See me, See me: An exploration in when and how drones should acknowledge a nearby person

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ABSTRACT

This paper presents the distance and gesture difference at which acknowledgement should be established for drone to human communication. We present three studies on human drone interaction. Specifically we 1. Identified the distances at which people wanted to be acknowledged by a drone. 2. Implemented four embodied drone gestures based on non-verbal human gestures (nod, toss, gaze) and fixed wing wobble acknowledgment signal; and evaluated how these perform in eliciting acknowledgement in people. 3. Evaluated how a combination of previously used gestures perform in a crowdsourced study using video recorded clips. Results showed that contrary to human robot interaction findings people want drones to communicate acknowledgement earlier than with humans/robots and for embodied gestures rotating the drone towards the receiver of the gesture elicits a higher degree of acknowledgement than without. Indicating that drones should perform gestures directly towards the person which it wants to acknowledge or communicate.

Author Keywords

Drone; UAV; Quadcopter; Online survey; Acknowledgement; Proxemics; Embodied gesture.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

As drones are becoming more autonomous and intelligent they are also becoming part of everyday life inevitably having to interact with humans for transactions (e.g. deliveries). To initiate contact with humans a drone will need to establish mutual awareness before interacting with the person it has to communicate with. In human - human interaction this is called the greeting phase and is normally used to ensure that both parties acknowledge each other and are ready to communicate.

Earlier research have looked into ways of drone to human communication by adding technologies to the drone (e.g. LED strips to communicate directional intent) and found that it improved speed and accuracy in predicting the intent [19]. However, there is no research investigating at what distances a drone should acknowledge a person or how to embody this acknowledgement.

This has motivated us to build on related human - robot and human - drone interaction proxemics [21, 20, 16, 3] research to investigate the distances for drones and explore embodied gestures that can acknowledge a person.

The aim is to establish comfortable distances for a drone to communicate from and to explore what embodied gestures a drone can perform to elicit the feeling of being acknowledged. We performed a distance experiment using an semi-autonomous drone in which people were approached and had to approach. Relevant literature on human greetings and gestures were used to develop four gestures which were used in an experiment. Finally based on feedback from the gesture experiment three new gestures were developed and used in an online survey. We found that the distances for drones were different than related robot and drone research and which gestures worked best at communicating acknowledgement.

RELATED BACKGROUND

Proxemics

Using drones in a social setting requires knowing the spatial zones at which people are comfortable interacting with them. Hall coined the term proxemics as the study of space used by humans, how we in relation space arrange ourselves and objects and how it makes us feel less or more comfortable [7, 6]. He defined human to human spatial zones that were later summarized for northern European demographics by Lambert (Table 1)[12].

Personal Space	Range (m)	Situation
Close Intimate	0 - 0.15	Lover or close friend touching
Intimate	0.15 - 0.45	Lover or close friend only
Personal	0.45 - 1.2	Conversation between friends
Social	1.2 - 3.6	Conversation with non-friends
Public	3.6+	Public speech making

Table 1: Spatial zones (Human to Human)

The human - robot interaction (HRI) field has researched how spatial zones differ from human - human to human -

robot. In the field of human - drone interaction (HDI) little research has replicated or studied drone spatial zones. Therefore HRI proxemics research is used to better understand how to investigate HDI spatial zones. Research with robots [21, 20, 15, 9] and drones [3] has shown that distance for human - robot and human - drone interaction is avg. 0.83m for 73%-91% of the people and as close as avg. 0.3m for 40% of the people. An approach the robot and be approached by the robot procedure was used in [21, 20] with people approaching as long as they felt comfortable and say stop when they started to feel uncomfortable being approached. Additionally [20] had the robots head gaze at either feet or head during the procedure. In [9] people had to walk around alongside a robot for 15 minutes performing different tasks such as showing the robot around and showing it objects in the environment, whereas [15] had people passing a robot. For [21, 20, 9] performed their experiments in a living room setting while [15] performed the passing in a hallway. The PeopleBot$^{\mathrm{TM}}$ (Fig 1) robot was used in [21, 15, 9] and a Personal Robot 2 (Fig 1) was used in [20].

Robot speeds ranging from 0.25m/s to 1m/s was used to investigate the level of comfortability when being approached. The procedure was similar to [21, 20]; they however used a mobile personal robot (Fig 1). People preferred speeds of 0.38m/s and reported 1m/s the least comfortable. In another study people preferred higher speeds (0.6m/s) in a hallway passing experiment compared to (0.5m/s), however the robot did not move faster than 0.4m/s during passing [16]. In a similar experiment to [16] a speed of 0.7m/s was used but was not evaluated [18]. The studies [21, 20] use speeds between 0.5m/s and 1m/s but does not report on it. Emotional states for a drone were defined and investigated for how well they were recognisable. The emotional states had a AR Drone 2.0 (52cm by 45cm, Fig 1) fly at speeds ranging from 0.5m/s to 3.5m/s. People could precisely identify the emotional states by observing the behavior and response of the drone [2]. Indicating that drone speed does not change people's perception of embodied gestures to communicate emotional states.

