Can You Dance with Drones? Exploring Performers' Perception of Augmented Drone Avatars in Mixed Reality

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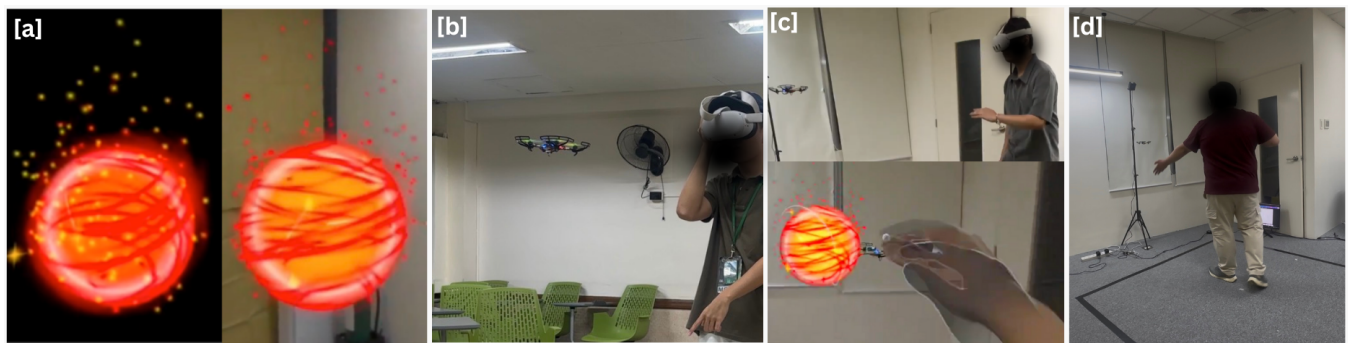Manila, Philippines
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Figure 1: Images illustrating MR. Drone in action across development and evaluation stages. (a) shows the avatar during iterative development and testing; (b) captures our team trialing the early prototype; (c) presents scenes from the pilot study under the MR. Drone (mixed-reality) condition; (d) presents scenes from the pilot study under the Drone-only baseline condition.

Abstract

Robots and drones are increasingly integrated into social and creative domains such as emergency response, entertainment, and performance. Studies have shown that co-located drones can evoke emotions like calmness or gentleness when designed with soft motion, ambient sound, and expressive intent. These findings suggest that human perception of drones depends on their form, motion, and context. In dance, however, drones are often perceived as rigid or intimidating due to their mechanical design. Recent Human–Robot Interaction (HRI) research explores Extended Reality (XR) as a means to reshape perception through augmented forms. This thesis investigates how XR-based avatars can influence performers' perceptions of drones in co-located dance contexts. Co-design workshops with dancers identify features and effects shaping perception, which inform the integration of drone avatars in XR performances. A subsequent user study evaluates perceptual changes, contributing to the understanding of how XR augmentations reframe social and expressive human–drone interaction.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; **Sound-based input / output**; **Usability testing**; **User studies**.

Keywords

drones, perceptions, augmentation, avatar, improvisational dance, co-located human-drone interaction, extended reality, semi-autonomous UAV

1 Introduction

Drones are increasingly used beyond utility domains (e.g., emergency response, communication, entertainment) toward embodied, co-located human–drone interaction (HDI) [13]. Somaesthetic work shows that close-range, intentional motion can support relaxation, bodily awareness, and mindful movement, suggesting that form,

motion, and context shape how people perceive drones [15]. In performance, drones have appeared as partners in dance and live shows; however, improvisational studies report that dancers often experience drones as rigid, controlling, or intimidating, leading to hierarchical rather than collaborative dynamics [8, 9].

Extended Reality (XR) can alter social perception by augmenting a robot's form and communicative cues [25]. We ask: ***How is an augmented drone as a performative avatar perceived in an improvisational dance context?*** We explore mixed reality (MR) overlays that anchor expressive avatars to a co-present, semi-autonomous UAV, aiming to soften authority, improve legibility of intent, and support co-presence.

Our approach combines co-design with dancers to elicit visual or behavioral cues, implementation of MR avatars synchronized with physical flight, and a within-subjects evaluation comparing a Drone-Only baseline with an MR-augmented condition. We focus on performers' perceptions of approachability, authority, legibility, stage presence, and expressive potential during short, improvised interactions.

1.1 Research Objectives

(1) Identify visual and behavioral features that shape the augmented appearance and perceived intent of the drone.
(2) Integrate these features into an MR environment that couples physical flight with synchronized avatar overlays for dance improvisation.
(3) Evaluate how MR augmentation influences performers' perceptions of drones as co-performers.

