Investigating Drone Motion as Pedestrian Guidance

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ABSTRACT

Flying drones have the potential to act as navigation guides for pedestrians, providing more direct guidance than the use of handheld devices. Rather than equipping a drone with a display or indicators, we explore the potential for the drone’s movements to communicate the route to the walker. For example, should the drone maintain a constant distance a few meters in front of the pedestrian, or should it position itself further along the navigation route, acting as a beacon to walk towards? We created a set of flying drone gestures and evaluated them in an online survey (n = 100) and an in-the-wild user test (n = 10) where participants were guided on a walking route by a flying drone. As a result, we propose an initial set of drone gestures for pedestrian navigation and provide further design recommendations.

Author Keywords

Drone; pedestrian navigation; human-robot interaction; spatial interaction; gestures.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Mobile and ubiquitous computing is emerging to new form factors, which enable expanding the use of technology to new ways of human-computer interaction. Flying drones are a technology, which has now become mainstream, with drones being available to large audiences at low prices. Through flying drones, computing devices have reached a new level of autonomous mobility, bringing new interactivity possibilities to outdoor spaces. Whereas drone technology can be found off-the-shelf, current applications for its use are predominantly for hobby use or for professional purposes in cinematography or search and rescue tasks. However, flying drones have the potential for a variety of other, currently largely unstudied, purposes.

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Figure 1. A field study participant being guided by a flying drone.

Movies have shown small flying sprites, such as Tinkerbell in Disney’s Peter Pan, guiding the hero along a challenging navigation route. Developments in flying drones in recent years have brought the possibility to actually create such navigation sprites as a near future possibility. Whereas earlier research has already suggested a drone as a companion when jogging or walking [10, 16], the use of the technology has monitoring or documenting purposes. In our research, we are interested in expanding the role of the drone to become a more active partner in the journey, and explore its potential use as a navigation aid.

Using flying drones as a navigation aid, to guide people from one location to another, is a potential use case for the technology. Although flying drones can easily find routes or points of interests (POIs), the vocabulary of how to signal them to a user is not yet clear. Approaches using displays or visual indicators mounted on drones offer one solution. However, solutions using semantic signalling based on the movements of the drone in space offer an interesting alternative that may be advantageous.

In this paper, we explore different movement gestures (cf. “body language”) for flying drones to act as navigation guides for pedestrians, and explore how well they are understood and accepted by people. These research questions are addressed through a field study (Figure 1) and an online survey. Our research paves the way for using drones to aid pedestrian navigation, and forms part of the larger body of research on designing drone-human communication.

RELATED WORK

Use Cases for Flying Drones

Studies on flying drones have proliferated during recent years, but taken the novelty of the area, the research is still sporadic, and leaves room for new exploration. Prior work has demonstrated drones as information links to places which are hard to access, for instance monitoring wildlife in a conservation park [12] or delivering of *in situ* information with a flying display [24]. Hovering displays enabled with drones have been demonstrated with various approaches. Scheible and Funk [22] showcased a drone-integrated canvas and picoprojector for showing messages. Gomes et al. propose self-levitating matter enable with drones, and showcase flying screens as one use case [5]. Drones have also been demonstrated for providing mid-air tactile feedback by Knierim et al. [11]. The usage domain here is immersive virtual reality. The drone is used to create haptic sensations for a user with a head-mounted display, e.g. by physically poking the user’s hand.

Another commonly suggested use for a flying drone is as a companion when on the move, e.g. when jogging [16] or for recording a sports performance [27]. Romanowski et al. have explored utilizing a drone for remote cheering during a long distance running race in a concept where the drone appears in the proximity of the runner during the run [21]. Kim et al. [13] have suggested a drone companion as a safety measure when walking in threatening environments. In our research, we are interested in a somewhat similar setting where the drone can accompany the user, but for navigation purposes.

