Integrated Apparatus for Empirical Studies with Embodied Autonomous Social Drones

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ABSTRACT

Current use cases for drones often involve a remote human operator and/or an environment which is inaccessible to humans. Social drones, which we define as autonomous drones that operate in close proximity to human users or bystanders, are distinct from these. The design of social drones,

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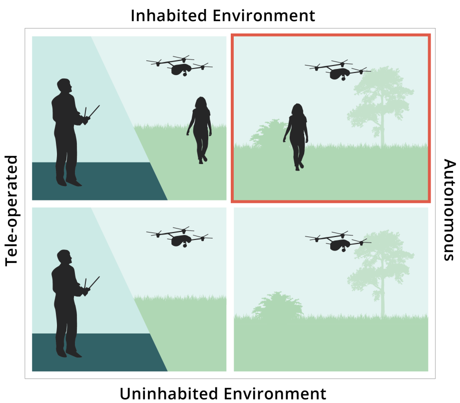

Figure 1: We use the term *social drones* for applications where an autonomous drone operates in an inhabited environment. (Figure from [7].)

in terms of both aesthetics and behavior, can involve particular human factors that require further study. Currently, in lieu of empirical studies with autonomous embodied agents, approaches such as Wizard of Oz methods, questionnaires, videos, and/or makeshift mechanisms are often employed to investigate interactions with social drones. For empirical design research using embodied, co-located drones, we have been developing an experimental setup that enables high precision drone control, as well as rich multimodal data collection and analysis, in an integrated fashion. We present this apparatus and its rationale in this paper. Using this setup, we aim to advance our understanding of the psychology and ergonomics of interacting with autonomous social drones through experiments, and extract design implications.

KEYWORDS

Drones, social drones, autonomous drones, empirical studies, experimental setup, motion capture, motion tracking.

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INTRODUCTION

In the near future, the drone has the potential to become a paradigm of human-computer interaction in itself [7, 13]. Taking advantage of the drone's ability to maneuver beyond human reach, many current use cases for drones involve a remote human operator and/or an environment which is inaccessible to humans (see [1, 12, 24]). Conversely, drones may also operate autonomously in close proximity to human users or bystanders (see Figure 1). We use the term *social drones* to describe this emerging class of applications [7]. Design and development in the context of social drones requires foregrounding human factors, some of which may not have been consequential when a drone is under human control or operating in uninhabited environments.

In previous work, researchers have investigated various aspects of the experience of interacting with social drones, considering the influences of various design dimensions on human experience outcomes (see [7] for a review). However, even though these studies aim to find out more about interaction with embodied autonomous agents, in many of these cases, researchers have not carried out studies using actual autonomous drones. Instead, many studies rely on other techniques: e.g. Wizard of Oz (WoZ) methods, questionnaires, virtual reality (VR), videos, and makeshift mechanisms. In turn, empirical design research with embodied prototypes can yield sophisticated insights into the psychology and ergonomics of interacting with social drones. To be able to conduct such studies, we have designed and implemented an experimental setup for real-time drone control and multimodal data collection in tandem. In this paper we present the rationale for this design, provide a description of the setup itself in sufficient detail for researchers looking to implement one like it.

RELATED WORK AND MOTIVATION

In empirical design studies[1][-5cm], there must be congruity between study methods and the purpose of the study (e.g. the design stage being addressed). For example, online surveys and various flavors of brainstorming, which rely on participants' faculties of imagination and articulation, can cater to earlier stages of design characterized by exploration, ideation, and lower-fidelity prototyping. Conversely, experiments with embodied autonomous agents are apt for evaluating design ideas at a higher-fidelity, e.g. capturing correlates of different aspects of the human experience and ergonomics, and efficiently uncovering quantitative design parameters.