An AirRobot AR-100B (102cm by 102cm, Fig 1) drone was used to investigate the effect of height (1.5m and 2.13m) on comfortable distances hypothesising that there would be a difference. The experiment was conducted similarly to [21, 20, 16]. The drone was mounted on a rail in the ceiling with which it was possible to adjust the height of the drone to the heights used. They reported there were no difference in the distances based on height [3]. Considering the robots used in the studies [21, 20, 9, 15, 1] (PeopleBot$^{\mathrm{TM}}$, Personal Robot 2 and Nomadic Scout II) had heights of 1.1m, 1.35m and 0.35m and reported similar findings of comfortable distances being in the personal spatial zone indicates that height can be anywhere from 0.35m to 2.13m.

To investigate social spatial zones for drones, it is important to start outside this zone (further than 3.6m).

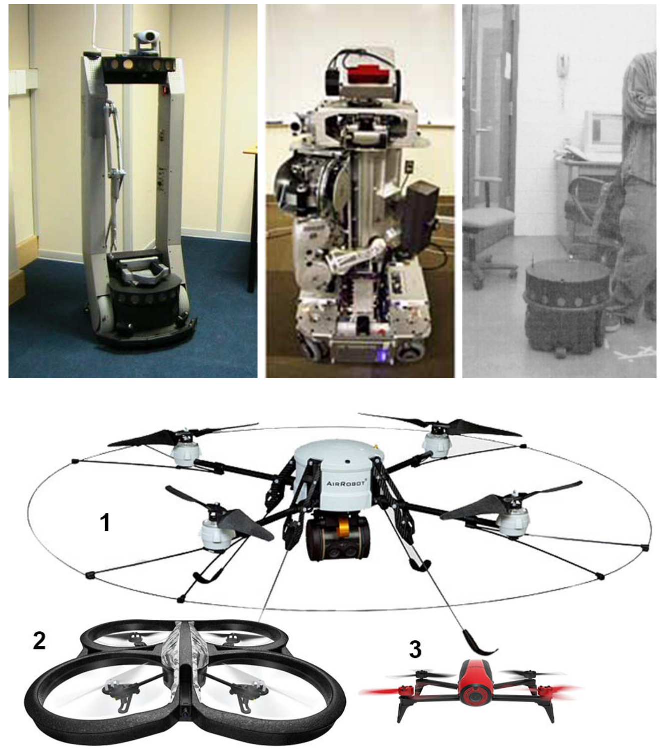

Figure 1: Top row: PeopleBot$^{\mathrm{TM}}$, Personal Robot 2 and Nomadic Scout II. Bottom row: AirRobot AR-100B (1), Parrot AR 2 (2). Parrot Bebop 2 (3). The drones are scaled in relation to each other.

In robotics this is correctly done in [21, 18] that had the robot or person start in the public spatial zone so the experiment required actively entering the social zone. Even with a start distance of 5.5m in [21] people still walked as close as the intimate zone (<45cm). Another study investigated initiating contact in a lobby / shop setting between a human and robot showed that people started their greeting at 2m and stopped it at 1.5m [17]. In the drone study [3] it is not directly reported what the maximum distance was, however the rail at which the drone can move had a length of 3.66m and they report there is a safety limit of 0.6m inferring that the start distance in their experiment was 4.26m. 37.5% asked the drone to stop before it hit the safety limit, which is well into the social spatial zone, indicating that for neither drones or robots the normal human - human social spatial zone apply and that starting distance yield no effect.

The proxemics experiment in this study will use the same procedure of habituating the participant as used by [21] and approaching and being approached as used by [21, 20, 3]. Speeds higher than 0.5m/s will be used considering [2] is more closely related to the premise of this study. Albeit height did not seem to have effect on distances the height of the drone will be 1.5m or above. To resemble a real life scenario of a drone approaching a person (e.g. delivering a package) the operational area might be larger. The starting distance of the drone should begin in or further out than the public zone (3.6m - 7.2m).

Non-verbal Gestures

Vital greeting behaviors occur before interaction can happen between people [10]. These behaviors normally consist of nonverbal communication and follows a structure of 6 phases; sighting, orientation and initiation of approach, distance salutation, approach, final approach and close salutation. This paper will focus on sighting and distance salutation.

1. Sighting, orientation and initiation of approach
Beginning a greeting varies from person to person. Typically it starts when one person has noticed the other and orients their gaze towards them. For initiation of greeting before the other persons gaze is met, the head is oriented toward them.

2. Distance salutation
When both gazes have met what follows is typically a physical movement as an indication the greeting is engaged. The bodies are either oriented towards each other or one or both typically perform one of the following physical behaviors; *wave, head toss, head lower, nod*, or *head dip*. This study will only focus on the head movement behaviors as they are implementable as drone motions.

