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Drone Approaching Me: At Which Vertical Angle Should A Drone Approach People For Personal Package Delivery In Public Space

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Abstract:
Currently, using drones to deliver packages to home addresses is being developed by Wing and Amazon. However, we can imagine going further, and delivering packages directly to people in public spaces. Contemporary research in the field of human-drone interaction often make use of methodologies that places a single drone in the test environment, which means the test participants are aware that the drone is for them. Therefore, this paper explores how a drone should approach a person that does know that a drone wants to approach them, but does not know which one. We devised four different trajectories for drones to use when approaching people, which all started 50 m away and 15 m above ground. These trajectories were; where the drone approached from above, where it descends while following an "s" shaped curve and then approaches, where it approaches straight towards a participant, and where it descended rapidly to eye height and then approaches from the front. These trajectories were implemented and tested in Virtual Reality. It was found that a trajectory with a vertical approach angle of 0° to 15° was the fastest to be recognised, while 65° was the slowest to be recognised.

Drone Approaching Me: At Which Vertical Angle Should A Drone Approach People For Personal Package Deliveries In Public Spaces.

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ABSTRACT

Currently, using drones to deliver packages to home addresses is being developed by Wing and Amazon. However, we can imagine going further, and delivering packages directly to people in public spaces. Contemporary research in the field of human-drone interaction often make use of methodologies that places a single drone in the test environment, which means the test participants are aware that the drone is for them. Therefore, this paper explores how a drone should approach a person that does know that a drone wants to approach them, but does not know which one. We devised four different trajectories for drones to use when approaching people, which all started 50 m away and 15 m above ground. These trajectories were; where the drone approached from above, where it descends while following an "s" shaped curve and then approaches, where it approaches straight towards a participant, and where it descended rapidly to eye height and then approaches from the front. These trajectories were implemented and tested in Virtual Reality. It was found that a trajectory with a vertical approach angle of 0° to 15° was the fastest to be recognised, while 65° was the slowest to be recognised.

Keywords

Drone, Public Delivery, Human-Computer Interaction, Gamification, Virtual-Reality, Drone-Human Interaction, Human-Human interaction,

1. INTRODUCTION

In the near future, small autonomous drones could deliver packages to people directly. We can imagine these deliveries happening in public areas, such as city squares or on sidewalks. The drones would need a designated pathway similar to cars, which should be at an altitude of 5 m or higher based on current regulations on how much open air is required above public roads [18]. The drone can then navigate closer to its intended recipient and personally hand over its package.

Companies such as Amazon Prime Air [2] and Wing [28] are already in the process of developing autonomous flying drones that can deliver packages. However, these drones currently only deliver to home addresses. The solution of Amazon Prime Air [2] requires a QR-coded landing platform and is at the time of writing still under development. Wing [28] differ, by delivering from the air via a hook on

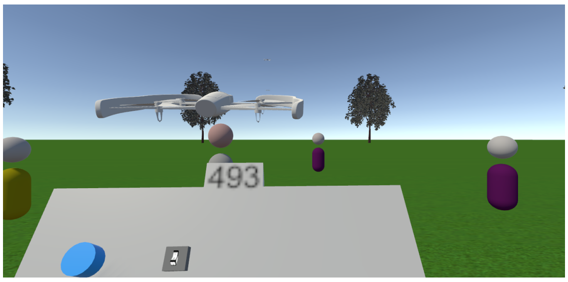

Figure 1: The public environment with a drone highway.

a winch, and is currently only operating in Canberra, Australia and Helsinki, Finland. As technology progresses, we can imagine a future where technology gives drones larger carrying capacities in relation to their size. Additionally, we can imagine future regulations to allow drones to commonly operate in public areas, similar to how heavy restrictions from the 19th century on automobiles in public areas are not present today [24].

When making a personal delivery in a public area, the delivery drones' flight behaviour must take into consideration that its recipient is not the only person in the area. The drone will have to indicate who is the intended recipient, which requires the drone to attract the attention of its target and make sure the target acknowledged they are indeed the recipient. At the same time, the drone should not distract or confuse other people in the same area. It then descends with a flight path that does not interfere with other people's activities, and is interpreted as safe by the recipient. How the packages should be handed over is also a question to be considered.

This paper focuses on the necessary behaviour of the drone to catch the attention of the recipient and make them sure of the drone's intention of delivery. More specifically, how different approach trajectories ending at various angles affect the drone's probability to catch the recipient's attention and successfully convey its intention to approach them.

In short, the research question of this papers is;

In which trajectory is the drone most recognisable?

In a study with 24 participant, four different approach trajectories ending at different approach angles were evaluated through virtual reality (VR) in a within-subject design to investigate which drone approach trajectories were most efficient in regards to the time it took the participant to notice the drone, and how often the participant was unsure of the drone's intention of approach. An example of the program can be seen in Figure 1.

2. BACKGROUND RESEARCH

In order to effectively deliver packages via drones, methods used to initiate effective interaction must be identified. In order to do this, this section explores the field of interaction between humans, and then investigates how these concepts relate to the field of interactions between autonomous agents and humans.

2.1 Interaction between humans

Humans primarily communicate through verbal expression and gestures with the intent to communicate with a specific purpose [16].
When looking at how people interact with each other, the distance at which the interaction occurs is important. Proxemics is a term that was used by Hall [10] to define the spacial area around a person and at what distances different interactions takes place. This is done by categorising the spacial area into four terms; *public, social, personal,* and *intimate* space as seen in Table 1. Each space is further subdivided into a *Close phase* and a *Far phase*. Public space is the zone where people can freely enter and go as they like. Social space is the zone where a person would interact with an acquaintance. Personal space is the zone a person would let a friend or family member enter when interacting. Intimate space is the zone a person only would let others in for embracing, touching or whispering interactions.

However, proxemics only focus on the distance a person allows another for specific interactions, but not how to initiate said interaction with another person. Kendon [16] has explored what is needed to establish communication with another person. In order to fully understand the mindset of communication, the intent to communicate is always with a purpose. There are initial steps to communicate to a person [15];

1. Establish eye contact with the target. If there is no eye contact, the target is not aware of your intention of communicate.

2. To signify the intent to interact with the target, greeting gestures are used to indicate that you want to communicate to that person. If the indication was not enough, the target person do probably not want to communicate or did not notice the gesture. This is when verbalisation would be used as the last option to establish communication.

2.2 Interaction with an Autonomous Agent

Interaction between humans has been explored and translated to autonomous agents [4, 9, 11, 23, 29]. Interactions between humans and autonomous agents, such as robots and drones, are similar to interaction between humans in that there is a specific purpose [7, 23]. With that in mind, it is important for the agent to successfully convey its intention to interact with the human target, and the agent must be able to recognise whether or not to abort its attempted interaction if it cannot reach or is rejected by the target [4, 23].