2 Related Works

2.1 Social Robots as Co-Performers

Social robots increasingly mediate social interaction across healthcare, education, and entertainment, drawing on verbal and nonverbal cues [3] and advances in affective ML/NLP [24]. In healthcare, systems can support emotion regulation and engagement [20], and aid language learning [19]. Beyond assistance, robots have entered performative settings (storytelling, theater, dance), contributing precise motion, synchronization, and audience engagement [1]. Yet achieving nuanced, humanlike expressiveness remains difficult due to preprogrammed gestures and limited affective motion [5, 14]. Iconic social robots such as PARO and KASPAR demonstrate sustained engagement through touch, sound, and minimally expressive behavior [6, 7, 22], but their roles are largely assistive rather than co-creative. Choreographic and somatic perspectives argue that robotic motion is inherently expressive and should be designed beyond human mimicry toward movement qualities and intention [2, 16, 23].

2.2 Human–Drone Interaction in Performance

Drones extend HRI into aerial, co-located interaction. Early exertion-centric systems (e.g., Joggobot) probed embodiment, control, and personality in casual social exercise [12]. Somaesthetic approaches (Drone Chi) emphasized slow, intentional co-movement for bodily awareness [15]. In performance, dancers adapt to drone behavior and spatial metaphors [8, 9]. Despite visually fluid swarms, conveying complex emotion through motion remains challenging [11]. A

recurrent finding is that dancers often perceive drones as rigid, controlling, or intimidating, which can produce hierarchical dynamics where humans accommodate the drone rather than collaborate with it [8, 9]. This points to a design gap around mutual responsiveness, legibility of intent, and cultivating a shared sense of stage presence in co-performance.

2.3 XR to Shape Perception and Presence

Augmentation technologies can make interaction with robots more seamless and intelligible [13, 26]. XR has been shown to enhance social presence and audience immersion in live contexts [17, 21]. Form also matters: fantastical or anthropomorphic/zoomorphic designs (e.g., *Drones in Wonderland*) shift mental models and promote social attributions relative to machine-like quadcopters [4]. For movement practice, AR/XR can guide choreography, provide real-time feedback, and support expressive co-creation when motions are fluid and responsive [10, 27]. Although drones cannot deliver touch, XR can visually mediate relationships and shared movement vocabularies [18]. Avatars further enable dancers to explore alternative bodies and identities, reshaping improvisation and perception [28]. However, most prior work examines XR or HDI in isolation, relies on static/VR stimuli, or does not anchor augmentation to a physical, co-present drone in live performance.

Summary and Contribution. Building on these threads, this paper investigates *mixed-reality* overlays that anchor expressive avatars to co-located drones. We (1) run co-design workshops with dancers to elicit visual/behavioral cues, (2) implement MR drone avatars that couple physical flight with augmented form, and (3) evaluate effects on performers' perceptions (e.g., authority, approachability, legibility, stage presence). Our work synthesizes HDI and XR to reframe drones from authoritative objects to expressive partners in improvisational dance, contributing design insights for social legibility and co-performance.

3 MR. Drone

3.1 System Overview

MR. Drone is a mixed-reality system that integrates an expressive avatar with a semi-autonomous UAV anchored in the same physical space as the performer. Instead of treating the drone as a purely functional machine, the system frames it as a co-performer whose visual form, motion, and timing are designed to convey presence, mood, and intent. Building on themes from our co-design sessions with dancers, the avatar focuses on glowing, abstract forms, soft motion, and subtle feedback rather than literal, mechanical shapes. This expressive layer is synchronized with a choreographed flight path so that the drone and avatar jointly follow a three-part dance segments: pre-dance, during-dance, and post-dance interaction.

3.2 Architecture

The MR. Drone architecture integrates three main components: (1) a Crazyflie 2.1 brushless drone with a Lighthouse positioning deck, (2) a Meta Quest headset running a Unity-based mixed-reality application, and (3) a laptop that executes Python control scripts. The Crazyflie runs pre-defined flight sequences triggered via `cflib`, an open-source Python library provided by Bitcraze for connecting

to and controlling the drone. At the same time, the Lighthouse system estimates the drone's 6-DoF pose.

On the laptop, we connect to these pose estimates through cflib and stream position and phase information to Unity over a local network (UDP). The MR application uses this data to render the avatar so that its position and motion stay aligned with the physical drone. This approach aims to let performers experience the drone and avatar as a single, coherent entity rather than two separate objects.