- *Head lower, Head dip, Nod* are of the more common distance salutations. Nod is typically performed in passing with the head raised rapidly after being tilted downward. Head lower is kept tilted downward for a little while before being raised again. Head dip often follows another distance salutation and is hypothesized by Kendon as a confirmation to proceed to next phase of the greeting.

- *Head toss* is tilting the head backwards and forward rapidly.

In conversation the listener is actively participating using non-verbal listener response or back-channel communication without interrupting the speaker [11, 8]. Nodding is one type of non-verbal responses used in conversation and was found to have head tilted between 11.2°to 26.8°[5].

Mutual attention between an outdoor autonomous drone and people has been investigated. In the experiment they used a Asctec Pelican quadrotor (65cm by 65cm) that would reply to hand waving with a wobble / waggle behavior which is also commonly known in fixed wing aviation as an acknowledgement / message received gesture [13]. In aviation it is used by pilots to signal to grounds people who are not in radio contact [14, 4].

The gesture experiment and online study described later will use the gestures *nod, toss, waggle* and rotation of drone which will be mentioned as *gaze* gesture.

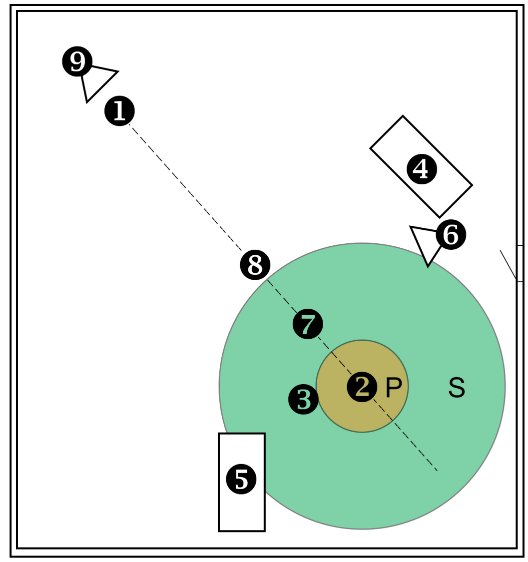

Figure 2: Experiment and filming area. P and S respectively show the personal and social spatial zone.

APPROACH

Three user studies were performed. The first in situ study investigated drone - human proxemics with the hypothesis that drones would have larger distances than robots. The second in situ study investigated which embodied gestures would mostly elicit the feeling of being acknowledged by a drone passing by. The last user study was performed online with video recordings of a baseline gesture and three combined gestures from the previous study. Both in situ studies and the recordings were performed in a closed off 14 by 12 meter workshop area (Fig 2).

PROXEMICS EXPERIMENT

Method

Participants. Sixteen volunteers (7 female, 9 male) participated in the study. *Average height 178.9cm (sd = 8.91). Each were recruited at the Department of Architecture, Design, and Media Technology at Aalborg University Denmark and were a mix of students and employees.* Nine had no experience with robots and 11 had heard of or no experience with drones. Participants were initially selected on the premise that they had no technical background or experience with drones. It was assumed that participants having experience with drones would have lower distances than those without due to already being accustomed to working with drones [20].

Design. The independent variables were being approached by the drone or approaching the drone and when being approached by the drone it would be either to the left or right side of the participant. Each participant would be approached and had to approach the drone twice for reliability. A double Latin square design was used. We believed that the first encounter would

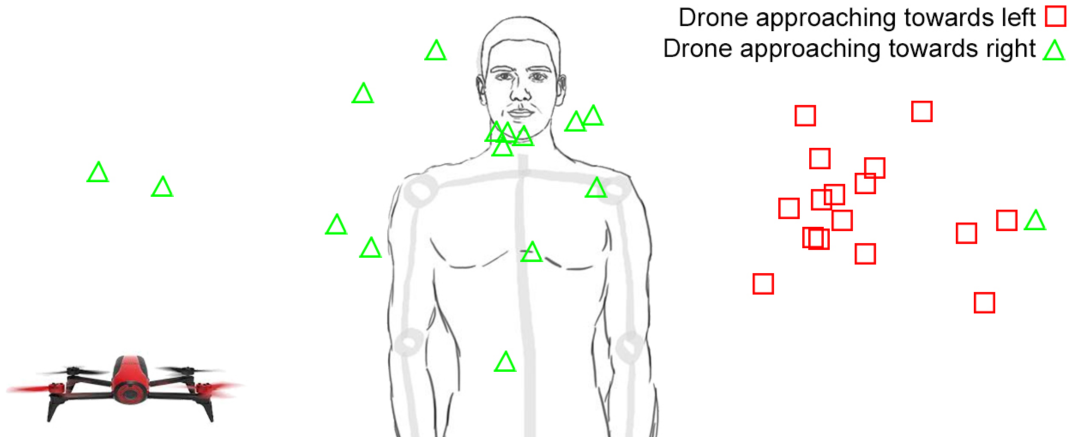

Figure 3: Drone lateral and horizontal offset at stopping point when approaching participant. Parrot Bebop 2 drone sized relative to body figure.

have larger distances to the drone than the second encounter. Later analysis found that this was not the case. The dependant variable was the distance at which the participant wanted the drone to acknowledge their presence when being approached and where they stopped and wanted the drone to acknowledge them when approaching it.

