analysis did not indicate any significant effects in the normal distance estimation task for illumination or distance conditions. However, most participants underestimated the distance in the normal distance estimation task and indicated that the LED drone was closer when it was illuminated during the relative distance estimation task, even though the drones were equidistant. In future studies, factors such as the weather conditions, lighting patterns, and height of the drone will be explored.

INTRODUCTION

Since the mid-2010s unmanned aerial vehicles, or more commonly known as drones have dramatically risen in popularity, from an initial number of 600,000 during the first year of registration in 2016 to roughly 1.8 million in 2021 per the FAA (FAA, 2021). Most of these drones are personal drones but about a quarter of these drones are registered as commercial. Commercial drones are being used in many fields, such as real estate, agriculture, construction, and mining. They are mainly used for inspection and surveillance tasks, due to their ability to access remote locations and record high-quality footage with their mounted cameras. However, soon, drones will also be used for delivery with numerous companies such as Amazon in the US (Palmer, 2020) and JD in China have started limited drone delivery systems (McNabb, 2019). The adoption rate of commercial drones has been increasing rapidly. The industry is predicted to grow from a $1.590 billion market size globally in 2019 to $8.527 billion in 2027 with the North American market dominating the market share (Fortune Business Insights, 2020).

As the interest in drones grows rapidly (Insider Intelligence, 2021), a new area of human machine interaction has emerged called human drone interaction (HDI). Like its close counterpart human robot interaction (HRI), it concerns the requirements necessary to improve the interaction between humans and drones (Tezza and Andujar, 2019). The emergence of these studies coincides (and even prompted) with the FAA directive in late 2015, which required all drone operators to register their drones with the FAA and eased restrictions in commercial drone usage, with 141 out of 150 studies listed under "human drone interaction" in IEEE Xplore is between 2016-2020 (IEEE Xplore). One of the first studies, Cauchard et al. explored gesture, sound-based interaction methods between an autonomous drone and a person (Cauchard et al., 2015). They have found that the interaction between the drone and the human resembles the interaction between humans and humans and pets. This led to a good number of gestures to have high agreement scores with the tasks associated. They also reported high levels of perceived safety among the participants, something they did not expect. Abtahi et al expanded on the modalities to include touch by enclosing the drone within a mesh cage (Abtahi et al., 2017). They reported that when the drone was in the mesh cage (called "safe drone") a majority of the interactions were touch based and 83% of participants felt safe touching the "safe" drone. Researchers also investigated possible user interfaces for multimodal HDI (Fernandez et al., 2016), the levels of human control of the drone (Christ et al., 2016), and even the influence of culture in gestures used to interact with the drone (Jane et al., 2017).

One factor that almost all HDI studies have discussed to a degree was safety and how safe the participants felt interacting with the drone and how distances were correlated to perceived safety. Abtahi et al. for example reported interacting with a "safe" drone resulted in a much lower mental workload (Abtahi et al., 2017). Cauchard et al. observed that as participants became more comfortable with the drone, the distance between them and the drone decreased (Cauchard et al., 2015). Even though proxemics has been understood as a factor in these studies, one important aspect of proxemics has been insufficiently explored, perceived distance of the drone. One of the only studies that have included perceived distance as a factor was by Wojciechowska et al. (Wojciechowska et al., 2019). They focused on drone related aspects such as drone speed, the drone's direction of approach, and the drones positioning. Although the main findings of the study and the discussion is to establish a "taxonomy" for human-autonomous drone interaction, in the proximity section they report that the distances of the drone had significant effects on the perceived distance of the participants. This finding although significant, cannot be generalized as the study was conducted indoors whereas most drones operate outdoors.

Light signals have been traditionally used in the aviation industry for many years and have been utilized in other human machine interaction studies (Hensch et al., 2019; Baraka and Veloso, 2018). In the HDI domain, however, only a handful of studies have investigated the use of lighting. In one of these studies, Szafir et al. used LED strips to test different lighting pattern configurations to increase the movement legibility of drones (Szafir et al., 2015). This study shows the potential of using LED based lighting systems to better inform the observers about where the drone intends to go, yet the relatively short distances in the experiment and the fact that the experiment is held indoors warrants additional experiments doors. Another study by Doran et al. proposed an LED based illumination system that would communicate the drone's movement and system condition. To our knowledge, this is the only proposal that has considered LED based illumination to convey drone related information to observers.