Humans initiate interactions between each other by using gaze, gestures, and verbal communication as presented by Kendon [15, 16]. Transferring the same initiation principles is possible in the domain of Robot-to-Human Interaction. Satake et al. [23] explore the effectiveness of these interaction behaviours, but from a different direction by using an autonomous ground agent meant to deliver advertisements within a mall. The study explored how the autonomous ground agent could effectively initiate interaction. The robot had five objective to complete in order when attempting to initiate interaction a person; *Target*, in which the agent detects a human in its operating area, determine if they can be reached, and then move towards them. *Reached*, by making the human aware of the agent's intentions of interaction by getting in front of the human at a public distance and orienting towards them. *Aware*, where the agent re-affirm its intentions of interaction at a social distance of 3 m, by keeping its head and body orientation towards the human while moving closer. *Sure*, where the agent begins a verbal conversation. If the human still seems to avoid the robot, it should more strongly show its intention to talk. Lastly, step *Acceptance* is where the robot has successfully initiated conversation. The model can be seen in its entirety in Figure 2.

Table 1: Proxemics zones with distance measurements [10]

Proxemics Zone	Phase	Distance (m)	Example Behaviour
Intimate Space	Close	0 - 0.2	Embracing, wrestling
	Far	0.2 - 0.5	Intimate conversation, whispering
Personal Space	Close	0.5 - 0.8	Spouses standing together
	Far	0.8 - 1.2	Talking with friends
Social Space	Close	1.2 - 2.1	Talking with co-workers and acquaintances
	Far	2.1 - 3.7	Formal business meetings
Public Space	Close	3.7 - 7.6	Speaking to a crowd
	Far	7.6 -	Public speeches, theatre viewed from back row

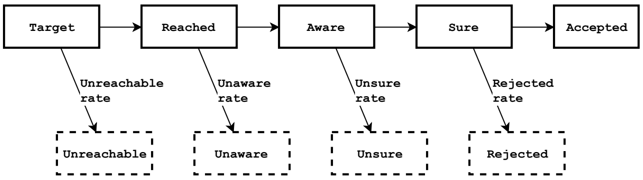

Figure 2: The necessary steps an autonomous agent must complete to successfully interact with a person from Satake et al. [23]

In the context of a flying delivery drone, it only has to successfully make the recipient aware of its presence and make them sure the delivery drone is intended for them. This is because the drone can always reach a pedestrian target in a public space due to its faster cruising speed, and a person that actively orders a package to be delivered to them by a drone is not likely to reject the delivery. Therefore, the drone's goal would be to manoeuvre in such a way that the recipient *acknowledges* the drone's presence, and *recognises* the drone's intention to deliver a package. In order to describe these manoeuvres, the model presented by Szafir et al. [25] can be used to describe an autonomous agent's motion over time through *trajectory*, *orientation*, and *speed*.

Acknowledgement

The presence of a human is recognisable by the orientation of the human body and eye contact [15]. However, exclusively using orientation with an autonomous agent to signify that it is aware of a person is not as recognisable. Satake et al. [23] that even if an autonomous agent is present within a persons field of view, 4% of people did not recognise its presence (unaware, N: 2), 18% did not recognise its intention of interaction (unsure, N: 11), and 27% of people did not want to interact (rejection, N: 16). However it is important to remember that these failure rates are with an advertisement robot, which can explain the relatively high rejection rate. Jensen et al. [11] explored the acknowledgement distance of drones that felt most comfortable for a person when it approaches, where they found that participants preferred the drone to acknowledge them at 1.8 m. It is known from Kendon [16] that when a person wants to interact with someone else, the target should respond in order to accept or reject the intended interaction. Monajjemi et al. [20] explored this by having a drone wobble as a response to a greeting gesture from a person, confirming that the drone has acknowledged the person's presence. The drone was successful in recognising a waving person 81.8% (N: 18) of the time.

Intent recognition

As mentioned in *section 2.1*, for human-human interaction one of the person need to initiate interaction by getting some attention and do gestures for further indication [16]. Szafir et al. [25] explore how drones needs to fly in order for a person to understand its behaviour and its next motion. They found that the use of the manipulators *easing* (when the drones' velocity is slowly increased or decreased), *arcing* (when the drone moves in a curve between two points), and *anticipation* (moving slightly in the opposite direction and then moving forward) significantly increased the mean rating of understanding from their participants (N: 24) of where the drone was headed, with an increased rating from approx. 47% to approx. 59%

Jensen et al. [11] explored the use of gestures by the drone to indicate its awareness and acknowledgement of a person's presence, specifically using the gestures *nodding*, *tossing*, *waggling*, and *orienting* towards the person. It was found with 16 participants that orienting gave a significantly higher rating of acknowledgement (82.5%) in comparison to any of the three other gesture (39.2% on average). However in a separate online survey with 129 respondents, where they combined the three other gestures with orienting, the three combination gestures gave a higher rating of acknowledgement (69.4% on average) than orienting alone (57.7%).

Approach Angle

When an agent approaches a person, they approach from a given direction, e.g. from the front, the side, or the back. In order to express the direction from which the agent approaches the person, we define *approach angle* to be the angle between the person's torso orientation and the directional vector of the agent–i.e. the path that the agent would take when approaching a person.

Since a drone is flying, the approach angle can be subdivided into two components; horizontal approach angle (*haa*) and vertical approach angle (*vaa*). The *haa* is the approach angle projected down to two dimensions and going left or right from the person, and is illustrated in Figure 3. The *vaa* is the approach angle projected down to two dimensions and going up or down from the person, and is illustrated in Figure 4.

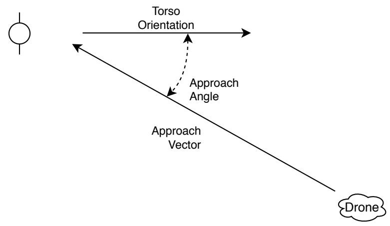

Figure 3: The horizontal approach angle (*haa*).

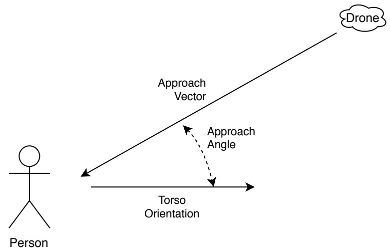

Figure 4: The vertical approach angle (*vaa*).

While many studies have investigated different factors when an autonomous agent approaches a person [1, 4, 9, 11, 30], they often default to having the autonomous agent approach a person with a *haa* of 0°.

