# Flyables: Exploring 3D Interaction Spaces for Levitating Tangibles

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**Figure 1: Left:** User performing touch interaction with a levitating tangible. **Right:** Grabbing and repositioning of a levitating tangible.

## Abstract

Recent advances in technology and miniaturization allow the building of self-levitating tangible interfaces. This includes flying tangibles, which extend the mid-air interaction space from 2D to 3D. While a number of theoretical concepts about interaction with levitating tangibles were previously investigated by various researchers, a user-centered evaluation of the presented interaction modalities has attracted only minor attention from prior research. We present Flyables, a system adjusting flying tangibles in 3D space to enable interaction between users and levitating tangibles. Interaction concepts were evaluated in a user study(N=17), using quadcopters as operable levitating tangibles. Three different interaction modalities are evaluated to collect quantitative data and qualitative feedback. Our findings show preferred user interaction modalities using Flyables. We conclude our work with a discussion and future research within the domain of human-drone interaction.

## Author Keywords

Tangible user interfaces; actuated tangible interfaces; 3D interaction; quadcopter; Human-Drone Interaction

## CCS Concepts

•**Human-centered computing** → **Haptic devices; Interaction techniques;**

## Introduction and Background

The vision of Tangible User Interfaces (TUIs) embodying digital information was proposed decades ago [9]. Holman and Vertegaal envisioned a future of Organic User Interfaces [8], where all physics act as display and interaction can be triggered by shape changes. In Radical Atoms [10], Ishii described a future in which all digital information is linked to some physical matter to enable direct interaction. For the most part, these works are rather theoretical and only scratch the surface regarding implementation.

On the roadmap to Radical Atoms, various TUIs have been developed and studied extensively. Reactable [11], a musical instrument, allows users to mix and control sounds by placing, moving, or rotating building blocks on an interactive surface. Since tangibles are passive, there are limited possibilities to indicate changes of digital information introduced by software processes. This breaks the illusion of a tight coupling of digital information and the physical matter. To overcome this limitation, Nowacka et al. [13] developed actuated physical objects for interacting with interactive multi-touch tabletops. These active tangibles can move around the surface and keep the link between digital and physical information even on software processes or remote input. However, the interaction remained limited to the 2D interaction space. Gravity inhibits tangibles from being set freely in the 3D space. 2.5D shape changing displays partly tackle this challenge, by allowing the actuation of passive objects and enabling dynamic affordances [6]. To make tangibles usable in 3D space, quadcopters have recently attracted attention in the research domain of TUIs. Gomes et al. [7] proposed BitDrones, a toolbox to model 3D tangible interaction leveraging quadcopters. This theoretical concept includes touching, dragging, picking, and throwing quadcopters as interaction modality. Various researchers showed how quadcopters could be used as floating touch

interfaces [2] or to generate force feedback [1]. Recently, we used quadcopters to facilitate tactile feedback in immersive virtual environments [12] or to support blind people during guidance and navigation [3, 4]. Previous work shows the applicability of using quadcopters in practical scenarios. However, a user study evaluating the presented interaction modalities was not conducted. Ongoing research about levitating tangibles, designing spaces of quadcopters as input or output modality for TUIs has scarcely been explored. Previous research concentrated on gestural input [5, 14], and on theoretical [7] or technical [15] concepts, leaving user-centered evaluations behind.

In our work, we present Flyables, a system capable of regulating levitating tangibles in 3D space. Using Flyables, we study the design space of tangible levitating devices. This is achieved by building self-levitating tangible cubes using computer controlled quadcopters, similar to Gomes et al. [7]. We conducted a user study with 17 participants to investigate the usability of *touch* and *draw* interaction, as well as the physical interaction space reached by users executing a *drag* interaction using Flyables. Results show a high acceptance for *touch* and *drag* interaction, where participants actively controlled quadcopters. However, participants were challenged to notice *draw*, an output modality in which the quadcopter generates forces in a certain direction. The contribution of this work comprises (1) the evaluation of the three prior mentioned interaction modalities in a user-centered study and (2) the presentation of potential future research that can be derived from the conducted user study.

## Interaction Modalities

Adopting flying quadcopters as levitating user interfaces allows to cover 3D interaction spaces. Input and output

modalities can be communicated between the user and quadcopter.

