



Exploring Human-Drone Collaboration Through Contact Improvisation

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ABSTRACT

In this work we used a dance performance to explore physical human-drone interactions during a collaborative task. We created drone behaviors to allow partnership and increase physicality between the dancer and drone. We found that extended moments of hovering increase the dancer's perspective of the drone as a partner. We found that using the amount of force exerted from the dancer to the drone is a sufficient input for designing drone responses and increasing the amount of physical contact between the partners.

CCS CONCEPTS

• **Computer systems organization** → **Robotics**.

KEYWORDS

drone, human-drone interaction, uav, dance, contact improvisation

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1 INTRODUCTION

Personal drones can be useful in applications where other robots are not because they can move agilely in six degrees of freedom and reach higher than humans, or ground robots can. Establishing trust [6, 11, 13] and a sense of collaboration [5, 8, 13] between humans and drones can help in tasks where the drone and human have a shared goal. Physical touch is a useful communication mode in human-robot collaborations [12], but has been explored less in human-drone interaction [3]. Physical human-drone interactions are important to understand in order to push the boundaries of how drones can be used in everyday life.

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In performance arts, drones have been increasingly used alongside humans [1], creating unique opportunities for human-drone collaboration. The role of the drone in the work can vary. However, in most human-drone dance performances there is not much variation in what the drone can do in the moment, as their trajectories are pre-choreographed. There are examples where the dancer can control the drone's movements [7, 9], thus expanding what it can do in the moment. However, to our knowledge, there is no instance where the drone's movements can impact the dancer's through contact. Thus, the drone's role during performances is still limited. Current human-drone performances lack physicality (bodily contact) and a collaboration between the dancers and the drone.

Enabling partnership between the drone and human dancer is one way to further human-drone collaboration in performances. Partnership is a common occurrence in many genres of dance. Contact Improvisation is one such genre that requires both partnership and intense physicality, thus making it an interesting landscape to examine. In Contact Improvisation, two or more partners use momentum and force to improvise a movement, with the caveat that they must remain physically connected in some way at all times. To achieve this, a high level of trust is needed between the partners. They must be able to adapt to new body shapes and directions as the movement evolves, and decide when to take the leading (call) or following (response) role during the improvised event.

To perform Contact Improvisation, a drone must interact with people onstage in real time. The drone must decide how much force to impart, understand when to lead or follow, and maintain physical contact with the dancer. Understanding how to design Calls and Responses for drones can be used in the future to enhance human-drone performances by adding larger elements of physicality and autonomy—creating more dynamic movement patterns for the dancer and the audience.

To explore human-drone partnership in Contact Improvisation, we pose the following research questions (RQ):

- RQ1: What kinds of drone behaviors are necessary to maintain physical contact during an improvisation event?
- RQ2: How does partnering with a drone instead of another human affect the dynamic of the partnership from the perspective of a dancer?
- RQ3: How often must the drone switch between calling and responding to be perceived as a partner?

We addressed these research questions by co-creating drone behaviors with a professional dancer (the research team was made

up of an engineer, "the researcher", and the professional dancer, "the dancer"). We used the rules of Contact Improvisation, exploratory studies, and interviews with the dancer to determine the design guidelines. We then conducted an experiment to test the behaviors in various improvisation events.

We contribute, to our knowledge, the first human-drone dance partnership involving full-body physical touch and a reflection on the algorithms and role adaptation necessary to create partnership. This work can help with identifying possible directions for future research in physical human-drone collaborations more broadly.

2 BACKGROUND

Contact Improvisation involves physical touch, shared weight, gravity, inertia, and momentum between two or more dancers. Ranging from complete stillness to athletic movement, Contact Improvisation is predicated on mutual trust between partners. All parties involved must be willing to cede some amount of muscular control and allow themselves to be guided by their partner. Successful Contact Improvisation relies on some codes of conduct. Some are philosophical, such as maintaining an egalitarian partnership and building trust before building momentum; and some are movement-specific, such as recognizing the weight and momentum of the pelvis, using enough pressure to guide your partner through space, and creating ledges and opportunities for leverage within your body. The typical movement profile seen in Contact Improvisation includes rolling, falling, inversion, following (contact), supporting, and weight release. [2]

While most human-drone performances are pre-choreographed, some work [7] has explored varying the drone's performance in real time. This is typically accomplished by controlling the drone's motion directly via a wearable device [9, 10]. In these examples, the drone did not make decisions based on the human's actions. There was also no physical contact between the human and the drone. Thus, an interactive, physical drone partner has yet to be developed.