Mobile Aids for Pedestrian Navigation

Navigation has for long been a popular use case for mobile technology. Mobile phones have been a key technology for a mobile navigation since their early days, e.g. [14]. Extensive amount of work has been done on investigating different visualization techniques on mobile navigation with handheld devices, including the use of augmented reality [4], stereoscopic 3D [20], and utilization of you-are-here maps [25]. Today’s *de facto* pedestrian navigation aid, smartphones, have been recognized for their limitations in this role e.g. engaging the user’s visual attention. This has led to proposing new types of solutions, especially in the area of body-worn systems. Shoe integrated systems have been demonstrated for way-finding [23] and for pedestrian safety for uneven ground [9]. Also other new type of navigation solutions such as tactile belts [7] and electrical muscle stimulation [19] have been suggested.

Drone Navigation and Gestures

Using a drone as a navigation aid for visually impaired people has been investigated in [1], and Obaid et al. [18] have explored the use of drones to guide users to trash cans using light beams. The behaviour of a flying drone and its interpretation has so far been explored from the viewpoint of human-robot interaction and affective computing [2, 3, 10]. Cauchart et al. [2] present a Wizard-of-Oz study on how people prefer to interact with drones, and report communication styles similar to those used with pets, combining gestures and voice. The addition of representations of emotional components to drone flying pattern is investigated by Cauchart et al. in [3]. Kim et al. [10] have investigated drone gestures in the context of what kind of behaviour people would like to have for a drone companion. They conclude, e.g. that many people wished their drone to act like a friend or a pet companion, and combine both utilitarian and hedonic aspects. However, these in prior art cases on drone gestures do not address the context of pedestrian navigation.

Rather than relying on indicators or displays mounted on the drone, we aim to convey instruction by the drone’s movement i.e. by the drone’s “body language” or gestures. This approach has been used by Hieida et al. [6] who report on the emotions conveyed by particular drone movements. To create solutions suitable for adoption by large user groups, the understandability and acceptability of different drone gestures for different contexts and messages should be studied.

Motivation and Novelty of Our Work

Current smartphone based pedestrian navigation solutions require users to hold the device in hand and take the user’s attention from their surroundings. In addition to personal navigation, use cases such as emergency services can benefit from improved pedestrian navigation solutions. To the best of our knowledge, we present the first work aiming to define a gesture set for flying drone movements to guide pedestrian navigation. In contrast to prior work that has used the drone as a means to carry a flying display or used illumination [18, 23], we explore the movements of the drone itself as a potentially rich and expressive communication medium between flying drones and human pedestrians.

GESTURE SPACE FOR DRONE - PEDESTRIAN GUIDANCE

Navigation Guidance Commands

Our domain of focus is that of urban pedestrian navigation. In this context, we considered *Walk straight ahead*, *Turn a corner* and *Cross a road* to be the core actions to be communicated to the user (see Figure 2), these being the fundamental actions when commuting from one place to another on foot. Especially, crossing roads has been highlighted as a central part of pedestrian navigation, e.g., Hill reports on walkers’ risk assessment when deciding to cross [7]. Guidance on road crossing has been explored e.g. by Shangguan et al. [26], who explored a smartphone based solution for the blind.

A cursory approach to drone based pedestrian guidance is that the done maintains a fixed distance a few meters in front of the walker, such that the pedestrian follows like a “dog on a leash”. However, this may result in the walker’s attention being too heavily focused on the drone, reducing awareness of environmental dangers. Additionally, this approach does not support the preferred approach of pedestrian navigation, that of walking towards static landmarks [15]. Thus, we consider approaches where the drone flies some way ahead of the pedestrian and presents guidance though its movements in space.