Interaction starts across three segments that structure the performance. In the pre-dance phase, the drone is grounded and the avatar is visible as it starts hovering, signaling readiness. During the dance, the drone follows choreographed movement (e.g., circling, diagonal, and horizontal movements) while the avatar amplifies these motions with trails, color shifts, and minimal movements. In the post-dance phase, both drone movement and avatar visuals gradually dim and fade, marking a clear sense of closure.

3.3 Tech Stack Overview

To support this architecture, the system uses a modular hardware–software stack designed for programmability, safety, and MR rendering:

- **Drone.** The Crazyflie 2.1 brushless is a small, programmable UAV. In our setup, it is equipped with the Lighthouse positioning deck, which uses Lighthouse base station to estimate the drone's position and orientation indoors with high precision.
- **Control and Scripting.** Drone behavior is scripted in Python 3 using Bitcraze's cflib. Our scripts define takeoff, translation, rotation, and landing, as well as reusable higher-level movement motifs that are called in sequence during the performance segments.
- **Mixed Reality Layer.** The MR application is implemented in Unity (2022 LTS) using OpenXR and the XR Interaction Toolkit. The Meta Quest headset renders the avatar as a passthrough overlay so that the performer can see both the physical environment and the virtual drone avatar at the same time.
- **Avatar Designing.** The avatar's meshes, particle effects, and animations are designed in Unity. The visual design uses layered, abstract elements to showcase rhythm and emotional tone instead of directly mimicking the quadcopter's geometry.
- **Networking and Synchronization.** A laptop connects to the Crazyflie using cflib and the Crazyradio link, and forwards pose and phase information to the MR application via UDP on the local Wi-Fi network. The same high-level motion script that drives the drone also drives the avatar, which helps keep the physical and virtual behavior synchronized.

3.4 Performance Space and Safety Zones

The interaction is staged within a bounded 2 m × 2 m × 2 m volume. This size balances the drone's operational constraints with the dancer's need for expressive movement while keeping the UAV at a safe distance from the body. The floor area is cleared of obstacles, and the drone is restricted to a central flight region so that the dancer can move around and through the space without a high risk of collision.

The layout follows proxemic layering inspired by interpersonal distance categories (e.g., intimate, personal, social). Horizontally, the drone is constrained to remain outside the dancer's intimate zone while still entering the personal zone where interaction feels close and relational. Vertically, the flight envelope avoids the performer's head and face, favoring chest and torso height for perceived connection while keeping clearance above and below. These constraints influence both the choreographed path of the drone and the avatar's framing in MR, contributing to a sense of safety without removing the feeling of co-presence.

3.5 Interaction Walkthrough

We describe the interaction from two parallel perspectives: the dancer's experience through the headset and the drone's physical behavior in the performance space.

3.5.1 Dancer Walkthrough in Mixed Reality. From the performer's point of view, the sequence proceeds as follows:

- **Setup and Initialization.** The dancer wears the Meta Quest headset while the Crazyflie rests on its designated position within the 2×2 m space. In MR, the avatar will only be visible when the script is executed.
- **Flight Synchronization.** As the drone lifts off, the avatar becomes more animated, its core starts to glow, trails brighten, and color shifts mark transitions between sections of music.
- **Performance Sequence.** Throughout the main dance segment, the avatar mirrors the drone's position and orientation while adding expressive behaviors such as shimmering and color changes. These cues are designed to suggest timing and direction and to invite improvisational responses without overwhelming the dancer with explicit instructions.
- **Closure.** As the performance comes to an end, the drone prepares to land and the avatar slowly dims and eventually fades out, visually marking the end of the interaction. The environment returns to a neutral "idle" state, ready for another trial.

This layered MR feedback is intended to support embodied improvisation and emotional framing, so that the performer can interpret the drone more as a partner than as a tool.

3.5.2 Drone Behavior and Flight Path. In parallel with the MR visuals, the semi-autonomous UAV executes a choreographed motion script:

- **Introductory Phase.** The drone takes off from its pad and rises to a safe, mid-torso height, hovering steadily to establish its presence without crowding the dancer.
- **Interaction Phase.** The drone then performs a series of lateral and vertical patterns, suchs as circling and diagonal movements, within the central region of the space. These motifs are chosen to represent different expressive tones of music and to provide varied spatial prompts for the dancer.
- **Landing Phase.** Finally, the drone returns to its starting zone, slows, and descends back onto its starting position. This closing gesture is synchronized with the avatar's fade-out, reinforcing a clear end to the shared routine.

The drone does not yet react in real time to the dancer's body movement, but the combination of a planned motion script and MR augmentation is designed to feel responsive and relational, supporting our broader goal of exploring drones as performative avatars.