3 PARTNERSHIP DESIGN

Three goals guided the design of the drone's behaviors. The primary goal was to address RQ1, that is to understand what behaviors are necessary to increase physical contact between the drone and dancer. As increasing contact alone is not enough to create a dynamic partnership, the second goal was to ensure the drone's behaviors fit into the movement profile of Contact Improvisation. Thus, we broke the behavior development into two parts, designing a Response and designing Calls. The last goal was to take full advantage of improvising with a drone partner by exploring behaviors that a human partner could not achieve.

3.1 Method

3.1.1 Procedure. We conducted 6, 2-4 hour, sessions with the dancer spanning a 4 month period. The dancer is a professional artist with over 20 years of experience in contemporary, modern, and ballet, and 7 years of experience in Contact Improvisation. The drone had self stabilizing functionality. In the first session, the dancer improvised with the drone several times with no behaviors added. The purpose was to observe how the drone's feedback controllers

responded to perturbations from the dancer and determine what modifications were needed. The researcher then piloted the drone during improvisation events to explore different movement patterns with the dancer. After analyzing the session, baseline code was developed. During subsequent sessions, the dancer improvised with the drone's programmed behaviors several times as the researcher modified the code. The dancer was interviewed after each improvisation. We recorded the sessions and the researcher analyzed the videos. We iteratively improved the Response and Calls based on the interviews and live and video observations. Once we developed the behaviors, we tuned the Response parameters in one session and the Call parameters during another. We tuned the parameters until the dancer felt comfortable and the drone could withstand the force the dancer was imparting during its maneuver. We also determined a force threshold for the drone to consider in its behaviors.

3.1.2 Implementation. We used a Tello Edu drone. It was 9.8×9.25×4.1 cm, weighed 108 g, and had a max speed of 100 cm/s. We used the IMU information available through the SDK to determine what force the dancer was imparting on the drone. We used the direction of the force to determine the direction the drone should enact its Calls and Response. We modified the CYNova Tello cage with mesh for safety and to increase the available contact surfaces of the drone. An ABS plastic strip of 0.025 mm thickness was added around the cage to reduce friction and allow sliding motions on the dancer's body.

We chose not to use motion tracking for two reasons: (1) using markers would have given the drone an artificial "front", undermining its omnidirectional capabilities and enforcing a human characteristic we wanted to avoid, (2) we experimented with an RGBD camera, but the occlusions and detection problems were beyond the scope of our work.

3.2 Response

We chose to use rotation and no other movement for the Response based on the rolling motions we observed the drone made across the dancer's body during session 1. We observed this when the dancer imparted impulses to the drone with any part of her body. This happened both when the drone was piloted and un-piloted. Rotation also enforced proximity between the dancer and the drone, preventing the drone from straying from the zone of potential contact. To control this rotation, we chose two parameters: the speed of the turn and the direction of the turn (clockwise and counterclockwise). This allowed the drone to have variability in its Response, either "complying" or "showing resistance". The speed was proportional to the magnitude of the force from the dancer. The direction was determined by the direction of the force from the dancer. The drone waited to Respond until it received an impulse from the dancer. We observed that the drone successfully maintained contact with the dancer more frequently with our Response algorithm than with the self stabilizing code alone. This rolling behavior both fit the movement profile and increased physical contact which addressed RQ1.

3.3 Calls

We developed three calls based on our design goals.

3.3.1 Push. This behavior fit into the movement profile of Contact Improvisation. The drone could achieve weight-sharing by pushing against the dancer with varying magnitudes of force and for varying lengths of time. Additionally, contact for protracted periods simulated a sense of shared momentum between the drone and dancer.

3.3.2 Altitude Change. We sought to explore the movement possibilities unique to a drone partner. Changing altitude leverages a dynamic of the human-drone partnership that is not present in human pairs—the air above the dancer’s head. Also, changing altitudes was an easy way for the drone to bring the dancer’s attention to a new body part (legs vs arms) or prompt a change in level (ie. crouch, stand tall).

3.3.3 Tap. In human pairs, some calls can feel more decisive than others. We used a double tap to emulate this in the drone. By tapping at different speeds, the drone could make decisive (fast) or more passive calls (slow). In instances when the drone did not contact the dancer during tap, the back and forth motion created an interesting visual cue—swaying.