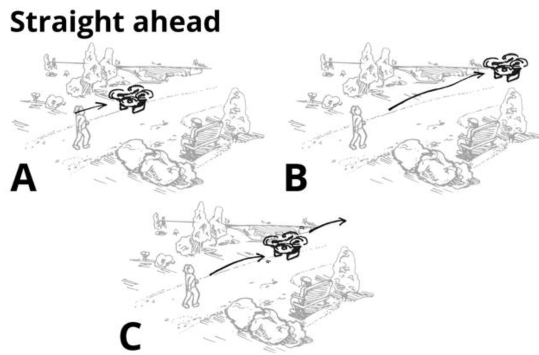
Design of Drone Gestures

Previous work on movement based robot-to-human interaction has utilised Laban motion as a design framework, separating the elements of motion into weight, space and time e.g. [6, 17]. Here, the focus has been largely on the emotion implicit in the gesture. Considering non-emotional gestures with semantic meanings, Zehng et al. [28] explore gestures of humanoid robots, for example exploring a “come here” gesture which is of relevance to our navigation task. Table 1 identifies the possible elements of drone movement that may be combined to form simple gestures that are visible at some distance, which were used as a starting point for the design.

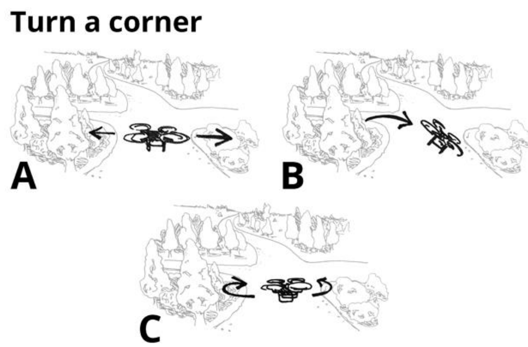
Drone action	
Drone distance from user	• Just ahead of user e.g. 3m in front • Hovering some distance away from user (beacon) and moving in e.g. 10m steps when user approaches current position • Hovering at next navigation action point e.g. the next turn (could be out of current view)
Drone motion *	• Vertical (up-down) • Horizontal (left-right & forward-back) • Rotation about x-axis • Rotation about y-axis • Rotation about z axis

Table 1. The possible elements of flying drone movement that may be combined to create simple gestures, visible from some distance. * The motions may be continuous or looping by returning to the initial position. In the latter case the speed of forward and return motions may be differentiated to emphasize one direction e.g. by more rapid motion.

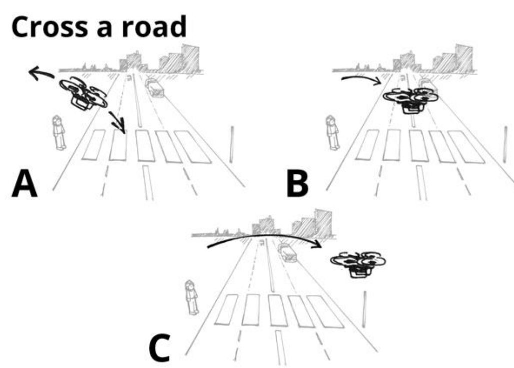
Based on possible motions (Table 1) and on the prior work, particularly the drone movements defined by Hieida et al. [6], and following the basic principles of animation, we defined 3 alternative drone motion gestures for each of our 3 navigation commands (Figure 2). For our initial gesture set we chose to use simple gestures consisting of only one type of drone movement. The selected gestures were then validated with an experienced drone pilot, and adjusted as required. The command *Cross a road* lacks a well understood semantic translation, requires the pedestrian to make complex decisions, and is a critical element in pedestrian safety [7]. Thus, for this gesture we adopted a more experimental approach, aiming to explore the perceived risk of the pedestrian simply following the drone across the road without regard for traffic conditions.



A: Drone moves maintaining 3 m in front of pedestrian
B: Drone positions itself far ahead as a static beacon
C: Drone positions itself 10 m ahead, when user reaches that point the drone moves a further 10 m ahead.



A: Drone moves rapidly horizontally in the direction of the turn, and then returns to the start position more slowly
B: As A. but drone tilts in the direction of the turn
C: Drone rotates about vertical axis, clockwise for right turn.



A: Drone stays at the curb and tilts
B: Drone hovers in the middle of the road
C: Drone flies to the other side of the road and waits for the user

Figure 2. The three pedestrian navigation actions explored, each with three alternative drone movement gestures.