Empirical studies with social drones could be said to have emerged as a sub-genre of research literature in more recent years, due to the availability of drone platforms as a consumer commodity. Examining a diverse and representative selection of works from this body of works, we have identified three main strands (see [7] for more detail). The first relates to more general issues of human-drone communication and user experience with social drones [9, 11, 16, 26, 27, 32, 32, 35]. Here, researchers have addressed high-level drone control by co-located humans (as opposed to real-time low-level piloting), conveyance of drone intentions and state through various modalities including motion qualities, and perceptions of comfort and safety in human-drone interactions; aiming to uncover design parameters for intuitive and efficient human-drone communication. A second strand of research deals with use cases involving navigation, assistance, and companionship; employing drones to improve or augment experiences of outdoor wayfinding, exercise and sports spectatorship, and living with sensory disabilities [4, 5, 10, 17, 20, 25, 28]. Finally, social drones have also been utilized to realize novel interaction designs for implementing different flavors of mid-air displays, haptic feedback devices, and interactive tangibles [2, 3, 8, 14, 15, 19, 29–31].

While the aforementioned studies are ultimately about interactions with embodied autonomous drones meant to be co-located with human users or bystanders, only a minority of the published studies utilize actual autonomous drones [16, 18, 25, 33]. In lieu of such high-fidelity prototypes, approaches reported in the literature include online surveys [10, 16, 17, 32], interviews (mostly semi-structured) [3, 5, 9, 11, 16, 20, 28, 31], design studies (including a broad variety of approaches, e.g. ideation sessions, focus groups, and expert critique) [17, 26, 35], WoZ studies [3–5, 9–11, 20, 26–28, 31, 32, 35], and user studies in VR [17].

RATIONALE

As indicated above, empirical studies with social drones is a growing research agenda. However, in the literature so far, studies with fully autonomous drone implementations are not as common as

[1] "According to one definition, empirical means *originating in or based on observation or experience*" [23]. In the context of this paper, we use the term "empirical studies" to denote studies that involve collecting data from (i.e. observing) human participants. In addition to controlled experiments, this includes "interviews, field investigations, contextual inquiries, case studies, field studies, focus groups, think aloud protocols, storytelling, walkthroughs, cultural probes, and so on" [23].

other kinds of studies. Our experience suggests that implementing drone behaviors and related data collection in a robust manner can require engineering prowess and time, which may pose a high barrier to entry for design researchers. In response to this issue, we aimed to construct and document an apparatus which would be able to collect and respond to highly detailed, multimodal data while implementing precise drone motion control. Based on our learnings from the literature discussed above, and our prior experience with stimulus presentation and data collection apparatus in behavioral experiments, we desired our setup to accomplish the following:

Drone control. The drones' position, orientation, and velocity profile should be controllable, to an appropriate level of precision, through pre-programming movement patterns and responding to events in the scene (e.g. following a human subject or props) in real time. In other words, autonomous flight must be possible, in lieu of a WoZ operator.

Drone capture. The setup should allow for recordings, at an appropriate precision, of the position, orientation, and other relevant behavior of drones. For some studies, for example, a video recording may suffice, but this must be synchronized with motion control to facilitate subsequent analysis. Studies requiring high-precision data or efficiently looking for quantitative design parameters (e.g. [21]) can benefit from more precise position tracking.

Human capture. It should be possible to record and respond to movements and other behavior of human participants, at reasonable precision. Behavioral measurements may include sophisticated data like motion capture, eye tracking, and physiological measurements (e.g. heart rate, skin conductance, electroencephalography, and electromyography), but may also be due to simpler means—for example, in studies on the psychology of musical perception, researchers have used simple linear potentiometers to acquire real-time, continuous measurements of tension experiences [6, 34]. The overall system must be able to accommodate and synchronize with such instruments.

Environment capture. The setup should be able to record and respond to any relevant happenings in the environment, e.g. positions of props or different sensor readings. In the future we expect social drones to surpass human sensory capabilities in many modalities, and communicate with other devices more efficiently [13]. We wish to provide the means for incorporating such novel capabilities.

Figure 2: Our Crazyflie drone with MoCap marker deck and markers installed; Micro-USB connector used to charge the drone is in the background, for scale.

OUR APPARATUS

While many simple sensor systems may be used to control and record drone behavior, such solutions often do not provide the flexibility we were aiming for, in that it is not straightforward to track arbitrary configurations of drones, human subjects, and props within the same coordinate system using such systems. Thus, we opted for an optical motion capture as the centerpiece of our control and data collection apparatus.

We utilized a motion capture studio equipped with a Qualisys[2] system, including 12 high-speed marker cameras, 2 spatially calibrated video cameras, and Qualisys Track Manager software (QTM).