Dautenhahn et al. [8] investigated if people preferred a *haa* of 0°, 45° (approached from the left-hand side), or -45° (approached from the right-hand side) while they were sitting and being approached by a ground robot with the task of handing them a remote for a tv. 60% of the participants (N:

23) preferred being approached from the right, with 24% (N: 9) preferred being approached from the left, and only 16% (N: 6) preferred being approached from 0°.

However, using flying drones are different than using a ground-based robot. Wojciechowska et al. [29] made a study focusing on at what horizontal angles delivery drones should approach people. For the test, participants were standing in a room and a flying drone approached them with a *haa* of 0° (from the front), -45° (approached from the right-hand side), or 180° (from behind).In this case, they found that out of 24 participants, the preferred direction to be approached from is at a *haa* of 0° (mean rank: 1.13), compared to being approached from -45° (mean rank: 1.92) or 180° (mean rank: 2.96).

Distance

When an autonomous drone approaches a person, it should not get closer than what the person would allow it. This is called *comfortable distance* [1, 9, 30], which is a self-reporting measure where a person is approached by a drone, and the person signals when they want the drone to not come closer. Studies have shown that a comfortable distance for people tends to be between 0.6 m and 1.4 m [9, 30]. Drones that have social features, such as a welcoming voice or a friendly face have been allowed closer to people than drones without such features [1, 30]. Physical safety measures on the drone, such as harnesses and cages, also induced a sense of safety for the users, which resulted in people allowing the drone to come within 0.6 m and 1.1 m [9, 30].

Yeh et al. [30] investigated how a lateral offset to a frontal approach ($haa = 0°$) affects the comfortable approach distance to a person, as seen in Figure 5. When a drone hovers at an altitude of 1.2 m, they found that that at an offset of 0 m gave a comfortable distance of 1.14 m, an offset of 0.3 m gave a comfortable distance of 1.02 m, and an offset of 0.6 m gave a distance of 0.95 m. Within the personal space of the person, the comfortable approach distance decreased as the lateral offset increased. When the drone was at an altitude of 1.8 m, they found no differences in comfortable distances.

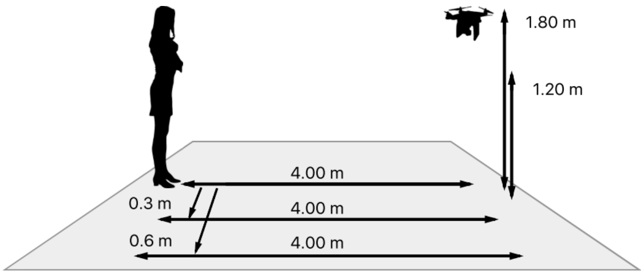

Figure 5: The diagram from Yeh et al. [30] which illustrates their different conditions for lateral offsets.

However as described by Kendon [16], in successful interactions, people tend to signal a mutual awareness before coming close enough to interact. Therefore, the drone should also signal its awareness of its target before it attempts to interact. Jensen et al. [11] investigated at which distance people preferred a drone passing by them to signal that it is aware of the human, called the *preferred acknowledgement distance* (*pad*). They found that their participants preferred drones to acknowledge them at 1.8 m on average. This indicate that the distance at which a drone should interact with a human should be around this distance.

In summary, when approached from the front, humans prefer the drone to acknowledge them at a distance of 1.8m–i.e., in the close social zone [11] and feel comfortable when the drone does not move closer than 0.6m–i.e., the personal zone [1, 9, 30].

Approach Speeds

The speeds used by autonomous ground robots and drones in various studies are different. The speed of ground robots were between the values of 0.3 m/s - 1 m/s m/s [4, 21, 22, 23], while the speed of drones vary between the values of 0.2 m/s - 3.44 m/s [6, 9, 11, 30]. The speed at which the autonomous agent is moving can influence how a person perceives the agent [4, 22]. With ground robots, a speed lower than 1.0 m/s is often associated with higher degrees of comfort and safety [4]. When in the context of drones, Wojciechowska et al. [29] investigated at which speed they should approach a person to deliver a package to be considered comfortable. The study found with 24 participants that the preferred approach speed was 0.5 m/s (mean rank: 1.21) over approach speeds of 0.25 m/s which was considered too slow (mean rank: 2.33) and 1.0 m/s which was considered too fast (mean rank 2.46).

2.3 Way to explore

Within the field of drone interaction, the research has generally been conducted in lab environments or city parks [1, 5, 6, 9, 11, 20, 25, 29, 30]. In the scenario of public drone deliveries being normal, a person would not be immediately certain if a drone is for them when seen. This is difficult to replicate in a lab environment, as participants are automatically aware of the importance of a given drone if it is the only one in the room. Furthermore, conducting it in a real life public environments is challenging due to current law- and safety regulations [7] and weather conditions [6], so conducting the experiment in an environment that does not have these limitations would be preferable.

Wojciechowska et al. [29] states in their study that indoor environments would lead to some flaws within the data when working with drones. They classified eight different methodologies on five factors; *Realism, Complexity, Safety Risk, Reproducibility* and *Scalability*, with each factor being rated between *none, low, medium* and *high.* The eight methodologies were *Outdoor Collocated Flight*, *Indoor Collocated Flight*, *Virtual/Augmented Reality*, *Non-Collocated Flight*, *Mimic Flight*, *Animations/Videos*, *Online Survey*, and *Interviews.*
From this, they state that VR/AR has a low safety risk and scalability, medium realism and complexity, and high reproducibility. Because of the assumed scenario being set in a public environment, a large space within the world would be a requirement. VR simulations makes this a possibility, while minimising safety risks and having a high reproducibility.

Additionally, Wang & Rau [27] states that VR can be a good method for simulating reality by testing the differences in trust and communication with a robot in real life, VR, Augmented reality, and tele-presence. They showed that the robot in real life and the VR robot did not have a significant difference between levels of trust, attachment, credibility, and social presence.

Virtual Reality

The medium of VR is described by Jerald [12] as *"a computer-generated digital environment that can be experienced and interacted with as if that environment were real"*. A VR environment allows people to become more immersed and focused while interacting with the virtual environment [19]. Examples of commercially available VR systems include the *HTC Vive, Oculus Rift, PlayStation VR*, and *the Microsoft Mixed Reality.*

VR also eliminates external factors that could effect a drone's movement, such as wind [5, 6] and internal ventilation systems [11]. The safety measures used in previous work could also have effected the results when it comes to comfortable acknowledgement and approach distances. Since no physical drone would be present in a VR setup, these safety measures does not need to be considered. This allows for designing a simulation that would be closer to a real-life scenario, where a person is approached by a public service drone from any given angle. However, technical limitations must also be considered, such as wind from the drone's propellers can theoretically be implemented, but is not available by default with most hardware solutions [29].