STUDY I - ONLINE SURVEY

Study description

We aimed to probe how clearly the participants understood the meaning of each drone gesture, i.e. how *clear* the command implied by the gesture was. Recognizing that the

Figure 3. Online survey video screenshots – Turn a corner (B). The drone is visible as a pink silhouette.

environment in which pedestrian navigation takes place is complex, some easily understood gestures may prove impractical, e.g. due to road traffic or other pedestrians. Thus, as a second dimension we asked participants to consider the *practicality* of each gesture in context. We created short videos showing each gesture in a real pedestrian scenario. The videos were created by filming a pedestrian walking in a city street and then superimposing a drone performing each of the gestures on to the live footage (Figure 3).

The video clips were incorporated in an online survey, in which participants rated each drone gesture and gave free text feedback on the concept. In addition, survey participants selected a preferred gesture for each action and, based on a set of images, selected a preferred vertical and horizontal distance between themselves and the drone.

The survey was promoted in several universities, distributed via mailing lists and social media platforms, and was open for approximately 3 weeks. Altogether 100 participants (44 female) fully completed the survey. The mean age of participants was 28.7 years (SD = 9.4). Of the participants, 28 had flown a drone before including 10 who owned one themselves. Most (71) had at least heard about drones, whilst 5 did not know anything about them.

Results

Rating Scale Responses

The participants' ratings on the suitability of the drone gestures for each navigation action on a 7-point rating scale are illustrated in Figure 4. To identify significant effects, Friedman tests, followed by post-hoc Wilcoxon tests were undertaken. To account for the multiple comparisons a Bonferroni adjusted alpha level of .017 per test (.05/3) was applied as the threshold for significance (Table 2).

For the go s*traight ahead* instruction, participants rated a constant moving drone (A) as preferred, with 77% of participants commenting on the positive side for its clarity and 75% for its practicality. Statistical comparison (Table 2) confirmed the preference for gesture (A) was significant. Accordingly, 69% of participants selected (A) as their preference for s*traight ahead* navigation. For the *Turn a corner* condition, tilting of the drone in the direction of the turn (B) was rated highest, with 74% and 68% of participants rating it on the positive side for clarity and practicality respectively. This preference for gesture (B) was found to be significant (Table 2) and was selected by the 81% participants as their preferred drone movement. Participants reasoning, e.g. "[gesture (B)] indicates clearly the direction of the turn" (p03) and "[gesture (B)] is easily visible from a distance" (p45).

The last navigational direction instruction rated was that directing the pedestrian to *cross a road*. Participants rated the drone flying across the street and waiting (C) highest in terms of practicality and clarity (M = 5.77 and M = 5.15). Considering its clarity, gesture (C) was rated on the positive side by 84% of participants and on the negative side by only 7%. Regarding the preferred distance between drone and pedestrian, participants selected a median distance of 3 m both horizontally and vertically. This seemed to be a perfect distance to not "hit any obstacles" (p68) and be nicely "in the field of view" (p96).

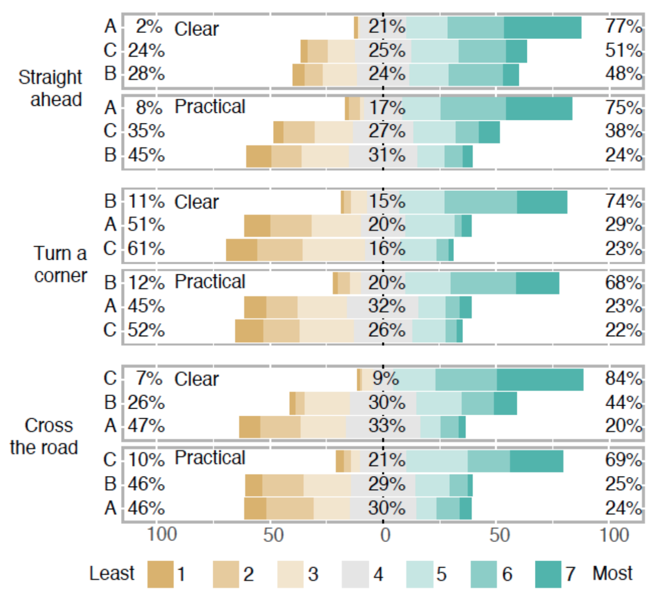


Figure 4. Rating scale results from the online survey for clarity and practicality of the gestures for each context. The percentage values indicate the amount of responses on negative neutral and positive side for each item. For definition of gestures A, B, C refer to Figure 2.