Equipment, Stimuli and Testing Conditions. A Parrot Bebop 2 drone (38cm by 33cm, Fig 1) was used in combination with an IndoTraq^{TM} tracking system and a host machine with in-house developed software to control the drone. The tracking system was used to track the drone so the software could control it and for measuring distances. The software was developed with scenarios reflecting each independent variable (approaching, being approached, left and right). When the participant had to approach the drone it would have to hover in place. Drones tend to drift due to wind and the software countered this. For drone approaching the participant the software would generate a flight path from its starting point to the participant and then adjust it 2°either to the left or right. Video analysis showed that when the participant was supposed to be approached at the right side delays in the tracking system resulted in the drone approaching them more randomly and at the left side far enough away that it would have flown past them (Fig 3). This resulted in a flight that from the point of view of the participant would seem as though the drone would hit them or fly past them. The drone approached the participant at a speed of 0.7m/s. At take off the drones fly height was manually adjusted to a height of approximately 1.5m.

Procedure. The participants entered the workshop area (Fig 2) one at a time. Numbers in the figure indicate: drone starting / hover point ❶, participant starting position ❷, facilitator table with consent form and demographics questionnaire ❹, host machine table ❺ , camera position ❾. Numbers not mentioned yet are used in later experiments. They were asked to sign a consent form and fill out a demographics questionnaire while the drone would hover for 1 minute at its starting point to habituate them of the drone. They were then given an introduction with the context that in the near future drones will be intelligent and autonomous and we want to investigate when people want to be acknowledged by drones. They were guided to the starting point and given information on what was about to happen at which point video recording was started. If being approached by the drone they were given the following information: *"In this task the drone will fly towards you. It is intelligent and will respond to you. What we would like you to do is to say stop when you want the drone to actively acknowledge your presence. If it gets too close for comfort you can also step away."* and for approaching the drone they were given: *"In this task you will approach the drone. The drone might or might not physically inform you that it has registered your approach. Stop when you would want it to actively acknowledge that you are there."*. After each interaction they answered a post task questionnaire while the distance was registered. The procedure was repeated four times with two times approaching the drone and two times being approached. The post questionnaire for when being approached contained a yes / no question on whether they felt uncomfortable during the experiment, a 1-5 scale of how the speed of the drone was with 1 being too slow and 5 being too fast, a scale of 1 - 5 of whether the fly height was comfortable. For the questionnaire after approaching contained a yes / no question on whether they felt uncomfortable during the experiment.

Results

Figure 4 shows the acknowledgement distances (mean and 95% confidence levels). When being approached horizontal drone offset from center of body mid line affected acknowledgement distances ($\chi^2(1)$=6.3, p=0.012), increasing it by 1.11cm $\pm$ 0.42(standard errors) the further

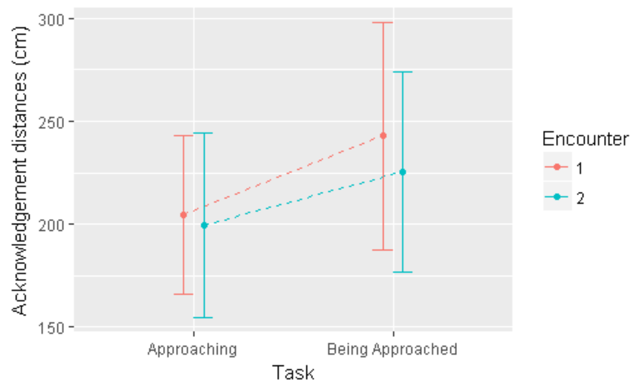

Figure 4: Acknowledgement distances as a function of task and encounter with .95 ci error bars.

away the drone was from the body mid line. There were no significant difference in stop distance when being approached or approaching the drone. Previous drone or robot experience had no significant influence. According to the questionnaires the participants found the speed at which the drone approached them (avg. 2.9) and the fly height (avg 2.9) was about right. Six out of sixteen felt uncomfortable while being approached during the first encounter and two during the second encounter. Two out of sixteen felt uncomfortable approaching the drone during both encounters. A one sample t-test was conducted to investigate if the mean distance was higher than related proxemics research (120cm) and showed significant difference; t(3.13)=15, p=0.003, confirming the our hypothesis that drone distance is higher.