For Push and Tap, if a force from the dancer was not detected in the last 5 seconds, it would act in a random direction. The parameters used for tuning the Calls and Response are in Table 1.

Table 1: Call and Response Parameters

C/CW = counter/clockwise FBLR = front/back/left/right UD = up/down

Parameter	Response	Tap	Push	Altitude Change
Magnitude (cm/s)	1-100	15-100	20	-
Duration (s)	3	-	1.5-2	-
Direction	C/CW	FBLR	FBLR	UD
Distance (cm)	-	-	-	35

4 EXPERIMENT

4.1 Method

To explore our research questions, the researcher designed an experiment to test how the partnership dynamic changed under different Call and Response conditions. We used probability to decide how often the drone would Call and Respond. The following Call-to-Response ratios were used: Condition 1: 50:50, Condition 2: 70:30, and Condition 3: 30:70. We ran three trials of each condition.

The researcher formed two hypotheses related to RQ1 and RQ3: RQ1|H1: Condition 1 would result in the most contact between the drone and dancer. RQ3|H2: Condition 1 would feel most like a partner from the perspective of the dancer, followed by Condition 2 then 3.

The dancer was informed that the drone was using different code before each condition, but was not told what the condition was. The dancer also did not know what parameters or behaviors were being altered between conditions. After each trial, the dancer was interviewed. The experiments were conducted in the same lab space used for the Call and Response development. The dance space was approximately 6x6x9 m. Each trial lasted about 2 minutes,

depending on drone battery life. To account for the difference, we used the percentage of time the drone and dancer were in contact, instead of the raw contact time. Each trial was recorded. The researcher did frame by frame video analysis to determine the contact time percentage. The researcher also took detailed notes during the interviews and analyzed the notes and the videos to find themes.

4.2 Findings

4.2.1 Data Verification. The actual average Call-to-Response ratios were 43:57, 70:30, and 24:76 for Conditions 1, 2, and 3 respectively. Push, Altitude Change, and Tap occurred on average 2:4.67:5.33, 6:8.67:5.33, and 2:4.33:3 times in Conditions 1, 2, and 3 respectively.

4.2.2 Contact Time. We report the contact time for Condition 1 (15.28%), Condition 2 (13.83%), and Condition 3 (21.34%). We performed a One-Way ANOVA, with the Call-to-Response ratio as the independent variable, and the percentage of contact time as the dependent variable. We found that $P(F > 0.18)$, $p = 0.8376$, therefore, the percent of time the drone spent calling and responding had no effect on the length of time the drone and dancer stayed in physical contact. Thus, we accept the null hypothesis and reject H1. With a human partner, contact is expected to be maintained for the majority, if not for the entire, improvisation event. In Condition 3, the drone and dancer maintained contact for over one fifth of the improvised event, which, to our knowledge, is more than any other human-drone dance performance.

4.2.3 Drone Behaviors for Increasing Physicality (RQ1). We found that using the force vector as an input for the algorithm was sufficient for generating motions that increased physical contact. Using this one metric, we designed a variety of behaviors (three Calls and the Response) by simply modifying the duration, speed, and/or direction of the drone’s action.

From the video analysis, we identified and categorized drone behaviors present when the dancer and drone were in physical contact: (1) “leaning” on the dancer, (2) allowing its body to be guided by the dancer, (3) rotating around the dancer’s waist or limb, and (4) Sliding horizontally or vertically across the dancer’s body.

While behaviors such as “leaning” and rotating were intentionally designed to match a Contact Improvisation movement profile, sliding and being guided by the dancer were not. Still, these two behaviors fit within the movement profile by “creating opportunities for leverage” and “weight release” respectively. Upon reflection, it makes sense that the drone’s unexpected behaviors which resulted in physical contact match the movement profile of Contact Improvisation, since the dance form is predicated on physicality.

4.2.4 The Drone as a Partner: Role Switching, Dancer Perspectives and Comparisons (RQ2,3). The dancer thought that the drone felt most like a partner in Condition 3, followed by Condition 2, and lastly Condition 1. Thus, we also reject H2.

In Condition 3, the dancer was surprised by the behaviors of the drone and the movements they created together. This was due in part to the dancer pausing as the drone hovered in Response mode waiting for an impulse. The dancer likened these pauses to reestablishing eye contact with a human partner which is essential in Contact Improvisation. She noted the pauses made it seem like

the drone was making choices—being more intentional about its movements.