	(A) – (B)	(B) – (C)	(A) – (C)
Straight ahead			
Clear	p < .001 *	p = .332	p < .001 *
Practical	p < .001 *	p = .001 *	p < .001 *
Turn a corner			
Clear	p < .001 *	p < .001 *	p = .303
Practical	p < .001 *	p < .001 *	p = .299
Cross a road			
Clear	p < .001 *	p < .001 *	p < .001 *
Practical	p = .862	p < .001 *	p < .001 *

Table 2. Significant differences in clarity and practicality of alternative gestures. * significant difference between cases.

Qualitative Feedback

The study participants' free text responses were analyzed using an open coding approach: One researcher defined the code-book and coded the responses, followed by a second researcher independently coding the responses based on the code-book. A third researcher then arbitrated the disagreements between the coders. Answers were coded such that an individual answer could produce codes in multiple categories.

In total, there were 71 positive and 74 negative responses related to the concept. Participants particularly liked drone guidance (mentioned by 28%) because they "can observe [their] surroundings while walking" (p74). In contrast, 15% were concerned that they would focus only on the drone instead of the environment. Further, participants preferred drone guidance in comparison to smart phones (26%) since they "don't need to look on my phone anymore" (p70). Concluding, 22% of participants consider the drone approach to be simpler than other navigation aids, commenting they are "easy to follow" (p22) and don't have to "interpret instructions or a map" (p05). On the downside participants were concerned about technical limitations such as noise (30%), battery life (16%) and cost (7%). Additionally, participants were worried (33%) that the drone "may crash somewhere and stop working" (p45). One concern mentioned several times regards scalability (27%), and requires further investigation, e.g. participants asked how to identify their navigation drone if there are several. Suggested future use cases included deploying drones as city sightseeing guides (24%) or as a guide while doing sports (13%) such as hiking, skiing or mountain biking. Survey participants (7%) could also imagine putting navigation drones into service to guide, support and supervise children on their way to and from school.

STUDY II – FIELD STUDY

Study Set-Up

To gain insights from a real world context, we conducted a field study, consisting of a walking tour in a park guided by a flying drone (DJI Phantom 3 Advanced). The walking route was 0.5 km long and consisted of five POI checkpoints (Figure 5).

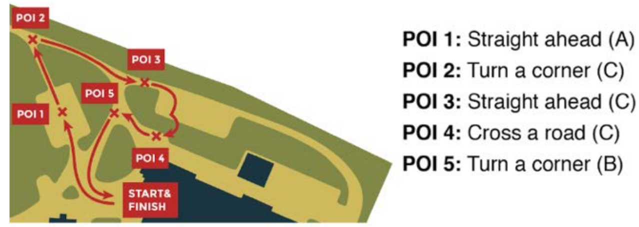


Figure 5. Map of the study walking route, with five POIs.

We selected a set of the gestures necessary for the in-the-wild route from the online survey, aiming to include as much variety as possible. The drone was operated by an experienced drone pilot, positioned behind the test participant, out of their view at all times. Participants completed the tour one at a time (Figure 1), and at each POI navigated based on the drone gesture and gave free form feedback. Following the approximately 20-minute tour, participants completed an end questionnaire. Sessions were shadowed by a researcher and video recorded for later analysis. The field study included 10 participants (5 female), aged from 19 to 49 (*M* = 31, *SD* = 8) of which 3/10 had flown a drone themselves.