VR Complications

Usage of VR can induce a sense of motion sickness caused by problems in the VR system which is called *simulator sickness* [13, 17]. Symptoms are similar to motion sickness, such as nausea, dizziness, sweating, amongst others. The main cause for simulator sickness is a mismatch between the perceived motion in the virtual environment and the physically felt motion. Input latency, flicker, refresh rate, field of view, and imprecise motion tracking can all cause simulator sickness [13]. Kennedy et al. presented the Simulator Sickness Questionnaire (SSQ) as a tool which groups symptoms into three categories; *Nausea*, *Oculomotor*, and *Disorientation* [17]. The SSQ is used to measure if a VR simulation induces simulator sickness

Simulator sickness is often induced from physical head motion with a system having more than ~30 ms of motion tracking latency [13]. In these situations, the VR content should be designed for infrequent and slow head movement. However, more natural head movement can be allowed with a system having latency lower than ~30 ms.

A consistent frame rate is also important to mitigate simulator sickness [13]. To achieve a consistent frame rate, preferably above 30 Hz, the scene complexity and optimisation must be considered in its design.

2.4 Summary

From the research, a pattern was found that all angles of approach to or from the person were from the front–i.e with a 0° *haa*, which Wojciechowska et al. [29] found to be the preferred *haa*. However, there was no research on drones approaching from different *vaa* to a person, at time of writing. Therefore, the paper focuses on this research gap. Since it was found that VR and real life are similar experiences [27, 29], VR was decided to be the medium used since it allows more control and minimise outside factors for the experiment and safety risks inherent in drone flight.

3. DESIGN

This section covers the overall design decisions when implementing the scenario within the virtual environment. It focuses on describing the experimental concept, how the drone will approach the participant, and the implementation itself.

3.1 Concept

The implementation will place a participant in the situation of having a drone approaching them while standing in a public space. The drones should have their own designated pathway, which should be at a minimum height of 5 m [18]. This allows them to safely travel at cruising speeds. The drone will approach the participant by descending from the drone pathway and following a designated trajectory. The participant will interact with an object with multiple interactive elements, which has a random sequence that they have to guess through trial and error. When the correct sequence of interaction is guessed a new random sequence will appear and the participant will continue the task. The console panel can be seen in Figure 6. These tasks are intended as a distraction element since in the scenario of having the drone deliver packages to the participant whenever they want. A person would probably not have their main focus on the drone and might be doing other distracting behaviour such as looking at a phone or talking to another person.

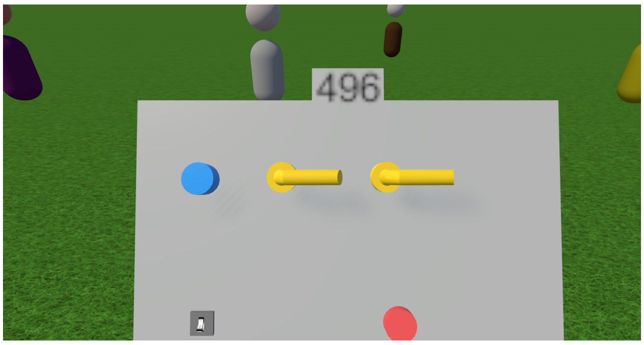

Figure 6: The console panel with a score at the top and four different interactive modules; blue button, red button, flip switch, and lever.

3.2 Approach Trajectory

We describe the trajectory the drone takes while descending towards its target from the drone pathway as the *approach trajectory*. We created four approach trajectories based on the motion manipulations *arcing* and *easing* of Szafir et al. [25]. When a drone exits the drone pathway, the starting horizontal angle for each conditions is 36.30° and a end degree of 0°. The four trajectories are as follows:

- *High (A)*: The drone stays close to the drone pathway, and then descends downwards via arcing in the latter half of its travel. The *vaa* in the last stretch of travel is approx. 65°.

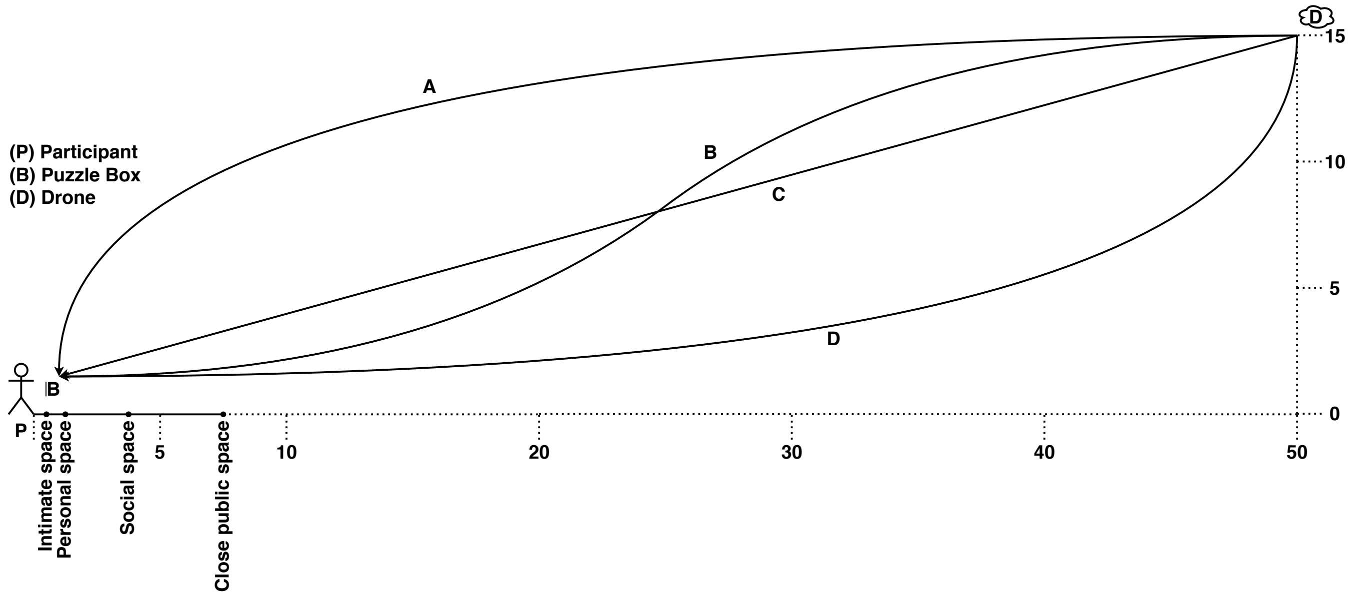

Figure 7: The four approach trajectory illustrated. A = High, B = Middle, C = Straight, D = Low.