Additionally, the variations of the rolling motions created by successively entering Response mode, created unique opportunities for contact. "We're not strategizing with one another the way you would with a human partner, but it felt more conversational". This is in contrast to Condition 2 where the dancer spent a large portion of time "wrangling" the drone. In Condition 2, she noted that while the drone felt like it was exerting more counter force, not all of the calls were recognizable. She also reflected that "It didn't feel equal. If it were a human, it would be a really excellent follower, but wouldn't really do a ton on its own." The counter force made it feel more corporeal, but this alone was not enough for it to feel like it was making its own decisions. Lastly in Condition 1, the dancer noted the drone felt like it was "calling into the ether." And while the drone did appear to be making decisions, it was making them without her.

The dancer compared differences between improvising with the drone and humans. For example, given the weight difference between the drone and dancer, they were unable to achieve any moments of true support. However, there were interesting moments of the illusion of support, especially during Condition 3. Communication during improvisation events greatly affects the dynamic of the partnership and experience of each partner. In this regard, the dancer highlighted two Calls specifically. Altitude Change was the most obvious visual call, leaving the dancer with no ambiguity as to what the drone wanted. In contrast, when the Tap speed was slow the Call could be unclear as it was difficult to determine if the drone was calling or drifting. At one point during Condition 2, the drone ascended to a height far above the dancer for several seconds. While at this height, the dancer crafted her movements based on the drone's visual cues. She described this as an isolating experience since the drone was so physically distant. This isolation can be experienced in Contact Improvisation events with a human partner, albeit, in different forms since flying away is not an option for human dancers. Ultimately we observed that pauses (hovering), a proportional Response (speed of rotation), and clear Calls (fast, decisive movements) were the kinds of behaviors necessary to increase the dancer's perception of the drone as a good partner.

5 DISCUSSION

The partnership dynamics exhibited by the drone can be related to humans. Partners can be selfish and a bad communicator (Condition 1), a good communicator and considerate (Condition 3) or too dependent (Condition 2). While Condition 3 was perceived by the dancer as the best partner, the drone still showed characteristics of a partner, whether good or bad, in all conditions. The dancer also adjusted to the drone's behaviors over time, taking learnings from each condition, and using the first trial of each, to identify patterns—assign a profile—to the drone's new personality. She used this information to adjust her own approach to the drone. This process was similar to the stages of learning a partner in improvisation events with a human. It also relates to themes identified by Ericksson et al. [7]. Our works differ in that the choreographer in their work did not want to ascribe human-like characteristics to the drone. However, the idea of the otherness of the drone forcing the

dancer to adjust their movements, and the technique of dancing "as if they were" the drone to better understand it arise in both works. In work by Cauchard et al. [4] they saw that different emotional states were recognizable by modifying speed, altitude, reactivity, and orientation. This is relevant to our work, as we identified the first three parameters as important for changing the partnership style of the drone. Thus these parameters lead to recognizable characterisations even when the drone's communication method is extended from purely visual to physical. Drones can express personality in physical human-drone interactions, allowing for further adaption and understanding in collaborative tasks.

5.1 Limitations

The algorithms for determining the correct behavior and direction of action could be improved. We used probability to determine when the drone should Respond or Call. As a result, the Call-to-Response ratio was not exactly what was programmed, as discussed in Section 4.2.1. Also, we used information about the force history, but the drone did not make predictions about future partner movements. As far as implementation, the drone's performance is very dependent on the lighting conditions in the room. Lastly, these results stem from work with only one dancer; ideally more dancers would be involved in the design process.

6 CONCLUSION

In this work we explored physical human-drone interactions in a collaborative task in the context of a dance performance. We created drone behaviors that would allow partnership and increase physicality between the dancer and drone. We found that our behaviors were able to increase the level of physical contact during the performance, which was the goal of the collaboration. We also learned what behaviors are important, and how often the drone switching behaviors affects the dancer's perspective of the drone as a partner, and how.

In future work, we will seek to further encourage momentum building in the partnership by inferring the human partner's movements instead of randomly deciding when to Call or Respond. We will also explore audience perceptions of the performance. This work provides insights into user perspectives and algorithm development for future human-drone collaborative applications.

7 AUTHOR ROLES

"Researcher" refers to the first author (R) and "Dancer" (D) refers to the second author. Both contributed to the design of the drone behaviors. NW: provided background and expertise in drones and robotics, designed the experiment, programmed the robot, and led the writing. LP: danced with the robot, provided background literature and expertise in contact improvisation. KP: supervised research. SA: supervised research.

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