### Input Modalities

In the following, we describe two gestures to communicate user input through quadcopters. We present *drag* and *touch* as input modality.

The first user input modality is *drag*, where the quadcopter is grasped by a user and positioned to a different point in space. The quadcopter retains its position until the next user input or moves to its default position after a timeout.

The second input modality is *touch* interaction. A *touch* is recognized when the quadcopter realizes a shift into a single direction. After recognizing a *touch*, quadcopters return immediately to their original position. User touch can be performed from different sides of the quadcopter, such as touching the front or sides.

### Output Modality

Similar to communicating input, quadcopters can communicate output by drawing the user into a direction upon a grasp. The grasped tangible *draws* the hand of the user into a direction, where the direction indicates the kind of feedback. In combination with *drag*, feedback can be instantly delivered by a draw gesture.

## Technical Overview

To evaluate physical interaction spaces using levitating tangible user interfaces, we constructed a system capable of tracking and controlling quadcopters. In the following, we present the implementation of *Flyables*.

### Quadcopter

An Eachine H8 Mini is used as levitating interaction component (see Figure 2). To make quadcopters graspable, a

small cage consisting of light but solid cardboard has been built around it (see Figure 3). We ensured that the cardbox was stable enough to provide protection from the rotors while being graspable at the same time. The top and bottom of the cubic cage is not covered to ensure unrestrained airflow. Reflective markers are attached on the cage to enable accurate motion tracking. Including the cage, the dimensions of the quadcopter comprise 11 cm × 11.5 cm × 11 cm. The overall weight of the levitating tangible is 26 grams.

### Tracking System

An OptiTrack system is used as tracking system for our flyable framework. Eight OptiTrack Prime 13W infrared cameras are used to cover a space of 2.7 m × 2.4 m × 2.5 m. The tracking system recognizes tracking markers mounted on the cage, thus delivering the current 3D position in real-time. Position data are processed with a refresh rate of 240 Hertz.

### Flight Control

To control the 3D position of the quadcopter, we connected an Arduino UNO to a remote control compatible with the quadcopter. The Arduino UNO is connected to a computer, which simultaneously receives position data of the quadcopter. A flight control software calculates the steering commands for the quadcopter to stay at a defined position. Using a PID loop, the position of the quadcopter is automatically reset to its origin if the position was changed manually.
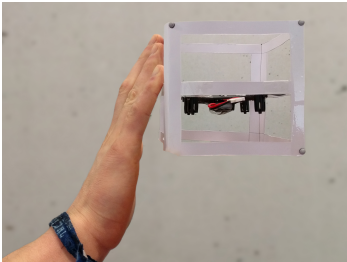
## Study

Using our system, we evaluate the interaction space and usability of levitating tangibles using our *Flyables* framework. By conducting a user study, quantitative and qualitative data is collected to evaluate the usability and user experience when using levitating tangibles as interaction



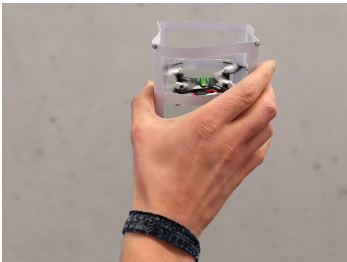**Figure 2:** Quadcopter used as levitating tangible device.



**Figure 3:** Quadcopter equipped with a cage to enhance tangible interaction.
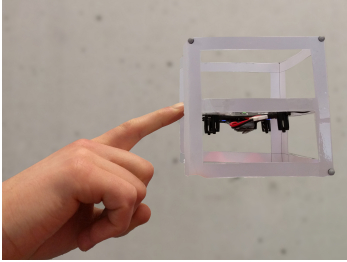
**Figure 4:** Participant touching the levitating tangible with the index finger.



**Figure 5:** Participant touching or pushing the levitating tangible with four fingers.



**Figure 6:** Levitating tangible grabbed by the user to be dragged to another physical location.

devices. The quantitative part of the study consisted of a *touch*, *drag*, and *draw* task. Qualitative data was collected during follow-up semi-structured interviews.