Thus, in this exploratory study, we investigated the effects of illumination via an LED system on distance perception in outdoor environments. We hypothesized that there would be a significant difference between the perceived distances of unilluminated and illuminated drones, and we expected the participants to underestimate the distances for the illuminated drone as it would catch the attention of the participant more. A broader goal of this study is to help establish guidelines for industry and the FAA as the current regulations regarding drone lighting are vague and quite limited (the requirement is to have anti-collision lighting for operations after sundown).

METHODS

Participants

Nine participants (5M, 4F) were recruited from the local student population. The participants were undergraduate and graduate students from the local university population. All participants were aged between 18-44 with 5 participants being in the 18-24 and 4 participants being in the 25-44 age range. Most participants had not flown a drone before. Only 2 out of 9 indicated that they had flown a drone before. The experiment protocol was approved by the local university Institutional Review Board (#IRB202002748). People who experienced COVID-like symptoms or had a positive COVID test in the last 2 months were not recruited due to safety reasons. The participants gave their consent virtually before arriving at the experiment site.

Experiment Design

There were two parts of the experiment, each part corresponding to a different task (Figure 1). The main purpose for task one was to see whether illumination had any effect in perceiving two equidistant drones. The main purpose for task two was to see if illumination affected the accuracy of the numerical horizontal distance estimation. The first task of the experiment was the relative distance estimation task. In this task, the participants were asked to tell which of the two flying drones were closer to them. The second task of the experiment was the normal distance estimation task, in which the participants gave a numerical value on their horizontal distance estimation. As the primary research question was to see if an illumination system influences drone perception, there was only one independent variable, whether the LED equipped drone was lit up or not. We investigated the effects of illumination on two dependent variables. Participant performance was measured by the accuracy of the distance estimations the participants made and the time they spent on making their estimation. The second category of the dependent variable was the cognitive workload (i.e. task difficulty), which was measured by deploying the NASA TLX questionnaire (after each part of the experiment). We also wanted to verify whether the distance of the drone would influence the accuracy, hence we included the distance from the participant as a secondary independent variable.

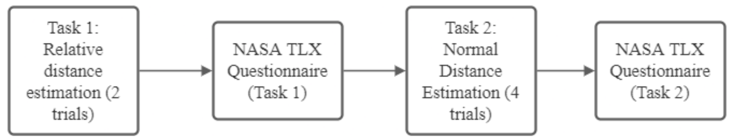

Figure 1. The Summary of the Experiment Protocol.

Apparatus and Experiment Layout

In this experiment, two DJI Phantom 3 Standard (Shenzhen, China) drones were used (Figure 2). One of the drones was fitted with a LED light strip that encircled the drone's skids while the other drone did not have any illuminations.

Figure 2. Two drones that were used in the experiment. One on the right is the LED drone and on the left the normal drone.

The experiment was held in an open field with no landmarks close by. The layout itself consists of eight points located at the cardinal directions of a compass and an additional point at the center as the participant's vantage point (Figure 3). Apart from the opposite points in the layout (for example points in the East-West direction), all points had a different distance from the vantage point. The points were identified by stakes with reflective ends but were concealed with surrounding grass to keep the points hidden from the participants. Apart from the placement of the vantage point, the participants did not know anything about the experiment layout.

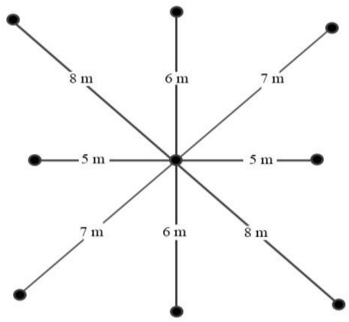

Figure 3. Experiment Layout. The upper part of the layout represents the north. Only 5m and 6m points were used in this experiment.

Experiment Protocol

Before the experiment started the participants were asked to fill out the demographics questionnaire which included age, gender, and whether they had flown a drone before. Then they filled out the drone knowledge test which measured the participants' existing knowledge about drone operations and regulations in the US. The questions were based on similar tests that were developed for drones (Reddy and DeLaurentis, 2016; Aydin, 2019).

When the participants arrived at the experiment site, they were briefed on the experiment procedure and asked to stand on top of the vantage point indicator. When they were positioned, the drones were launched, and the first half of the experiment started. The participants were asked to close their eyes while the drones were positioned into their appropriate hovering points. This was done to ensure that the participants were unaware of the experiment layout. When the drones were positioned, the participants opened their eyes. The pilot in command asked the participants whether the two drones that hovering were at the same height and adjusted the altitude of the drones according to the participants' direction. When the drones were level, the participants indicated to the second experimenter that they were satisfied, and second experimenter started the timer. The participants again let the second experimenter know when they completed their estimation. In total, there were six trials, two for the first half and four for the second half. After each part, the participants filled the NASA TLX questionnaire for the particular task. After the experiment ended the drones were landed and the participants were briefed about the experiment layout and the purpose behind the design.