[2] qualisys.com

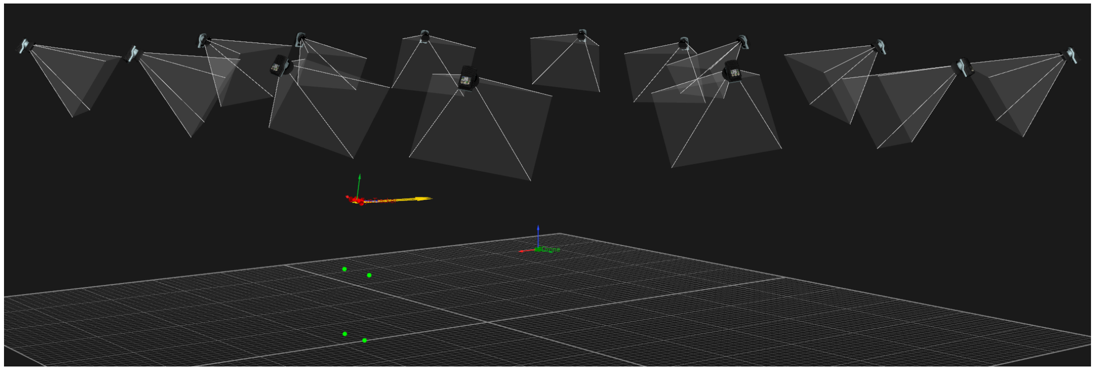

Figure 3: We used optical motion capture to handle drone motion, human movements, and eye tracking within the same spatial coordinate system. This screenshot taken from the motion capture software shows 6DOF tracking of the drone and the human head, point tracking of the hands and feet, and the gaze vector from the eye tracker.

The system was readily configured for optimum coverage, mainly for biomechanics and animation performance use cases. The total size of the room was 14 m × 10 m × 4 m, while the motion capture system was able track a capture volume of approximately 9 m × 8 m × 2 m in the middle of the room. This motion capture system was configured to track at 100 Hz and used both for data collection and closed-loop control of the drone.

Integration of the motion capture system and the drone was implemented in Python scripts using the open-source cflib[3] and qtm[4] libraries. We have made these scripts available online as open source, under a permissive license[5].

We used a Bitcraze[6] Crazyflie 2.0 drones, with chassis dimensions of approximately 10 cm × 10 cm × 2 cm. Four spherical infrared-reflective motion capture markers, 9.5 mm in diameter, were attached to the drone using a "MoCap marker deck" fabricated from the same printed circuit board material as the frame of the drone. QTM was configured to track this marker set in 6DOF as a "rigid body." (As an implementation detail, we note that proper 6DOF tracking requires the markers to be attached asymmetrically.)

We incorporated a Tobii Pro[7] Glasses 2 wearable eye tracker into our setup. This device was equipped with 6 motion capture markers of the same size as on the drone, again configured for 6DOF tracking. In QTM, gaze vectors for both eyes were overlaid onto the motion capture data (see Figure 3).

[3]pypi.python.org/pypi/cflib

[4]pypi.python.org/pypi/qtm

[5]github.com/qualisys/crazyflie-resources

[6]bitcraze.io

[7]tobiipro.com

Along with head and gaze tracking, attaching other markers to participants can provide information on participants' reflexive reactions to drone behaviors, and may be used to enable gesture control or other responsive drone behaviors. In addition to motion tracking, we incorporated a wired trigger button used to obtain binary input and record it with precise timing. This button was connected directly to the motion capture system on a hardware level to minimize signal latency.

Finally, we considered safety measures. Our experience has been that our drone is small and lightweight enough to be incapable of damaging clothes or skin upon contact. To protect participants' hair from possible contact with the drone's propellers, we procured a hair net. Eye protection was provided by a clear plastic attachment fitted onto the eye tracker.

EXPERIENCES, LIMITATIONS AND FUTURE WORK

A subset of the apparatus we propose in this paper has been used to implement a technical demonstration that explores how a small drone can be used to facilitate meditative movement exercises [22]. We also note that fundamentally similar equipment has been used by other researchers to prototype and demonstrate free-flying tangible user interfaces [15, 29].