- *Middle (B)*: The drone descents in an "S" shape, by arcing downwards in its first half of travel, and then arcs forward in the latter half. The *vaa* in the last stretch of travel is approx. 0°.

- *Straight (C)*: The drone flies in a straight line towards the area in front of the participant. The *vaa* is approx. 15°.

- *Low (D)*: The drone descend rapidly downwards right after exiting, and then proceeds to arc forward. The *vaa* in the last stretch of travel is approx. 0°.

These four trajectories are illustrated in Figure 7.

The distance the drone stops from the user is within the close social space (1.2 m - 2.1 m) due to the fact that this is the preferred space for a person to be acknowledged by a drone, as discussed in *subsection 2.1.* The close social space is also the proxemics zone where people keep others whom they are less familiar with.

When the drone is within 50 m of the participant, the drone begins its descent from the drone pathway. During its descent, the drone decelerates from its cruising speed down to a comfortable approach speed when close to the participant. The drone moves at a specific speed in certain distance bands, with distance bands closer to the participant having lower speeds based on the concept of *easing.* We call these distance bands *Initial Approach*, *Medium Approach*, and *Final Approach*, going from furthest away to closest, respectively. Each distance band is defined by the distance to the participant, and the speed of the drone, which can be seen in Table 2.

Table 2: The speeds at which the drone approaches the participant, depending on distance travelled.

	Initial Approach	Medium Approach	Final Approach
Speed (m/s)	8.0	1.0	0.5
Distance from participant (m)	50.0 - 8.6	8.6 - 4.7	4.7 - 2.0
Time spent (High) (s)	7.3	4.1	5.1
Time spent (Middle) (s)	5.1	3,5	5.1
Time spent (Straight) (s)	4.7	5.0	5.0
Time spent (Low) (s)	6.8	3.5	5.3

3.3 System Description

The scenario was made utilising VR within the Unity Game Engine. The system places the participant within an environment that is a park with the drone pathway 15 m above them. The participant is then given a task of interacting with different buttons and levers on a console panel, which can be seen in Figure 1. The participant is tasked with interacting with the console panel's elements in the right sequence, which is unknown to the participant and must be discovered through trial and error. While interacting with the console panel, a drone will then descent from the drone pathway to the participant.

To maintain the participants' focus on the console panel, a point system which slowly decreases over time is implemented. Whenever a participant completes a correct sequence through trial and error they are awarded points. The drones that descend from the drone pathway will descend following one of the four trajectories. The drones always have their orientation towards their target when approaching. The participant has the opportunity to guess if a descending drone is targeting them or not. If they think the drone is targeting them, the participant should click a button on the controller, and ignore the drone if they think the drone is not targeting them. By guessing correctly that a drone is targeting them, they will be awarded a points bonus. However, if the drone is not targeting them, they will get a point penalty. Interacting with the console panel and guessing on drones gives separate auditory feedback to indicate if the participant's actions are correct or not.

For each approach trajectory, a total of four descending drones will target the participant, and is instantiated around every minute over a duration of four minutes. For the spawning of each drone there is a small variance of 15 seconds around the minute mark in order to eliminate learning. When the drone reach its target, it will indicate its presence by nodding and flying away, and ascends back to the drone pathway above.

To simulate a public space, the participant is not the only one that is waiting for a delivery in the area. Twelve dummy targets are implemented to simulate a person that is also in the area. The closest targets were 5 m away while the furthest targets were 10 m as shown in Figure 8 which places them within the close and far public space, respectively. These dummy targets will get deliveries from drones semi-randomly with 1-3 drones between each correct drone, resulting in an average of eight drones not targeting the participant throughout the four minutes. This is done in order to instil the sense that not all drones are for the participant. This gives the possibility of *false positives* since the participant can guess on a drone that is not for them.

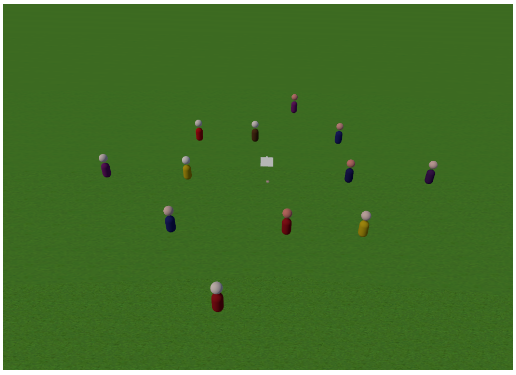

Figure 8: The environment seen from a bird's eye perspective.

To keep track on the participant guesses, a logger was implemented that logs the time from when the drone exited the pathway, the location of the drone in relation to the participant, if the drone targeted the participant or not, and the approach trajectory the drone is following. The location of the drone will help calculate the *vaa* of when the participant guess that the drone is targeting them. The correct drone guesses will help identify the amount of false positives and false negatives. The time will help to see the reaction time of when each participant is certain that the drone is targeting them.

4. EVALUATION

This section will cover those methods used to evaluate and what results that was gathered from the experiment, which took place at Aalborg University. The experiment was used to investigate at which angle participants noticed the drone, the degree of uncertainty with each approach trajectory, the participants' reaction time, and how often they guess right and wrong with each approach trajectory.

4.1 Evaluation Tools

In order to evaluate the system in the most efficient way, we decided to use established tools; The *SSQ* [17] and the *System Usability Scale (SUS)* [26]. The SUS is a well known evaluation tool [3, 14] that measures if the system as a whole meets the purpose. When using the SSQ, it is recommended [17] to use it both before and after the VR experience so a baseline for each participant can be established, thereby giving a clearer picture if the VR experience induces simulator sickness.

4.2 Setup

The test was carried out in the HRI Lab at Aalborg University City Campus (CREATE). As seen in Figure 9, the setup included a HTC Vive Deluxe headset and a camera were present to capture the participants movement within the room. From the computer running the VR application, all of the tests were screen captured for further data and potential investigation of behaviour within the virtual environment. Two laptops were present for the participant to fill out the questionnaire, including the SSQ and SUS. Two facilitators were present; one was in charge of briefing and guiding participants through the experiment, helping them take the VR headset on and off, and operating the camera. The other facilitator, named the tech operator, was in charge of managing the VR application.