Data Processing and Analysis

The main independent variable was whether the drone was illuminated or not. As mentioned before, to increase the validity of our potential findings, in addition to the illumination variable we also added one independent variable: the distance of the drone from the original point. For the distance variable, there were 2 levels, 5 meters, and 6 meters. The main dependent variable was the accuracy of the participant respective of the actual distance. Due to the exploratory nature of the project, no statistical analysis was conducted. Instead, simple descriptive analysis was performed on all measurements.

RESULTS

Tables 1 and 2, show the results for the first and second parts of the experiment, specifically the error rate of the participants for the normal distance estimation task and which drone they deemed closer for the distance estimation task. Table 3 shows the NASA TLX scores of both trials. The demographic questionnaires indicated that the participants were largely uninformed when it comes to drone relate regulations and a large majority of them never flew a drone before.

Table 1. Responses for Task 1

	Participant Guess		
Condition	Normal Drone Closer	Drones Are Equidistant	LED Drone Closer
Illuminated	1	2	6
Unilluminated	4	2	3

Table 2. Error Rates for Task 2

Error Rate for Unilluminated Drone (Percentage)	Error Rate for Illuminated Drone (Percentage)	P-Value
22.5 (26.2)	14.77 (58.00)	0.461
Error Rate for 5 Meters (Percentage)	Error Rate for 6 Meters (Percentage)	P-Value
12.89 (55.39)	24.37 (30.73)	0.276

Guesses for the Part 1 of the Experiment

A majority of the participants did not accurately depict the drones were equidistant with only 2 participants each for both illuminated and unilluminated LED drone conditions indicating the drones were equidistant (Table 1). For the illuminated condition 6 out of 9 participants indicated that the LED drone was closer than the normal drone, with only one participant mentioning the normal drone was closer. When the LED drone was illuminated, the results were much less lopsided, with 4 people indicating the normal drone was closer and 3 the LED drone.

Error Rates for Part 2 of the Experiment

For the error rate, the average value for the unilluminated condition was 22.5 (26.2) percent and for the illuminated condition, it was 14.77 (58) percent (Table 2). As for distance-based error rates, for 5 meters, the error rate was 12.89(55.39) percent and for 6 meters it was 24.37 (30.73) percent. The p values were 0.461 and 0.276 respectively.

NASA TLX Scores for Both Parts of the Experiment

Comparing the scores for both parts there are some observable increasing and decreasing trends in the values that complement each other, yet like the results in the first two tables, none of them was significant (Table 3). The responses for how mentally demanding the task were and how hard the participants had to accomplish both increased, from 2.44 (1.13) to 3.11 (1.69) and from 2.4 (1.13) to 2.78 (1.09) respectively. Interestingly, although high levels of inaccuracies were reported in both tasks, the participants thought they were successful with their performance with scores of 5.67 (1.12) and 5.56 (1.74) for part one and two, respectively.

DISCUSSION

In this exploratory study, we investigated the effects of an LED illumination system on the perception of the drone, namely its perceived distances from an observer. This was done by firstly letting participants give a judgment about which one of the two drones seemed "closer" to them and secondly by asking them to give a numerical estimation for the horizontal distance between them and the LED equipped drone. We also evaluated the task difficulty of discerning relative distance between two drones versus giving a numerical guess of a singular drone.

For the relative distance estimation task, we detected a clear preference towards the LED drone when the LED drone was illuminated, compared to the unilluminated condition where the responses were more evenly distributed. We postulated that it occurred because the participants did not have a clear heuristic methodology for decision-making and hence purely guessed which drone was "closer". This postulation was verified by asking participants how they made their decision. Most participants commented that they "felt" that one drone was closer than the other. When giving her reasoning on why she thought the LED drone was closer in the illuminated condition, one participant mentioned that the LED drone looked "bigger". What is interesting, however, is that participants reported high levels of confidence in their results, even though most of their estimations were wrong.

For the normal distance estimation task, we did not detect any significant differences that were caused by the introduction of illumination. This was also true for the distance between the drone and the participant. We observed that apart from one participant, all participants consistently underestimated the drone's horizontal distance. This was a result that we expected, as humans have been found to underestimate distances of objects that are farther away from them (Volcic et al., 2013; Zahorik et al., 2005; Button et al., 2016).