*Method*
The study was divided into three parts, each requiring participants to use one of the three prior mentioned modalities. Accordingly, two tasks comprised the usage of quadcopters as input device corresponding to the *drag* and *touch* gesture. The third task evaluated the *draw* modality to communicate output.

We analyze a subset including *touch*, *drag*, and *draw* of the previously described interaction modalities. A continuous stream of position data of a single quadcopter was collected during all tasks of the study. The experimenter instructed the participant during the study about their current objective.

During the evaluation of *touch*, participants were required to touch the levitating tangible. Participants were also instructed to perform *touch* interaction as they would prefer to. *Touch* has been evaluated for three different heights above the ground (120 cm, 140 cm, 160 cm), resulting in 15 *touch* interactions. Participants rated the interaction comfort for different heights on a 7-point Likert scale.

The second input task dealt with dragging the tangible to one of nine directions (up, up right, right, down right, down, down left, left, up left, and forward). Participants had to *drag* the quadcopter to a specific position according to spoken commands from the experimenter. We recorded the 3D position in space of the tangible with respect to the origin (140 cm above the ground in front of the participant) as well as the way participants grabbed the quadcopter. The quadcopter was moved twice in each direction in a random order. We did not explain how far the tangible should be

moved as we aimed to get unbiased measures. During the *drag* condition, participants were instructed to remain their initial position.

The last task focused on the feasibility of using our levitating tangible as haptic output interface. Participants were asked to grab the tangible with their right hand while holding a wireless controller in the other hand. The tangible started to *draw* the participant in a direction (forward, backward, left or right) after a randomized delay. Each time the participant noticed a *draw* by the quadcopter, they were requested to press a button and communicate the direction they felt. Every direction was presented three times during this task. The time participants reacted to the draw as well as errors such as incorrect *draw* or wrong direction were recorded.

Qualitative data, such as user feedback and further ideas for using levitating tangibles were collected at the end of the study through semi-structured interviews and questionnaires.

*Procedure*
After participants signed a consent form, we explained the prototype including a flight demonstration to the participants and informed participants that are allowed to abort the experiment at any time. The tasks were performed in a counterbalanced order to prevent sequence effects. All participants were in an upright position. Furthermore, we asked them to keep their initial position during the experiment.

*Participants*
We recruited 17 participants (6 female) with a mean age of $M = 21.6$ years ($SD = 1.62$). Participants were recruited through university mailing lists and by asking acquaintances for participation. 14 participants had a technical background. All participants are right-handed and had an

average height of $M = 178$ cm ($SD = 10.94$ cm). Twelve participants had no prior experience with quadcopters. The overall duration of the study was 50 minutes. Participants provided their demographics upon completion of the study.

*Results*
We compared the ratings for the different heights above the ground while interacting but could not find any statistically significant differences. However, 53% of the participants stated in the interview that they liked the altitude of 140 cm most. In detail p03 and p09 agree on a preferred height of 140 cm since "the tangible is not on eye level" and "most easy to grasp" (p05, p07, p13). Interestingly, there are two equally used techniques to touch the tangible. Eight participants used their index finger of the right hand to touch the tangible in the center (see Figure 4) while nine participants used all four fingers of the open hand to interact (see Figure 5). All participants used their whole hand during *drag* interactions (see Figure 6).

We recorded 306 individual drag interactions in nine different directions. The derived physical interaction space users naturally tend to use is illustrated in Figure 7. The space is almost rectangular with a median height of 93 cm to 189 cm above the ground and a width of 109 cm. Participants dragged the tangible in average 5 cm further to the right than left. The median forward movement is 50 cm.