Our preliminary work with the apparatus has revealed a set of improvement possibilities. So far, we have only been using the Crazyflie drones, which are smaller compared to drones used in much of previous work, and thereby have limited use cases. Future work can address developing the software to integrate different drones in the setup, and identifying different use cases where the smaller drone is more appropriate. Furthermore, while the particular motion capture system we had at our disposal has advantages in terms of precision and flexibility, such systems are costly. Systems with different cost/performance characteristics can be substituted in its place, but the software will need to be reworked—a more general software framework to interface motion tracking, drone control, and other systems can be explored in future work. Lastly, future work can also investigate adding further data acquisition capabilities. For example, sensors for recording electrodermal activity (a.k.a. skin conductance or galvanic skin response) or other physiological measurements could be introduced.

CONCLUSION

In this paper, we have presented our design and implementation of an experimental apparatus for empirical research on human factors in social drones. This apparatus supports integrated multimodal data acquisition at high spatial and temporal resolution, and real-time closed-loop drone control with high precision. Here, along with details of the setup itself, we reported on its design rationale and how various aspects of it relate to previous work. Through this report, we have aimed to share a description of our apparatus at some detail, in order to serve as a resource for other researchers looking to undertake similar studies. We would also like to open up our approach to critique; and we invite others in the field to provide feedback and share experiences regarding how future work on the apparatus can better serve the community.

REFERENCES

[1] Goodrich Michael A., Morse Bryan S., Gerhardt Damon, Cooper Joseph L., Quigley Morgan, Adams Julie A., and Humphrey Curtis. 2007. Supporting wilderness search and rescue using a camera-equipped mini UAV. *Journal of Field Robotics* 25, 1-2 (2007), 89–110. https://doi.org/10.1002/rob.20226 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/rob.20226

[2] Muhammad Abdullah, Minji Kim, Waseem Hassan, Yoshihiro Kuroda, and Seokhee Jeon. 2017. HapticDrone: An Encountered-Type Kinesthetic Haptic Interface with Controllable Force Feedback: Initial Example for 1D Haptic Feedback. In *Adjunct Publication of the 30th Annual ACM Symposium on User Interface Software and Technology (UIST ’17)*. ACM, New York, NY, USA, 115–117. https://doi.org/10.1145/3131785.3131821

[3] Parastoo Abtahi, David Y. Zhao, Jane L. E., and James A. Landay. 2017. Drone Near Me: Exploring Touch-Based Human-Drone Interaction. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 34 (Sept. 2017), 8 pages. https://doi.org/10.1145/3130899

[4] Mauro Avila, Markus Funk, and Niels Henze. 2015. DroneNavigator: Using Drones for Navigating Visually Impaired Persons. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS ’15)*. ACM, New York, NY, USA, 327–328. https://doi.org/10.1145/2700648.2811362

[5] Mauro Avila Soto, Markus Funk, Matthias Hoppe, Robin Boldt, Katrin Wolf, and Niels Henze. 2017. DroneNavigator: Using Leashed and Free-Floating Quadcopters to Navigate Visually Impaired Travelers. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS ’17)*. ACM, New York, NY, USA, 300–304. https://doi.org/10.1145/3132525.3132556

[6] Mehmet Aydin Baytas, Tilbe Goksun, and Oguzhan Ozcan. 2016. The Perception of Live-sequenced Electronic Music via Hearing and Sight. In *Proceedings of the International Conference on New Interfaces for Musical Expression (2220-4806)*, Vol. 16. Queensland Conservatorium Griffith University, Brisbane, Australia, 194–199. http://www.nime.org/proceedings/2016/nime2016_paper0040.pdf

[7] Mehmet Aydın Baytaş, Damla Çay, Yuchong Zhang, Mohammad Obaid, Asım Evren Yantaç, and Morten Fjeld. 2019. The Design of Social Drones: A Review of Studies on Autonomous Flyers in Inhabited Environments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI ’19)*. ACM, New York, NY, USA, Article 250. https://doi.org/10.1145/3290605.3300480

[8] Sean Braley, Calvin Rubens, Timothy R. Merritt, and Roel Vertegaal. 2018. GridDrones: A Self-Levitating Physical Voxel Lattice for 3D Surface Deformations. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA ’18)*. ACM, New York, NY, USA, Article D200, 4 pages. https://doi.org/10.1145/3170427.3186477