For the NASA TLX scores, we also did not observe any significant differences. This could be because of the difficulty of the distance perception task itself. The existence of depth cues and the number of the cues have been found to increase the accuracy of depth perception (Kunnapas 1968; Proffitt and Caudek, 2003). Without any additional depth cues in the air, it is plausible that the participants found both tasks difficult, even though task 1 did not require participants to give a numerical estimate of the distance, only relative.

With the recent ruling by the FAA easing restrictions on certain drone operations, commercial drone usage, especially in the delivery sector, is expected to increase (CNN, 2020). With drones starting to occupy spaces that are inhabited by humans, whether it is residential areas for drone delivery or a construction site for surveying work, safety becomes a significant concern, especially in outdoor settings.

Ensuring the participants feel safe while interacting with or being around drones is not merely an ethical commitment In terms of technological acceptance and intention to use, perceived safety plays an important role. Perceived safety was found to be influential in the intention of using autonomous vehicles (Montoro et al., 2019; Zoellick et al., 2019). Perceived risk, closely related to perceived safety, affected the intention to adopt web-based applications, such as e-commerce (Chiu et al., 2014; Salam et al., 2003) and online banking (Lee,2009).

There were several limitations of this study that needs to be addressed. Perhaps the most significant limitations are the sample size and the number of repetitions for each trial. With many variables and a small dataset, the significance of our results was inevitably affected. Another limitation is that for this study, we did not consider the effects of weather for distance perception, which might have affected the participants' judgment differently depending on the cloud cover. Also, we did not have a robust system to ensure the drones were level, meaning the height of the drones was equal as the phone application was observed to be inaccurate. We tried to mitigate this by asking the participants to let us know if the drones appeared level, but a more robust solution is needed. Finally, more distance variety is needed to test the effects.

In future studies, in addition to mitigating the limitations mentioned, we plan to expand our analysis into multiple areas that we think are relevant in the context of drone operations. The first area is investigating not just the effects of illumination but different configurations of illumination, such as different lighting patterns and different colors. The effects of different lighting patterns have already been investigated in the context of movement legibility (Szafir et al., 2015) however that study was conducted indoors which limits its external validity. Doran et al. also proposed an LED system to communicate system condition and direction of flying (Doran et al. 2020) yet the design has not been tested yet.

Investigating the effects of different colors is especially important as its interaction effects with the levels of sunlight may affect the drone's visibility itself and obscure the lighting pattern and color that is used to communicate which direction the drone is headed. The noise of the drone is another element that needs to be investigated regarding humans' perception of distance. Finally, there is also the important domain of visual angle that needs to be considered as it is a critical element in distance perception (Proffitt, 2006).

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No.2024656. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Tezza, D., & Andujar, M. (2019). The state-of-the-art of human–drone interaction: A survey. *IEEE Access*, *7*, 167438-167454.

Insider Intelligence. (2021, February 04). Drone market outlook IN 2021: Industry growth trends, market stats and forecast. Retrieved February 22, 2021, from https://www.businessinsider.com/drone-industry-analysis-market-trends-growth-forecasts

Hensch, A. C., Neumann, I., Beggiato, M., Halama, J., & Krems, J. F. (2019, July). How should automated vehicles communicate?–Effects of a light-based communication approach in a Wizard-of-Oz study. In *International conference on applied human factors and ergonomics* (pp. 79-91). Springer, Cham.

Baraka, K., & Veloso, M. M. (2018). Mobile service robot state revealing through expressive lights: formalism, design, and evaluation. *International Journal of Social Robotics*, *10*(1), 65-92.

Fortune Business Insights. (2020). Small drone market Size, share & COVID-19 impact analysis, by TYPE (Fixed Wing, ROTARY wing, and Hybridwing), By End-use (Military & Defense, consumer, and commercial & Civil), by Maximum take-off Weight (less than 5 Kg, 5-25 kg, and ABOVE 25-150 kg), and Regional Forecast, 2020-2027.

McNabb, M. (2019, January 17). JD, China's e-commerce GIANT, making deliveries to remote areas by drone https://dronelife.com/2019/01/16/jd-chinas-e-commerce-giant-making-deliveries-to-remote-areas-by-drone/

Palmer, A. (2020, August 31). Amazon wins FAA approval for Prime air drone delivery fleet https://www.cnbc.com/2020/08/31/amazon-prime-now-drone-delivery-fleet-gets-faa-approval.html

Cauchard, J. R., E, J. L., Zhai, K. Y., & Landay, J. A. (2015, September). Drone & me: an exploration into natural human-drone interaction. In *Proceedings of the 2015 ACM international joint conference on pervasive and ubiquitous computing* (pp. 361-365).