Discussion

Participants wanted the drone to acknowledge them in the social zone (1.2m - 3.6m) which is a significantly increased distance from related robotics and drone experiments. We believe this is because the drone without a safety guard exhibits more danger than a ground moving robot or a drone flying with a safety guard attached. The overall average distance (2.18m) however does align itself with the greetings distances found in [17] where people started greeting the robot at a distance of 2 meters. A few of the participants mentioned that they felt uncomfortable during the experiment with comments such as *"I don't like propellers at eye height :D"*, *"Slightly intimidating having a non-human agent approach you in such a way - in mid air, when its not visibly attached to anything"* and *"It was kind of hard to judge when it will become too dangerous. . ."* indicating that our belief of not having a safety guard and that the drone can fly freely in all directions increases the distance. Our results also differ greatly from the drone proxemics study [3] where distances were shorter than our results. Their drone was equipped with safety guards around the propeller and attached to a rig in the ceiling only moving at 0.2m/s under 1/3 of the speed used in our experiment. Further-

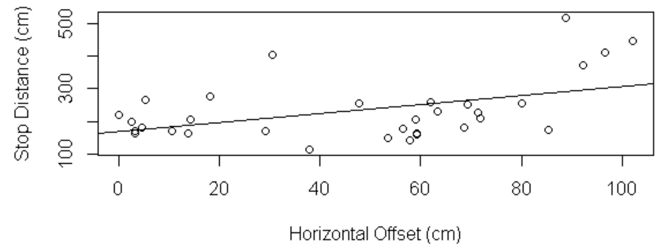

Figure 5: Acknowledgement distance as a function of horizontal drone offset from body mid line.

more participants were instructed that everything was under control and that the drone could not harm them.

The design of the experiment was meant to be balanced by being approached from either side, however technical difficulties resulted in offsets where most of the right approaches did so directly at the participant and left approach so far out the drone would simply fly past them. Figure 5 shows a plot of the horizontal offset vs the stop distance with the line showing the linear relationship. In the results there are a few outliers with stop distances higher than 350cm $\pm$ 20 which are outside of the social space defined by [7].

The participants were asked during the experiment if they were sure about their distances to which they all answered that that was the distance they wanted the drone acknowledge them. An interesting note in the linear relationship between offset and distance is that it increases as the offset gets higher. We initially believed that it would be the other way around with stop distances being reported higher the closer the drone was to the body based on results in [16] where the closer the robot passed them in a hallway setting the less comfortable their participants felt.

We found no evidence that drone, robot or pet experience decreased the distance people wanted the drone to acknowledge them. Whereas Leila found that pet ownership and robot experience, decreased their participants distances from the robot [20]. This could suggest that the more people are used to being with robots or pets the less you care about them getting closer, however the distance at which acknowledgement should happen is still the same. Another factor is that proxemics studies looked at what distance the robot or drone was being uncomfortable close to them, where as our study looked at the distance of which they wanted the drone to acknowledge them. We found no difference in being approached or approaching similarly to [21, 20, 9].

GESTURES EXPERIMENT

Method

Participants. Sixteen volunteers (9 male and 7 female) were recruited from the same place and premise as the Proxemics experiment.

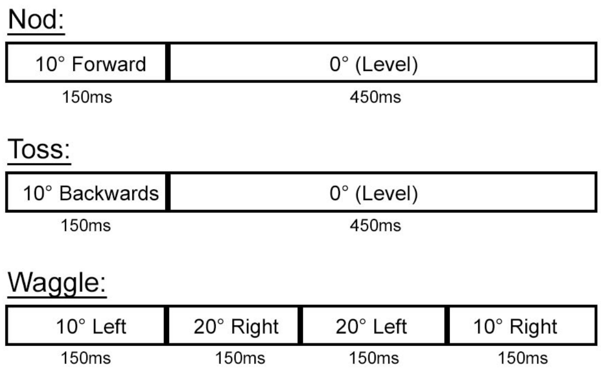

Figure 6: Timings, direction of rotation and degree of rotation per gesture.

Design. The independent variables *gesture* (gaze, nod, toss and waggle) and gesture *distance* (near and far). Both gesture and its distance were varied within participants with each participant experiencing the near and far distance twice. To ensure novelty and balance a latin square design was used which allowed us to alleviate first encounter responses versus the following responses. The dependant variable was the participants degree of feeling acknowledged by the drone.

Equipment, Stimuli and Testing Conditions. A new software application was developed using the same technical solution as the proxemics experiment. The gestures were programmed using a fixed amount of time and amount of degree of rotation in desired direction (Fig 6) and to be activated when reaching the near or far gesture distance. Due to the physicality of drones; drone will fly in any given direction it tilts and tilt amount affects speed; trial and error was used to adjust the tilt value of the drone and timing of the gesture so that they resembled respectively a nod, toss, waggle and gaze while still being safe to fly. The timing diagram shows that for nod and toss a 10°and 0°angle was used with the 0°being used to keep the drone level for a fixed amount of time before the systems control would take over again. Both gesture distances were based on results from the proxemics experiment with near distance (2.18m) being based on the average distance and far on a density plot of the distances (Fig 7). We used 4m as the far distance based on the second peak in the density plot. The software was developed to generate a flightpath from the drones current position and along the dotted line (Fig 2) at each start of the flight. This makes sure the drone flies closely along the path. During development we experienced problems with the drone having excessively unstable flights if flight paths were not generated per flight. Based on the results of the Proximity experiment flight speed and height were kept at 0.7m/s and 1.5m.