Caused by the lightweight construction of the levitating tangible the induced draw is very gentle. From the 204 draw signals, only 127 (62%) were noticed. The average delay of realizing the draw was 1.36 sec. Participants stated in 50% that they prefer the draw in forward direction because "it was most perceptible" (p10) and they were "not concerned, that the quadcopter (tangible) would crash into them" (p08).
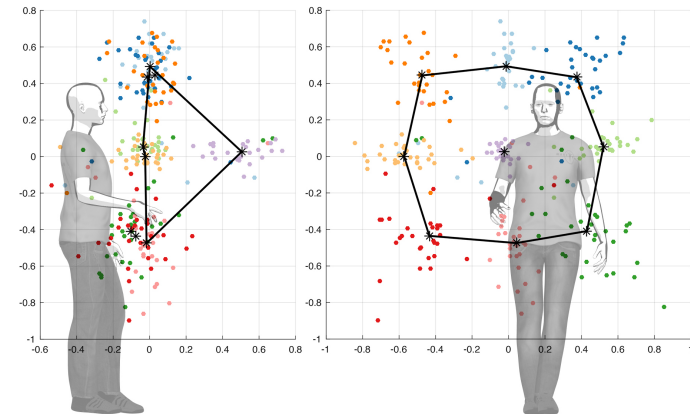


**Figure 7:** Physical interaction space covered during the study. Key: Up ●, Up Right ●, Right ●, Down Right ●, Down ●, Down Left ●, Left ●, Up Left ●, forward ●, Median ∗

During the course of the study and the follow-up semi-structured interview participants mentioned that they enjoyed the interaction. Five participants presented the idea to use levitating tangibles to control smart home devices. Further, one participant (p05) proposed to combine this tangible with virtual reality applications to enable haptic feedback. Beside this positive feedback participants had three major concerns. Precisely, they stated the noise and battery life as a drawback. Further, participants criticize the weak drag emitted by the tangible.

## Discussion
Based on our findings, we discuss the implications of our results for future research in human-drone interaction.

*Interaction Design*
Results show great potential for *touch* and *drag* interaction. When designing *drag* interactions, we suggest staying within the described physical interaction space to prevent users from walking while holding levitating tangibles. When

possible, the tangible should idle at an altitude between elbow and breast (140 cm) to enable a comfortable use. Unfortunately, *draw* as output modality did not provide convincing results. Due to the light design of the tangible and the low-powered engines, the haptic feedback was not sufficient to be noticed by the users. From a technical view, we will investigate how the *draw* gesture can be improved by using draw gestures which would not be expected by the user. Furthermore, stronger engines will be incorporated in the current prototype to amplify *draw* gestures.

*Hardware Design*
For a satisfying user experience, the size of the cage should consist of a size between 10 cm × 10 cm and 12 cm × 12 cm. This makes it easy to grasp levitating tangibles even with small hands. We learned from our user study, that quadcopter and cage interfered together, thus creating a noisy environment. Furthermore, quadcopter frames should enclose levitating tangibles as good as possible to avoid injuries due to spinning rotor blades. These design limitations will be addressed for future development of the *Flyables* framework.

*Limitations*
Our current implementation is limited to unimodal interactions, which means that quadcopter can communicate single input or one output at the same time. However, *Flyables* can orchestrate multiple quadcopters and can thus extend the interaction space. Finally, the systems PID Loops are only capable of controlling tangibles within an accuracy of approximately ± 5 cm. Additionally, minor tracking inaccuracies can occur.

## Future Work
Our preliminary results explore the feasibility of using quadcopters as levitating tangible interfaces. Our findings re-

vealed spots to improve, such as fine-tuned PID controller, a more rigid frame to reduce vibrations, noise, and a visually blocking enclosure to avoid the doubt of touching the rotor blades. In future work, we want to evaluate *drag* interaction with a heavier quadcopter to improve output modalities communicated by levitating tangibles. This enables bimodal interaction between the user and levitating tangible, where feedback is communicated immediately after user input. Also, we will explore more complex interactions with more than one levitating tangible. Possible interactions could be *dragging* two tangibles at the same time to trigger rotation or resizing of digital objects. Moreover, we see enormous potential to create diversely shaped cages and investigate the affordance in learning scenarios as well as to control home appliances in a smart home environment.

## Conclusion
We designed an actuated self-levitating tangible based on a quadcopter and studied potential interaction spaces in terms of communicating input and output. We conducted a user study with 17 participants to gather qualitative and quantitative data from participants interacting with levitating tangibles. Our prototype supports two input and one haptic output interaction, which were evaluated in the user study. The presented results facilitate a better understanding of how to use 3D tangible interfaces and how feasible interaction modalities can be designed. We further described guidelines on how to design levitating tangibles on basis of quadcopters, including appropriate interaction design.

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