Abtahi, P., Zhao, D. Y., E, J. L., & Landay, J. A. (2017). Drone near me: Exploring touch-based human-drone interaction. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, *1*(3), 1-8.

Fernandez, R. A. S., Sanchez-Lopez, J. L., Sampedro, C., Bavle, H., Molina, M., & Campoy, P. (2016, June). Natural user interfaces for human-drone multi-modal interaction. In *2016 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 1013-1022). IEEE.

Christ, P. F., Lachner, F., Hösl, A., Menze, B., Diepold, K., & Butz, A. (2016, October). Human-drone-interaction: A case study to investigate the relation between autonomy and user experience. In *European conference on computer vision* (pp. 238-253). Springer, Cham.

Jane, L. E., Ilene, L. E., Landay, J. A., & Cauchard, J. R. (2017, May). Drone & Wo: Cultural Influences on Human-Drone Interaction Techniques. In *CHI* (pp. 6794-6799).

Montoro, L., Useche, S. A., Alonso, F., Lijarcio, I., Bosó-Seguí, P., & Martí-Belda, A. (2019). Perceived safety and attributed value as predictors of the intention to use autonomous vehicles: A national study with Spanish drivers. *Safety Science*, *120*, 865-876.

Zoellick, J. C., Kuhlmey, A., Schenk, L., Schindel, D., & Blüher, S. (2019). Assessing acceptance of electric automated vehicles after exposure in a realistic traffic environment. *PloS one*, *14*(5), e0215969.

Chiu, C. M., Wang, E. T., Fang, Y. H., & Huang, H. Y. (2014). Understanding customers' repeat purchase intentions in B2C e-commerce: the roles of utilitarian value, hedonic value and perceived risk. *Information Systems Journal*, *24*(1), 85-114.

Salam, A. F., Rao, H. R., & Pegels, C. C. (2003). Consumer-perceived risk in e-commerce transactions. *Communications of the ACM*, *46*(12), 325-331.

Lee, M. C. (2009). Factors influencing the adoption of internet banking: An integration of TAM and TPB with perceived risk and perceived benefit. Electronic commerce research and applications, 8(3), 130-141.

Wojciechowska, A., Frey, J., Sass, S., Shafir, R., & Cauchard, J. R. (2019, March). Collocated human-drone interaction: Methodology and approach strategy. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 172-181). IEEE.

Szafir, D., Mutlu, B., & Fong, T. (2015, March). Communicating directionality in flying robots. In *2015 10th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 19-26). IEEE.

Volcic, R., Fantoni, C., Caudek, C., Assad, J. A., & Domini, F. (2013). Visuomotor adaptation changes stereoscopic depth perception and tactile discrimination. Journal of Neuroscience, 33(43), 17081-17088.

Zahorik, P., Brungart, D. S., & Bronkhorst, A. W. (2005). Auditory distance perception in humans: A summary of past and present research. ACTA Acustica united with Acustica, 91(3), 409-420.

Button, C., Schofield, M., & Croft, J. (2016). Distance perception in an open water environment: Analysis of individual differences. Attention, Perception, & Psychophysics, 78(3), 915-922.

Kunnapas, T. (1968). Distance perception as a function of available visual cues. Journal of experimental psychology, 77(4), 523.

Proffitt, D. R., & Caudek, C. (2003). Depth perception and the perception of events. Handbook of psychology, 213-23

Table 3. NASA TLX Results from both Trials

Prompt	Part I (Relative Distance Estimation)	Part II (Normal Distance Estimation)	P-Values
How mentally demanding was the task?	2.44 (1.13)	3.11 (1.69)	0.332
How physically demanding was the task?	2.11 (1.96)	2.33 (1.5)	0.738
How hurried or rushed was the pace of the task?	3.11 (1.45)	3 (1.32)	0.760
How successful were you in accomplishing what you were asked to do?	5.67 (1.12)	5.56 (1.74)	0.849
How hard did you have to work to accomplish your level of performance?	2.4 (1.13)	2.78 (1.09)	0.438
How insecure, discouraged, irritated, stressed and annoyed were you?	2.33 (1.41)	2.11 (1.27)	0.594