Procedure. Participants entered the workshop area one at a time. For this experiment the numbers (Fig 2) indicate: participant position ❸, camera position ❻, near gesture position ❼ and far gesture position ❽. Drone

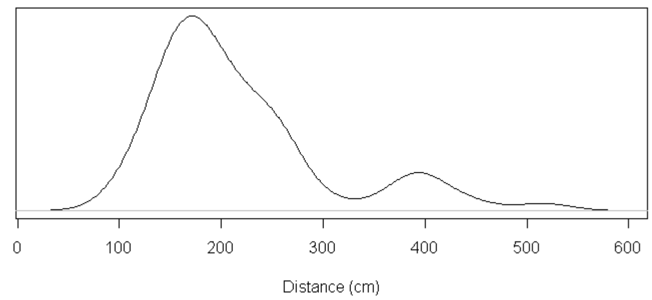

Figure 7: Density plot of Proximity experiment distances

start position, facilitator table and host machine table were positioned the same between experiments. Participants were instructed to sign a demographics questionnaire and consent form at the facilitator table. They were then introduced to the experiment and guided to the participant position. At this position they were told that the drone was about to fly and would do something during flight; and that it will happen four times. After each flight they answered a post questionnaire which contained three questions: *"What did the drone just do?"*, *"What did that mean/indicate to you?"* and *"To what degree did you feel like the drone acknowledged your presence? (Answer in percentage)"*. They were instructed that when answering the degree they were allowed to also add comments to the percentage if they felt the need to clarify their answer.

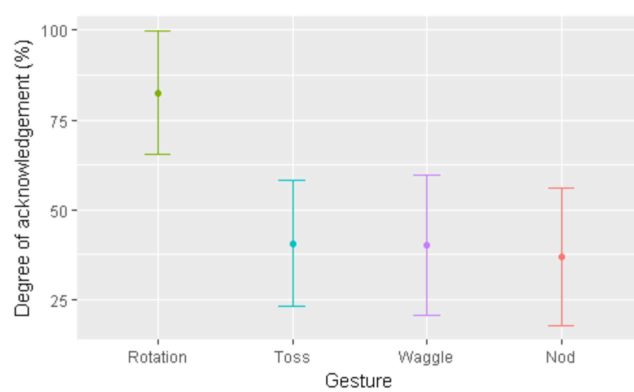

Figure 8: Degree of acknowledgement by gesture with .95 ci error bars.

Results

Figure 8 shows the results of acknowledgement degree pr gesture . Analysis of variance on the data showed significant difference in gesture, $F(3) = 6.26$, p=0.0009. Acknowledgement at 2.18m(near) against 4m(far) showed no significance difference in acknowledgement degrees reported. A post hoc Tukey test on gestures showed that gaze yielded significantly higher degrees of acknowledgement than all other gestures (Table 2). Robot and drone experience responses were categorized (none, low, medium and high) with e.g. having seen or heard one would be categorized as low, owning one (e.g. Roomba vacuum cleaner) as medium and building or working with as high. Neither drone or robot experience had an effect on the degree of acknowledgement.

Gestures	Difference in means	Lower confidence interval	Upper confidence interval	Adjusted p-value
Gaze-Nod	45.635	13.16	78.07	0.003
Toss-Nod	3.75	-28.71	36.21	0.99
Waggle-Nod	3.34	-29.09	35.84	0.99
Toss-Gaze	-41.88	-74.34	-9.41	0.006
Waggle-Gaze	-42.25	-74.71	-9.79	0.006
Waggle-Toss	-0.38	-32.84	32.07	0.99

Table 2: Tukey post hoc results on gestures.

Discussion

The gaze motion showed significantly larger degree of acknowledgement established than nod, toss and waggle. Kendon found that normally mutual eye contact would be established between humans before resolving in a head toss, nod or a hand wave, the drone, however performed the motions without facing the participant except for the gaze motion. From the results and from Kendon's findings, it could suggest that eye contact or the semblance of eye contact is essential before communicating acknowledgement gestures. Acknowledgement degree between near and far execution distance did not yield any difference indicating that the 2.18m should be seen as a minimum distance where as all the way to 4m does not influence the percieved acknowledgement. One of the participant mentioned before leaving the experiment area that the gestures would work better if paired with gaze. Essentially creating a gesture in which the drone would first rotate its body towards the participant and then perform the gesture. This will later be investigated in the online survey. Some comments from the quantitative analyses supports the findings in the proxemics study with comments such as *"It kept a fine distance from me"* and *"It will not hit me, if i'm in the way it will fly over me"*; suggesting that the participant felt acknowledged, and that the drone knew they were present.

