Investigating Human Comfort with Unmanned Aerial Vehicles Approaching from Different Heights

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Abstract -- **This paper investigates how people react to unmanned aerial vehicles (UAVs) when approached by small UAVs at different heights. The current research with sUAVs has been limited so far. Previous work has focused on how humans interact with unmanned ground vehicles compared to aerial vehicles. We extended this work with different aerial vehicles at varying heights to see how these variables would affect the participants' comfort. These results will contribute to understanding of social, collaborative, and assistive robots, allowing people to be more comfortable integrating drones into society.**

I. INTRODUCTION

This work will contribute to further understanding of how humans perceive small Unmanned Aerial Vehicles. UAVs have great potential to be a common element in social situations. The specific research question being investigated is: *How does the height of an aerial vehicle impact the comfort of people interacting with the robot?* To understand this question, we are interested in the distance at which people stop an approaching robot along with qualitative responses about the experience.

This paper introduces claims about the comfort of participants when interacting with a sUAV at the height of 3 feet, 5 feet, and 6.75 feet. These claims will contribute to the foundation of human-sUAV interactions. This work will uniquely test how the three different heights will influence the participant's apprehension or comfort towards the vehicle.

II. RELATED WORK

This section will cover related work in human-sUAV interaction and personal space with both human and robot agents in order to situate the current work.

A. *Human-sUAV Interaction*

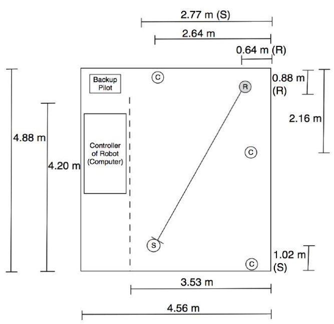
There has been limited studies to date that evaluate how humans view personal space with free flight sUAVs, but there has been a handful of simple human-robot interaction studies. Some studies have looked at gestural control and how that can progress the human-robot relationship. Studies such as [1] have started to look at the personal space issue in human-robot interaction. It has been found that many of the participants assume the sUAV is much safer than it is in reality and have often allowed the vehicle to approach to a close distance. Work may now need to focus on how to alert passerbys of the dangers of these aerial vehicles to prevent safety hazards.

B. *Personal Space*

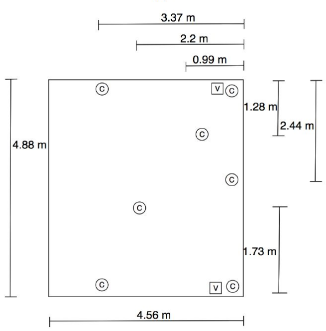
Human-human studies on personal space have often been conducted using Kinzel's stop-distance technique [2] in order to gage when a person feels uncomfortable. There have been many studies that change the independent variable in order to see what truly affects a participant's personal space boundaries. These variables can be used when now testing human-sUAV interactions, as the hope is to assimilate UAVs into society beside humans.

III. HUMAN-ROBOT DISTANCING TESTBED

The experimental setup of Acharya, Bevins, and Duncan [1] was replicated to conduct the experiment. Trials in [1] compared a ground vehicle with an aerial vehicle, so the path was useful for the UAVs at different heights. A moveable wall was used to replicate the room size of the experiment. Ten Vicon cameras were installed to track the flight path of the vehicle using motion capture. Fig. 1 shows a layout of the experiment including the room size and the flight path of the vehicle.

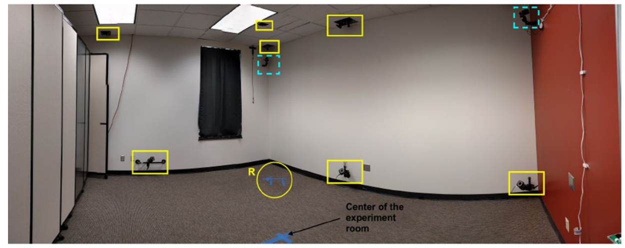


(a)



(b)

Fig. 1: Diagrammatic top view of experiment room, with top cameras (1a) and bottom cameras (1b). Left and bottom measurements reflect room dimensions and length of the movable versus stationary wall. Top and right measurements reflect distance of Vicon cameras, starting point of the robot (R), and position of subject (S) from the corner.



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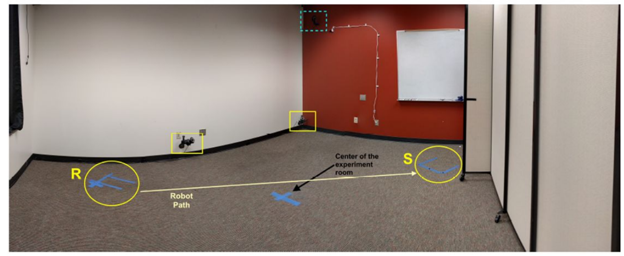


(b)

Fig. 2: Experiment room from subject view (2a) and opposite corner (2b). Vicon cameras are shown in solid rectangles, video cameras in broken rectangles, and the starting position of the robot (R) and participant (S) are shown in circles.

As the experiment is set up in [1], the room measured 4.88m x 4.56m, which was partitioned in two sections with a moveable wall to make the testing space 4.88m x 3.56m. The ceiling height was 2.74m. The computer control system was in the enclosed room, which measured 4.88m x 1.03m. The backup pilot and a live video feed of the experiment was also included in the smaller section. The Vicon motion capture cameras were arranged to view the vehicle at all times during the flight path. One Sony CX440 video camera was set up in a corner to capture the live video. Pictures of the experiment space is provided in Fig. 2, where the Vicon cameras are highlighted by solid rectangles and the video camera is highlighted inside a cyan rectangle.