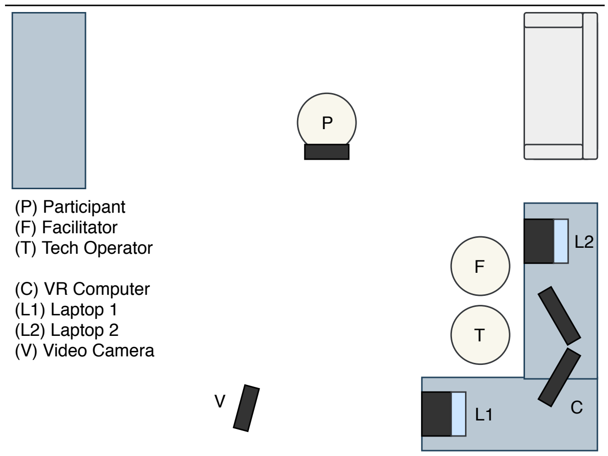

Figure 9: A diagram illustrating of the experimental setup.

4.3 Participants

In total, 24 participants (M = 16, F = 8) were recruited from within local academic institutions, ranging from 20 to 30 years old (μ = 24.42, σ = 2.04). The experiment was handled as a within-subject design with a determined order of conditions for each participant. Each permutation of the four conditions was covered by one of the participants to

eliminate learning as a possible source of error. The complete experiment lasted approximately 30 minutes for each participant.
Regarding previous experience with drones, 15 participants had seen a drone in-flight before, and seven participants had not. One participant had personally flown a drone before, and one personally owned a drone. Regarding the previous experience with VR, 13 participants had tried VR multiple times before, one participant had tried it once before, and two participants had never tried VR before. Six participants reported that they used VR frequently, and two participants personally owned a VR setup. The participant that owned a drone was not part of the two participants that owned VR setup.

4.4 Procedure

Before the experiment began, participants were asked to sign a consent form, fill out a demographic questionnaire asking age, gender, occupation, and general experience with VR and drones. Additionally, participants were given a pre-test SSQ questionnaire. After this, they were briefed about the virtual environment, and told that their task was to solve sequences on the console panel through trial and error, and doing so quickly would give them a high score. They were also told that by identifying drones that were targeting them for approach would gives them bonus points. If participants identified a drone not actually targeting them as a drone they thought was targeting them, they were given a point penalty.

After the introduction of the system, participants then ran through the VR application, with the first approach trajectory designated by their assigned permutation. After the last drone had approached the participant for the given approach trajectory, they were asked the following question:

How often were you uncertain if the drones approaching were going for you?

- *Never*
- *Once or twice*
- *A few times*
- *Often*
- *Every time*

This process was repeated for the three additional conditions in the permutation sequence.

When the participant was done with all of the approach trajectories they were given the post-test SSQ, the SUS, and asked for general comments on the experiment. At this point, a new participant could fill out the demographic data questionnaire and pre-test SSQ.

4.5 Results

Data was gathered from the program in order to potentially determine if any of the approach trajectories are more effective in conveying the drone's intended target to the participant. The system gathers data when a participant guesses on a drone; the drone's position, and the time from when the drone exited the drone pathway in seconds. This was done for both correct and wrong guesses.

Logged Data Results
As mentioned earlier, the data logged was the used approach trajectory, drone position, time it took for a participant to guess on a drone from when it exited the drone pathway, and if the guess was correct or not.

In order to review the data for normal distribution, a Shapiro-Wilk Test was performed at a significance level $e = .05$. None of the gathered data had p-values that would indicate normal distribution.

Table 3 and Figure 10 shows the resulting minimum and maximum time of each path. The *minTime* is the shortest time when a participant thought that the drone was for them and *maxTime* is longest time when they thought the drone was for them.

Table 3: Time data results when drone exited the drone highway to when the participant thought it was for them.

Approach Trajectories	minTime (s)	maxTime (s)	Median	MAD
High (A)	4.53	18.64	9.49	2.91
Middle (B)	1.00	15.91	4.09	1.34
Straight (C)	0.04	13.68	4.08	1.75
Low (D)	0.48	16.42	4.82	2.12

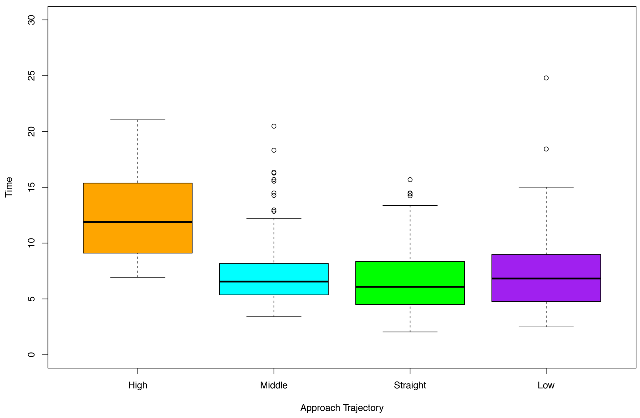

Figure 10: Boxplot of the reaction time for each approach trajectory.

In order to compare the time data per trajectory, a Friedman test was performed with a comparing of a significance level $e = .05$, which gave $p = 2.581e - 09$. However to find the p-value from each condition a Post Hoc Wilcoxon signed-ranks pairwise test was used. Additionally the effect size r was calculated for each comparison. These results can be seen in Table 4.

Table 4: p-value and effect size (r) between reaction times.

Approach Trajectories	p	r
High - Middle	3.9e-05**	0.41**
High - Straight	1.8e-05**	0.43**
High - Low	6.4e-05**	0.40**
Middle - Straight	0.47	0.07
Middle - Low	0.27	0.11*
Straight - Low	0.10	0.17*

For p-values, entries marked with * is below $e = .05$, and ** is below $e = .01$. For effect size, entries marked with * is above $r = .1$ (small).

For the logged drone position, Figure 11 shows when the participant got the placement of the drone correct within the VR environment. Each coloured mark denotes the drone's position when the participant guessed it was for them, with each approach trajectory having a different colour. The black circle on the far right is where the participant was standing in relation to the drone's position. Table 5 shows the maximum and minimum positions for each approach trajectory as well as the distance from the participant to the drone.

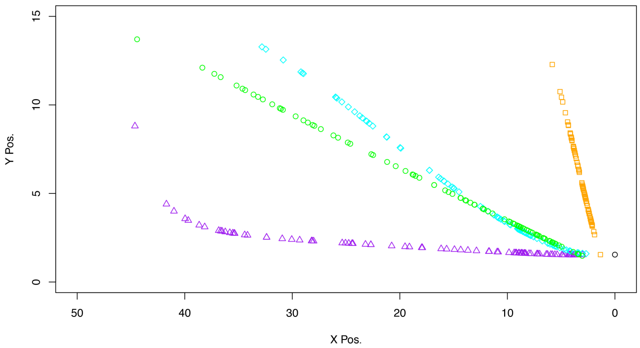

Figure 11: Each approach trajectories in a scatterplot. High (A) is orange, Middle (B) is green, Straight (C) is cyan, and Low (D) is purple.