[9] Jessica R. Cauchard, Jane L. E, Kevin Y. Zhai, and James A. Landay. 2015. Drone & Me: An Exploration into Natural Human-drone Interaction. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp ’15)*. ACM, New York, NY, USA, 361–365. https://doi.org/10.1145/2750858.2805823

[10] Ashley Colley, Lasse Virtanen, Pascal Knierim, and Jonna Häkkilä. 2017. Investigating Drone Motion As Pedestrian Guidance. In *Proceedings of the 16th International Conference on Mobile and Ubiquitous Multimedia (MUM ’17)*. ACM, New York, NY, USA, 143–150. https://doi.org/10.1145/3152832.3152837

[11] Jane L. E, Ilene L. E, James A. Landay, and Jessica R. Cauchard. 2017. Drone & Wo: Cultural Influences on Human-Drone Interaction Techniques. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI ’17)*. ACM, New York, NY, USA, 6794–6799. https://doi.org/10.1145/3025453.3025755

[12] T. Fong, C. Provencher, M. Micire, M. Diftler, R. Berka, B. Bluethmann, and D. Mittman. 2012. The Human Exploration Telerobotics project: Objectives, approach, and testing. In *2012 IEEE Aerospace Conference*. 1–9. https://doi.org/10.1109/AERO.2012.6187043

[13] Markus Funk. 2018. Human-drone Interaction: Let's Get Ready for Flying User Interfaces! *Interactions* 25, 3 (April 2018), 78–81. https://doi.org/10.1145/3194317

[14] Antonio Gomes, Calvin Rubens, Sean Braley, and Roel Vertegaal. 2016. BitDrones. *interactions* 23, 3 (April 2016), 14–15. https://doi.org/10.1145/2898173

[15] Antonio Gomes, Calvin Rubens, Sean Braley, and Roel Vertegaal. 2016. BitDrones: Towards Using 3D Nanocopter Displays As Interactive Self-Levitating Programmable Matter. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 770–780. https://doi.org/10.1145/2858036.2858519

[16] Walther Jensen, Simon Hansen, and Hendrik Knoche. 2018. Knowing You, Seeing Me: Investigating User Preferences in Drone-Human Acknowledgement. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 365, 12 pages. https://doi.org/10.1145/3173574.3173939

[17] Kari Daniel Karjalainen, Anna Elisabeth Sofia Romell, Photchara Ratsamee, Asim Evren Yantac, Morten Fjeld, and Mohammad Obaid. 2017. Social Drone Companion for the Home Environment: A User-Centric Exploration. In *Proceedings of the 5th International Conference on Human Agent Interaction (HAI '17)*. ACM, New York, NY, USA, 89–96. https://doi.org/10.1145/3125739.3125774

[18] Pascal Knierim, Thomas Kosch, Alexander Achberger, and Markus Funk. 2018. Flyables: Exploring 3D Interaction Spaces for Levitating Tangibles. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. ACM, New York, NY, USA, 329–336. https://doi.org/10.1145/3173225.3173273

[19] Pascal Knierim, Thomas Kosch, Valentin Schwind, Markus Funk, Francisco Kiss, Stefan Schneegass, and Niels Henze. 2017. Tactile Drones - Providing Immersive Tactile Feedback in Virtual Reality Through Quadcopters. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17)*. ACM, New York, NY, USA, 433–436. https://doi.org/10.1145/3027063.3050426

[20] Pascal Knierim, Steffen Maurer, Katrin Wolf, and Markus Funk. 2018. Quadcopter-projected in-situ navigation cues for improved location awareness. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 433.

[21] T. Kosiński, M. Obaid, P. W. Woźniak, M. Fjeld, and J. Kucharski. 2016. A fuzzy data-based model for Human-Robot Proxemics. In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. 335–340. https://doi.org/10.1109/ROMAN.2016.7745152

[22] Joseph La Delfa, Mehmet Aydın Baytaş, Olivia Wichtowski, Rohit Ashok Khot, and Florian Mueller. 2019. Are Drones Meditative?. In *Proceedings of the 2019 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '19)*. ACM, New York, NY, USA. https://doi.org/10.1145/3290607.3313274

[23] I. Scott MacKenzie. 2013. *Human-Computer Interaction: An Empirical Research Perspective* (1st ed.). Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.