An additional component adapted from Acharya, Bevins, and Duncan was the participant interaction and a script. The script was modified for use with robots. The following script was read to participants before the study began:

> "A robot will approach slowly from the mark near the opposite corner of the room, it will launch and then come slightly forward and turn, the robot will then hover and proceed to come towards you. You are requested to stay in place, keep your hands by your side, like this, and say 'stop' when the robot's closeness begins to make you feel uncomfortable. After you say stop, the robot will stop at that position, go back to the center of the room and land."

IV. HUMAN-sUAV INTERACTIONS

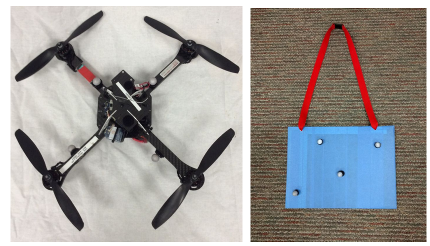
The goal of this study was to directly compare personal space with a sUAV from different approach heights. This section will describe the robots, hypotheses, study design, participants, and procedures.

A. Hypothesis

The primary hypothesis in this study was that people would display different levels of comfort through the distance at which they stopped the robot, the difference in affective state reported after interactions, and qualitative reports.

B. Participants

Participants were recruited through flyers posted around the campus. The study consisted of 21 participants(12 male, 9 female). Few participants reported prior interactions with remote controlled aircraft. The robot experience questions were phrased to solicit interactions in a broad context. The participant answered the question: "Have you ever interacted with a robot?" followed by a "Yes" and "No" to circle. A follow up question was asked, instructing the participant to indicate which type of robot they have interacted with. The types included "a consumer robot", "an industrial robot", "an educational robot", and "an entertainment robot", with each listing a brief example of what common robots would fall into each category.



(a) (b)

Fig. 3: Materials used for interactions with participants, AscTech Hummingbird (3a) and participant fiducial marker to track their locations (3c).

C. Experimental Materials

The robot system used in this work was the Ascending Technologies (AscTech) Hummingbird (Fig. 3a). This sUAV is a quadrotor weighting at 368 grams (0.81lbs) with a diameter of 0.54m (21in) which is widely used for research. The system was controlled by a ROS script, in coordination with a Vicon motion capture system to approach the person. The reduce variability, the vehicle's path was scripted with set starting and ending points, with the participant standing in a designated position. The participant was wearing a marker (Fig. 3b) that was tracked using the same Vicon system as the sUAV. Participants were protected from collision through the use of both a software controller and a backup pilot to take control of the vehicles if needed. Distance from robot to the participant was measured by the Vicon system and will be reported in minimum horizontal distance.

D. *Experimental Procedure*

The study took approximately one and a half hours and consisted of four parts: i) pre-interaction, ii) interaction, iii) survey evaluations, and iv) post-interaction.

1) *Pre-Interaction:* The pre-interaction began when participants were greeted and provided consent forms with information about the study and participant rights. After agreeing to the consent from, participants were asked to complete a pre-questionnaire to collect data about background relating to the participant and the participant's experience with robots thus far. After the pre-questionnaire was completed, the heights and eye-heights of the participants was recorded. The participants were then given another explanation of the experiment and directed to put on the marker and protective glasses. After the participant was in place and given the path of the robot, the moveable wall was closed.
2) *Interaction with the Robots:* The participants were randomly assigned the order of the heights. A random number generator was used to choose an order of 3ft., 5ft., and 7ft. The Hummingbird had a safety zone of 60cm (2ft) to 35cm (1.15ft), in which the sUAV would autonomously stop if the participant had not instructed the vehicle to stop prior to that distance. This information was omitted so that the participants would stop the robot instead of letting it stop on its own, but was required by IRB to ensure that we did not strike any participants. The Hummingbird approached participants at a speed of 21.2cm/s in a straight, single direction.
3) *Survey Evaluations:* Participant feelings were collected in the pre-questionnaire through the Positive and Negative Affect Schedule [3] as well as the Negative Attitudes towards Robots Scale [4]. In the first and second post-interaction survey, the Positive and Negative Affect Schedule was added to track any changes to the participant's emotions.
4) *Post-Interaction:* After the third and final interaction with the sUAV, participants were taken out of the experiment room and administered a post-questionnaire to assess the information of their affect after interaction with the robots.

E. *Analysis and Results*

The primary hypothesis was not supported, suggesting that participants were not more comfortable interacting with the Hummingbird at a height of 3 feet, 5 feet, nor 7 feet. The average stopping distance at 3 feet was 67.73 centimeters, while to average. stopping distance at 5 feet was 67.31 centimeters. These two averages only differ by 0.42 centimeters. The average stopping distance at 7 feet was 67.99 centimeters, which is even closer to the average distance of 3 feet, differing by 0.28 centimeters. Since these measurements are all extremely similar to one another, it can be assumed that one height does not result in stronger or weaker feelings of comfort with the sUAV approaching. Each height is within an average distance of 67 cm - 68 cm, which is within an average arm’s length of the participants. This distance is alarming, as when the sUAV is in arm’s length, there is a great chance that the participant could reach out and touch the vehicle, causing injury. Future work can be used to evaluate how to alert the public of the dangers of sUAVs in public, hopefully avoiding future injuries.

V. CONCLUSIONS

In this work, we explored human comfort in interacting with sUAVs by comparing approach heights. Looking at past human-human and human-sUAV studies, it could be expected that the distances would be similar when comparing the human-sUAV distances collected in this study. This work supported the need for further research in distancing of aerial vehicles that will be used in public spaces due to the small distances maintained in this study. The findings here found that the different heights of the sUAVs do not have statistically significant differences, allowing further work to focus on which factors do affect a participant’s comfort zone.

REFERENCES

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