ONLINE STUDY

Method

Participants. One hundred and twenty-nine (113 male, 15 female and 1 other) participated in the study. The volunteers were recruited from subreddits (SampleSize ,Drones, Multicopters) on the website www.reddit.com with respectively 41k, 21k and 42k readers and two Facebook groups with 4.9 and 6.5k members for people attending the University.

Design. The independent variable within participants was gesture (gaze, "gaze and nod", "gaze and toss", and "gaze and waggle") and between subjects it was camera pan (pan and no pan).Every possible gesture order was used and was varied for each participant. The dependant variable was to what degree they felt their presence was acknowledged.

Equipment, Stimuli and Testing Conditions. The software and technical solution from the Gesture experiment was used with the three new gestures added. Each of the new gestures are a combination of rotation and their gesture. A 150ms rotation in and 150ms rotation out were added to them to allow for the drone to rotate towards the participant before performing the gesture. A Panasonic PV750 camcorder mounted on a tripod at height of approximately 1.7m (based on average height from results of previous experiments minus 0.1m to get the approximate eye height) was placed at the participant position from the Gesture experiment. For the no pan recording it was positioned such that the drone would start in the topleft of the view and fly out of view in the bottom right. Positioning the camera this way ensured that the entirety of the flight was recorded. For recording with pan one facilitator would follow the drone with the drone in the middle of the viewport as best as possible while stopping the pan at approximately the same point as the recordings with no pan (Fig 9). The recordings were post processed so that the drone had similar starting positions in the frame and a similar length of 10-13sec. Additionally the recordings with pan were stabilized to improve smoothness of camera movement. An H263 codec encoded all video clips at a resolution of 720p.

Procedure. When participants opened the link to the Google Form questionnaire they were presented with a eleven page questionnaire. The first page shortly mentions that they were to fill out a demographic and following watch four short video clips and then for each answer a few questions. The demographic contains the same questions as in the previous two experiments, however it also contains an image of a quadcopter on top of the question regarding drone experience. This is to make sure each participant understands which kind of drones the question relates to. The third page contains a text about the context and an explanation that in the next pages they will be asked to open a link to a video clip and then answer questions. They were told to imagine themselves in a future were drones are a part of everyday life and that they are standing outside watching their surroundings. The rest of the pages are repeats of an intro page and questionnaire page for each video. The intro page asks to watch the following video, that they can watch it as many times as they want, that they remember to have audio turned on and finally that when ready to answer they can close the browser tab with the video clip. The link to the video is coded so that no unwanted information is shown[1]. The questionnaire asks the same questions as in the Gestures experiment. However in this questionnaire the question To what degree did you feel that the drone acknowledged your presence? was a 0 - 10 scale with 0 being 0% (Not at all) and 10 being 100% (Fully). Additionally an Any additional comments? was added.

[1] `https://goo.gl/aETl8b`

Figure 9: Drone position in camera viewport. Top row: No pan recording at beginning and end. Bottom row: Pan recording at beginning and end.

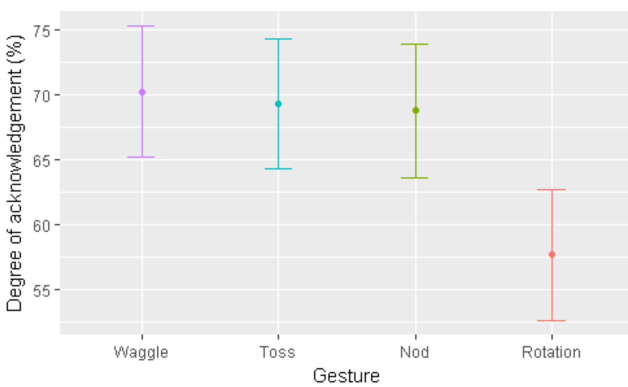

Figure 10: Degree of acknowledgement by gesture with .95 ci error bars.

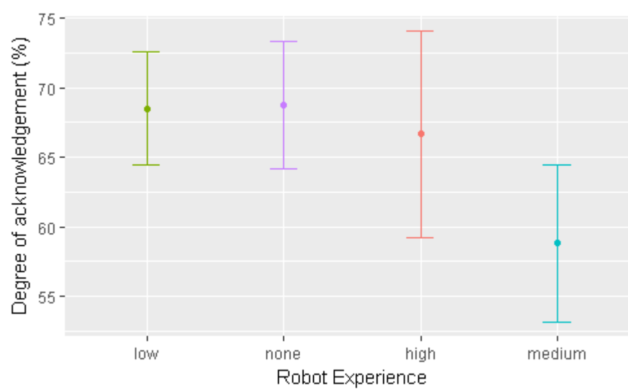

Figure 11: Degree of acknowledgement by robot experience with .95 ci error bars.