From the experiment, false positives, false negatives, and true positives were logged and is shown in Table 6. True negatives were not gathered from the experiment but an average of eight drones targeting dummy targets were spawned over the duration of each trajectory condition, which has been used as the basis for the amount of condition negatives all negative positions can be seen in Figure 12.

Questionnaire Results

From the questionnaire, the data from uncertainty, SSQ and SUS were collected. From this, the SUS yielded a mean of 72.92 and a standard deviation of 13.05. The mean indicate it is within the "acceptable usage" segment due to it has a mean that is higher than 70 [3].

From the SSQ data, the mean score of the symptoms associated with nausea (7.6) are below the mean of the nausea calibration range (7.7) presented by Kennedy et al. [17]. The

Table 5: Position data (m) when the participant thought it was for them. Distance data is from participants feet to the drone.

	High (A)	Middle (B)	Straight (C)	Low (D)
X Pos. Min	1.35	3.00	3.04	2.68
X Pos. Max	5.83	32.82	44.43	44.63
X Pos. Median	2.94	10.25	12.67	11.71
X Pos. MAD	0.71	4.70	6.11	7.488
Y Pos. Min	1.55	1.53	1.48	1.60
Y Pos. Max	12.28	13.28	13.71	8.81
Y Pos. Median	5.25	3.42	4.25	1.72
Y Pos. MAD	1.79	1.48	1.80	0.19
Distance Min	2.05	3.30	3.38	3.12
Distance Max	13.59	35.41	46.50	45.49
Distance Median	6.02	10.81	13.36	11.83
Distance MAD	1.90	5.03	6.37	7.38

Table 6: Probabilities of recall, selectivity, miss rate, fall-out, precision, and accuracy.

	High (A)	Middle (B)	Straight (C)	Low (D)
Recall (TPR)	94.79%	94.79%	93.75%	93.75%
Selectivity (TNR)	99.48%	95.83%	98.44%	97.40%
Miss Rate (FNR)	5.21%	5.21%	6.25%	6.25%
Fall-out (FPR)	0.52%	4.17%	1.56%	2.60%
Precision (PPV)	98.91%	91.92%	96.77%	94.74%
Accuracy (ACC)	97.92%	95.49%	96.88%	96.18%

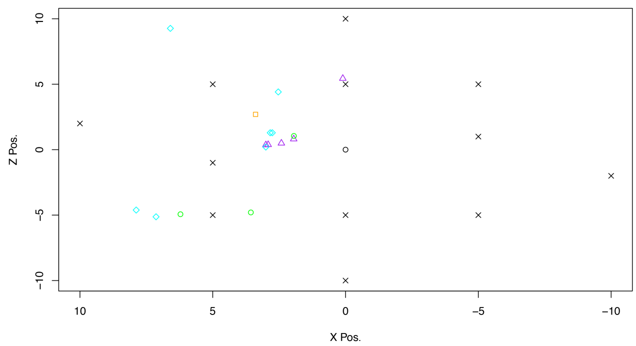

Figure 12: All false positives. High (A) is orange, Middle (B) is green,Straight (C) is cyan, and Low (D) is purple

mean score of symptoms associated with oculomotor strain (9.5) are also below the mean of the oculomotor calibration range (10.6). The mean score of symptoms associated with disorientation (11.6) are above its respective calibration mean (6.4) but does not exceed the maximum value of its respective calibration range (12.4).

The mean total score (10.8) also exceeded its respective calibration mean (9.8) but also did not exceed the maximum expected value of its respective calibration range (18.8). The standard deviation across all symptom categories (N σ = 8.9, O σ = 9.3, D σ = 12.1, and TS σ = 8.6) are below the standard deviation of the calibration range (σ = 15). This is all summarised in Table 7.

Table 7: The SSQ data gathered from the experiment, with the mean, maximum value, and standard deviation from the calibration range presented by Kennedy et al. [17]

	N	O	D	TS
Experiment Mean	7.6	9.5	11.6	10.8
Calibration Mean	7.7	10.6	6.4	9.8
Calibration Max.	14.7	20.0	12.4	18.8
Experiment σ	8.9	9.3	12.1	8.6
Calibration σ	15.0	15.0	15.0	15.0

This means the VR simulation on average does not induce simulator sickness to a degree that is problematic for the participants.

The uncertainty ratings that the participant had from each approach trajectories is shown in Table 8. All of the answers that was possible was ranked from 1-5 in order to compare and calculate the mean and standard deviation which can be seen in Figure 13. In order to compare the different answers of uncertainty, a Wilcoxon signed-rank test was performed with a comparing of a significance level of $e = .05$ for testing against the null hypothesis that there is no difference between the rank means. Table 9 show the results of the p-value, with no entries being below the significance level.

Table 8: Uncertainty from the questionnaire.

Approach Trajectories	Median	MAD
High (A)	2	1
Middle (B)	2	0
Straight (C)	2	1
Low (D)	2	1

Table 9: p-value and effect size (r) for between each answer of uncertainty.

Approach Trajectories	p	r
High - Middle	0.11	0.32**
High - Straight	0.11	0.32**
High - Low	0.14	0.30**
Middle - Straight	0.86	0.03
Middle - Low	0.53	0.12*
Straight - Low	0.64	0.09

For effect size, entries marked with * is above $r = .1$ (small), and ** is above $r = .3$ (moderate).

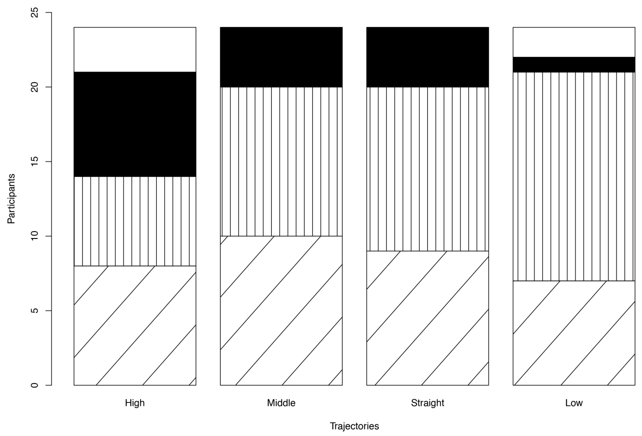

Figure 13: Each approach trajectories based on answers in a barplot. Diagonal = Never, Vertical = Once or twice, Black = A few times, and White = Often.

5. DISCUSSION

During the evaluation and from the data analysis, some points was revealed that required further discussion.