[24] Mark Micire, Terrence Fong, Ted Morse, Eric Park, Chris Provencher, Ernest Smith, Vinh To, R Jay Torres, DW Wheeler, and David Mittman. 2013. Smart SPHERES: a Telerobotic Free-Flyer for Intravehicular Activities in Space. In *AIAA SPACE 2013 Conference and Exposition*.

[25] Florian 'Floyd' Mueller and Matthew Muirhead. 2015. Jogging with a Quadcopter. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2023–2032. https://doi.org/10.1145/2702123.2702472

[26] W. S. Ng and E. Sharlin. 2011. Collocated interaction with flying robots. In *2011 RO-MAN*. 143–149. https://doi.org/10.1109/ROMAN.2011.6005280

[27] Mohammad Obaid, Felix Kistler, Gabrielė Kasparavičiūtė, Asim Evren Yantaç, and Morten Fjeld. 2016. How Would You Gesture Navigate a Drone?: A User-centered Approach to Control a Drone. In *Proceedings of the 20th International Academic Mindtrek Conference (AcademicMindtrek '16)*. ACM, New York, NY, USA, 113–121. https://doi.org/10.1145/2994310.2994348

[28] Andrzej Romanowski, Sven Mayer, Lars Lischke, Krzysztof Grudzień, Tomasz Jaworski, Izabela Perenc, PrzemysKucharski, Mohammad Obaid, Tomasz Kosizski, and Paweł W. Wozniak. 2017. Towards Supporting Remote Cheering During Running Races with Drone Technology. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17)*. ACM, New York, NY, USA, 2867–2874. https://doi.org/10.1145/3027063.3053218

[29] Calvin Rubens, Sean Braley, Antonio Gomes, Daniel Goc, Xujing Zhang, Juan Pablo Carrascal, and Roel Vertegaal. 2015. BitDrones: Towards Levitating Programmable Matter Using Interactive 3D Quadcopter Displays. In *Adjunct Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (UIST '15 Adjunct)*. ACM, New York, NY, USA, 57–58. https://doi.org/10.1145/2815585.2817810

[30] Jürgen Scheible, Achim Hoth, Julian Saal, and Haifeng Su. 2013. Displaydrone: A Flying Robot Based Interactive Display. In *Proceedings of the 2Nd ACM International Symposium on Pervasive Displays (PerDis '13)*. ACM, New York, NY, USA, 49–54. https://doi.org/10.1145/2491568.2491580

[31] Stefan Schneegass, Florian Alt, Jürgen Scheible, and Albrecht Schmidt. 2014. Midair Displays: Concept and First Experiences with Free-Floating Pervasive Displays. In *Proceedings of The International Symposium on Pervasive Displays (PerDis '14)*. ACM, New York, NY, USA, Article 27, 5 pages. https://doi.org/10.1145/2611009.2611013

[32] Daniel Szafir, Bilge Mutlu, and Terrence Fong. 2014. Communication of Intent in Assistive Free Flyers. In *Proceedings of the 2014 ACM/IEEE International Conference on Human-robot Interaction (HRI '14)*. ACM, New York, NY, USA, 358–365. https://doi.org/10.1145/2559636.2559672

[33] Daniel Szafir, Bilge Mutlu, and Terry Fong. 2015. Communicating Directionality in Flying Robots. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction (HRI '15)*. ACM, New York, NY, USA, 19–26. https://doi.org/10.1145/2696454.2696475

[34] Bradley W. Vines, Carol L. Krumhansl, Marcelo M. Wanderley, and Daniel J. Levitin. 2006. Cross-modal interactions in the perception of musical performance. *Cognition* 101, 1 (2006), 80 – 113. https://doi.org/10.1016/j.cognition.2005.09.003

[35] Alexander Yeh, Photchara Ratsamee, Kiyoshi Kiyokawa, Yuki Uranishi, Tomohiro Mashita, Haruo Takemura, Morten Fjeld, and Mohammad Obaid. 2017. Exploring Proxemics for Human-Drone Interaction. In *Proceedings of the 5th International Conference on Human Agent Interaction (HAI '17)*. ACM, New York, NY, USA, 81–88. https://doi.org/10.1145/3125739.3125773