Results

Figure 10 shows the results of degree of acknowledgement per gesture. Analysis of variance on the data showed significant difference in gesture, $F(3) = 2.83$, p=0.038. A post hoc Tukey's HSD test showed significantly higher degrees of acknowledgement from the combined gestures than gaze at the .95 confidence level. This indicates that to have optimal communication it should be performing the embodied gestures directly at the person. Analysis of variance on robot experience also showed significant difference, $F(3) = 2.95$, p=0.032 (Fig 11). A post hoc Tukey's HSD test showed no experience and low experience were significantly higher than medium experience. There were no significant difference in drone experience.

Discussion

Results from the online study showed that the baseline gaze gesture on average elicited the lowest degree of acknowledgement (57.7%) whereas nod, toss and waggle were at respectively (68.8%, 69.3% and 70.2%). This shows that when performing a gesture doing so directly at the person with which the drone has to communicate is optimal. Compared with findings from the acknowledgement experiment where gaze alone on average was rated at (82.5%) and the other gestures at (36% to 40.6%) verifies that gaze is a very strong component when drones has to acknowledge or initiate communication with people. That nod, toss and waggle was rated nearly identical was somewhat surprising for us. We had believed that nod would elicit the strongest sensation of acknowledgement as it is used in Western and European countries in the greeting phase to initiate communication [10]. We find it interesting that robot experience showed significant difference between none and low against medium (Fig 11) with a difference of 10%. However we believe it can be neglected as the difference in our opinion is low and the survey was conducted online and very subjective. The categorization of low experience was for people who had only heard of or seen a robot where as medium was categorized for people who owned a robot. Owning a robot involves interacting with it and experiencing different forms of communication, e.g. a Roomba vacuum cleaner uses beeping sounds as notifications for when it start and stops. That experience might have influenced those to rate the degree of acknowledgement lower due to them being used to different kinds of communication whereas those who only heard of or had seen a robot would not have this experience.

A total of 135 participated in the survey, however 6 were removed due to inconsistent or unusable responses (e.g. 0 degree of acknowledgement on all videos and leaving everything else blank). We believe this is because of the sites we chose to use to publish the survey, Reddit and Facebook groups where essentially anyone with an internet connection can join. Another option would have been using services such as MechanicalTurk with which people can get paid a small amount of money to participate in the survey, this however poses other problems such as people answering as many surveys on MechanicalTurk as possible to earn money and thereby not properly spending the time we would want them to.

The survey used video recordings of gestures which is a different thing than experiencing it in real life. We did code links, so that videos would open in highest quality, be maximized in the browser and asked the participants to ensure sound was on. However we have no way of ensuring that participants kept it full screen or watched the clips till the end. In a future survey using a service that ensures these conditions are upheld is preferable.

CONCLUSION

This paper presented three different experiments. The first free flying drone proxemics distances, integration of human nonverbal gestures in the embodied motion of a drone and how they perform in an online survey where degree of acknowledgement was reported. We contribute the distance (218cm) at which acknowledgement should be established and give examples on how to establish acknowledgement using embodied drone gestures. We found that drones increase the distances at which people feel comfortable interacting with them compared to distances found in earlier robot and drone studies. Through analyses we learned that factors that influences human - drone distances such as pet ownership, and drone experience do not influence the distances kept to drones. Being approached versus approaching showed no difference in the distances measures. The online survey however showed that robot experience changes the level of acknowledgement felt, lower robot experience showed larger degree of acknowledgement. Furthermore our results show that people feel more acknowledge by having the drone rotated towards them, than doing motions without first having established a direction towards the receiver. Pairing the drones orientation towards the receiver before doing gestures, showed to be better at communicating acknowledgement than only rotating.

FUTURE WORK

Drones come in many sizes and we believe this could affect comfortable distances for interactions with drones. Although not investigated in this paper, we also believe the sound of the drone affects comfortability in how close people want drones to approach them. A few comments from the online survey specifically mentions this; *"The sound was overwhelming"*, *"I really hate the buzzing sound these drones make. It reminds me of bugs."* and *"I hope in the future that they get quieter, that noise is by far the most intimidating aspect!"*. The proxemics experiment should be replicated using a different sized drone to investigate if size affects the distances and how sound affects the distances.

Additionally the drone used has a camera lens in the front of it where other drones might have uniform bodies with no distinct sides and as was found to be an important factor for acknowledgement ratings the gesture experiment should be replicated using a drone with a uniform body.

In the gestures experiment only a limited amount of possible gestures were implemented and tested. It would be interesting to study e.g. spatial formations, flying in a circle or bop up and down and how those affect acknowledgement if at all. Also establish meaning of the gestures already studied as they were rated equally in degree of acknowledgement elicited.

ACKNOWLEDGMENTS

The studies were conducted using the IndoTraq™ tracking system. The authors wish to thank the team at IndoTraq™ for their quick responses and invaluable help whenever needed.

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