Data Analysis

When looking at the uncertainty level for whether the drone is for the participant or for others, as seen in Table 8, the mean score of the answers is in the segment called *Once or twice*, which indicate that none of the trajectories induced a feeling of complete certainty in the participants on average, but none proved to be worst in that regard.

From the data on reaction time, as seen in Table 4, the p-values when comparing each condition with each other with the Post Hoc Wilcoxon signed-rank test it is clear that there is a statistically significant difference when comparing the High trajectory with all of the others, with Moderate effect sizes ($r > .3$) for all the others. When looking at Table 3 the High trajectory has the slowest reaction time across the board by a significant margin. While it is potentially the one that would be the least disrupting to others surrounding the recipient, it cannot be recommended do to the chance of recipients themselves also getting surprised.

When looking at the other trajectories, none are significant to each other ($p > .05$) in both reaction time and uncertainty rating. This indicates that none of these trajectories are better in relation to each other, only that the high trajectory is significantly slower than the rest. Because of this, the data suggests that approaching a person with a drone at a *vaa* of 15° or lower is most optimal.

When looking at the probabilities in Table 6, each conditions has almost the same Miss Rate with a difference of 1.04 percentage point. This indicates the difference between the different trajectories is negligible in this regard. When looking at Fall-out, Middle has the highest probability of 4.17% which would indicate that it is easier in this trajectory to mistake another drone as targeting you. Meanwhile High has the lowest probability of Fall-out with only 0.52% out of the entire sample group.

From these values it can be seen that there is a small chance for a person to guess wrongly, both with drones for them and vice versa.

Summary
Since the High trajectory had significantly slower reaction times it seems to not be a favourable option. The reason for this is probably because the drone spends most of its time at an angle that is above eyesight so the only real indicator would be the sound that it produces.
The Middle, Straight, and Low trajectories had no significant difference between them in terms of reaction and level of uncertainty. Therefore, an approach trajectory that approaches a person at a *vaa* between 0° and 15° is indicated to be more optimal than approaches at a *vaa* of 65°.

5.1 Reliability

While running the experiment, we observed that some factors could affect the reliability of the results. One factor is the height of the participant. Three participants had difficulties looking over the console with the interactive buttons due to their heights which they expressed in their general comments (P2: *I was too short! I could not really see much above the edge of the console thingy*). Because of this, drones approaching at around eye height–i.e. in Low trajectory, was partially hidden behind the console panel which can be seen in Figure 14. In order to make it consistent between participants, the console should be automatically placed by the system in relation to the participant's height tracked by the VR headset.

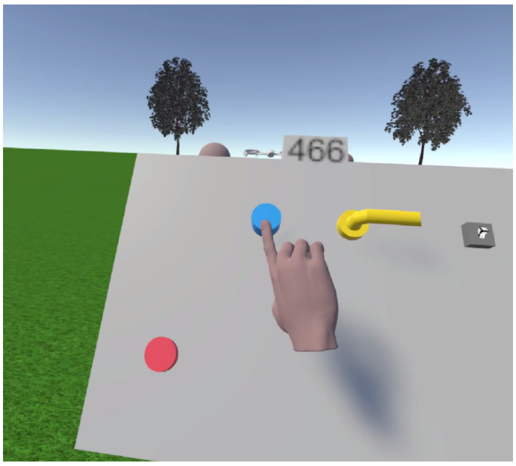

Figure 14: Participant with low height interacting with the control panel, with a drone partially hidden to the left of the score counter.

The system to introduce distraction drones that are not meant for the participant randomises which non-participant character the distraction drone should target. The intention was to make it harder for the participant to recognise a pattern of how many drones would arrive and to what target. However, after the experiment we discovered that the random nature of the system makes it harder to track when a participant guesses incorrectly because not all participant had the same amount of distraction drones, and the dummy targets were selected at random. This potentially introduced unnecessary inconsistency between participants in terms of Miss Rate and Fall-out.

Sometimes the participants had trouble activating the lever and the flip switch, which the participants generally commented on. This lead to frustration and could potentially be too much of a distraction that it might delay their reaction to the drone. To solve this, it might be an idea to implement easier interactive elements to activate or refine the interaction with the already implemented elements.

5.2 Validity

Whenever a user guessed on a drone they would either receive a positive or negative sound indicating if they guessed correctly or incorrectly. This could negatively impact validity by influencing how participants recognised a pattern between the different approach trajectories. It was observed that some participants were able to complete sequences on the console panel while not looking at it, which would indicate that it did not fully serve its purpose of keeping their attention while interacting. This leads to a negative impact on validity. To solve this, a more complex task that requires more focus to solve could be implemented. Another solution would be to only give visual feedback on the console panel to how the participant is performing.

6. FURTHER WORK

It could be interesting to see what kind of approach trajectory the drone would have to follow in regards to how it will place itself in front of the user, as can be seen in Figure 15. Many studies, including this one, uses a *haa* of 0°. However, because of the three-dimentional nature of drone flight, changing the *haa* could be an interesting experiment to c.

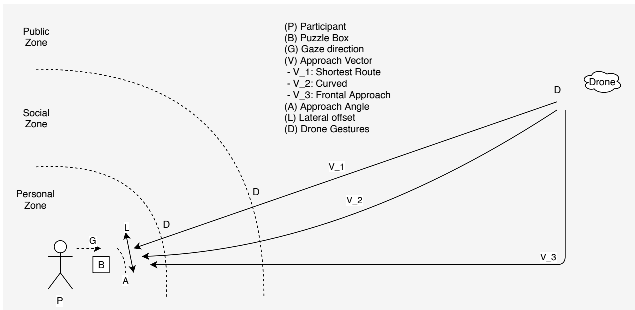

Figure 15: Three methods of initiate approach from drone to the target.

Another suggestion would be to have the participant moving (either in virtual or real space) while conducting the experiment to see if this has an effect on the felt certainty and measured performance.

Finally, it would also be interesting to conduct the test in a real life setting with multiple real drones flying above and delivering packages to the participant. However, at the time of writing, this can prove to be a task that is difficult to perform with current regulations regarding drone flight and safety.

7. CONCLUSION

This paper explores a scenario where drones deliver goods directly to people. In relation to this scenario it is tested what kind of approach trajectory is easiest and fastest to recognise by the drone intended target. The experiment tested four trajectories that were in the range of 0° to 65°. From the data gathered we can conclude that drones approaching a person with a vertical approach angle of between 0° and 15° induces a faster reaction time in our participants. In comparison, approaching a person from above while arcing downwards and ending at a vertical approach angle of 65° induces the slowest reaction time in our participants.

In terms of our research question, *"In which trajectory is the drone most recognisable?"*, we found no single approach trajectory to perform the best, either in terms of measured reaction time and self-reported ratings of uncertainty.

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