Results

The *turn a corner* (B) gesture at POI5 was universally understood. When the drone tilted strongly left several times all (10/10) participants understood it meant turn left, e.g. "Turn left, it's obvious" (p2). Participants had different interpretations for the *turn a corner* (C) gesture, where the drone rotated clockwise around its vertical axis. Here, 3/10 thought it meant "Turn right", 3/10 "Stop!" and 2/10 that it was a warning e.g. "Maybe it tried to tell me to stop or that we are going in the wrong direction" (p3 at POI 2). The *straight-ahead* gestures were both understood by all participants, but with some difference in interpretation. When the drone maintained a short distance in front of the pedestrian (*straight ahead* (A)), 9/10 participant understood it as "follow me mode" e.g., "Well, it tries to tell me to follow it and come here" (p5). This compares with the straight ahead (C) gesture, which 8/10 understood to mean "Go faster" and made participants feel unsafe (3/10) or lacking control (3/10). The *cross a road* (C) gesture, was almost universally misunderstood. It was understood as "follow me mode" (3/10), an indicator of challenges ahead (3/10) or even that you had arrived at your destination (2/10). Participants verbalized their confusion e.g. "I don't have a clue! Maybe I should go there?" (p7 at POI 4).

Participants' preferred distance from the drone, ascertained by flying the drone according to the participants' wishes, was 4.0 m (*SD* = 1.7 m). Preferred flying height for the drone was 2.6 m (*SD* = 0.8 m). The drone's loud noise was commented negatively by 7/10 participants.

DISCUSSION

Our online survey and field survey produced generally similar findings, adding validity to our findings. Thus, we can present a recommended gesture set for drone guided pedestrian navigation.

Straight Ahead Navigation

For straight ahead navigation, the drone should maintain a distance of approximately 3 - 4 m in front of the pedestrian and move at normal walking speed (straight ahead (A)). This contrasts with our initial hypothesis that considered this movement would create a feeling of the drone being in control and become the focus of the pedestrian’s attention (although the latter concern was raised by 15% of survey participants). Similarly, this differs from prior research on pedestrian navigation, which has suggested a preference to walk towards static landmarks [15]. This difference should be further explored in future works on the topic.

Turn a Corner

For indicating the need to turn a corner, both studies delivered a strong preference for a tilting gesture, rapidly towards the direction of the turn and returning more slowly to horizontal (turn a corner (B)).

Cross a Road

Drone motion for cases where the drone is required, e.g. due to environmental circumstances, to move further away from the pedestrian were found to be challenging. Whereas in the online survey participants significantly favored the gesture where the drone crossed the road and waited for the pedestrian (cross a road (C)), our field test participants were generally confused when the drone moved away from them. Thus, it is apparent that gestures for such cases will require further study.

Overall Findings and Limitations

Overall many positive aspects of drone guided pedestrian navigation were reported, such as not requiring the user to hold or look at a smartphone whilst walking, and finding it simpler than having to interpret instructions or reading a map. However, an almost equal number of comments on the negative side were given, mostly related to noise and safety. Indeed, one user in our online survey used extremely strong terms to express his dislike for the concept, and it is likely a view shared by many, outside the novelty effect of our survey conditions. Current commercially available drones are typically rather large and noisy, and are in no way comparable to the guiding sprite Tinkerbell, who we introduced as our motivation. However, we believe the future evolution of drones will no doubt bring small, almost silent drones to the mass market.

We acknowledge that our work is limited by the fact that it does not evaluate the proposed solutions in real use. However, we feel that our combination of a large online survey (n = 100) and a smaller volume field study (n = 10) was a good compromise to gain an initial understanding of the design space. As future work, we plan to conduct a study in a more realistic urban environment.

CONCLUSION

In this paper, we have addressed the outdoor environment as an interactive space for designing human-computer interaction with flying drones. Rather than using displays or indicators mounted on drones, we report on the use of drone movement gestures to guide human walking. Drone guided pedestrian navigation was perceived positively by participants in an online survey (n = 100) and a field study using a flying drone (n = 10), e.g. in its ease of interpretation and lack of need to look at a handheld smartphone navigator. However, concerns related to noise and safety were raised by many participants. Preferred drone gestures for walking straight ahead and turning a corner were identified. However, for other navigation cases such as crossing a road, further work is required to establish suitable gestures.

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