4 Pilot Study

To validate the feasibility of the MR. Drone prototype, assess safety procedures, and identify perceptual differences across conditions, we conducted a small-scale pilot with two dancers. The pilot tested all study components, such as MR. Drone experience, Drone-only experience, questionnaires, environment setup, and semi-structured interview protocol—prior to the main user study. We also specifically compared interaction at 0.5 m and 1.0 m drone and dancer distances to determine which distance was more suitable, immersive, and safer for the user evaluation.

4.1 Protocol and Participants

The pilot study followed a counterbalanced within-subjects design comprising four conditions: (1) MR. Drone with a virtual avatar masking the physical drone at a 1.0 m drone–dancer distance, (2) MR. Drone at 0.5 m, (3) Drone-Only at 1.0 m, and (4) Drone-Only at 0.5 m. Trials were conducted within a taped 2 × 2 m safety area in a standard room. A Crazyflie 2.1 Brushless with Lighthouse tracking executed an identical semi-autonomous routine across all conditions.

Two adult dancers participated:

- **P1:** Female, contemporary dancer, intermediate movement experience, no prior XR use.
- **P2:** Female, contemporary dancer, more experienced performer with improvisational background.

Before the pilot sessions for both experiences, all recruited participants completed an informed consent form. Each session began with an orientation, during which the procedures, safety measures, and flow of the activities were explained.

The pilot followed a counterbalanced structure to reduce order bias. Participant 1 began with the MR condition at a 1.0 m drone–dancer distance, followed by Drone-only at 1.0 m, and then proceeded with both MR and Drone-only at 0.5 m. Participant 2 experienced the opposite sequence, starting with the 0.5 m Drone-only and MR conditions, followed by the 1.0 m Drone-only and MR conditions. This approach ensured varied experience orders across participants and produced more diverse insights during analysis.

Before each MR routine, participants completed a pre–Simulator Sickness Questionnaire (SSQ). After every condition (MR and Drone-only), they completed the NASA-TLX, the Godspeed questionnaire, and the UEQ-S. For MR conditions only, participants also answered the MREQ and the post-SSQ. In the Drone-only condition, participants completed the same set of questionnaires except for the MREQ and the SSQs. Each experience concluded with a short interview and participant reflection to support qualitative analysis. All sessions were video-recorded for further qualitative review.

Each participant completed two trials at two distances (0.5 m and 1.0 m), resulting in four experiences per participant. Each experience lasted for up to 30 minutes, for a total session duration of approximately 120 minutes per participant.

Throughout each pilot session, we captured their insights both through interviews and questionnaires. Questionnaires serving for our quantitative data to assess, while through a video observation and recordings, the interview captured their qualitative insights, specifically which distance and condition they preferred more.

5 Early Findings

Overall, the pilot suggested that the MR. Drone prototype is feasible, safe, and capable of producing distinct experiential differences between conditions and distances. Across both dancers, the MR condition was consistently preferred over the Drone-only experience, and the two distances (0.5 m and 1.0 m) produced meaningful contrasts in perceived safety, workload, and expressiveness that informed the design of the main study.

Quantitatively, both participants completed all measurement instruments. SSQ scores remained in a low-to-moderate range but increased more at 1.0 m than at 0.5 m, indicating that dancing with MR. Drone at a farther distance produced more visual strain than when the avatar–drone remained closer. NASA–TLX results showed that at 0.5 m, MR often reduced workload compared to Drone-only, especially for P2, who reported lower overall effort when the avatar structured the interaction. At 1.0 m, however, Drone-only became the easiest setting for both dancers, while MR. Drone remained more mentally demanding, suggesting that the added MR layer at distance requires extra attention to track and interpret the avatar. Godspeed and UEQ-S questionnaires resulted in MR. Drone , particularly at 0.5 m, increased perceptions of anthropomorphism, animacy, and overall user experience, whereas Drone-only conditions were more mixed and sometimes slightly negative. Circumplex ratings further positioned MR 0.5 m in a "delighted/excited" zone and MR 1.0 m as more "strained," while Drone-only 1.0 m felt positively engaged but less immersive. MREQ scores for MR. Drone were positive at both distances, with higher and more consistent ratings at 0.5 m than at 1.0 m.

Qualitative feedback from interviews and video observations helped explain these numeric patterns. Both P1 and P2 described MR. Drone as more immersive and creatively stimulating than Drone-only. P1 highlighted that masking the physical drone with the avatar substantially reduced her fear; she reported feeling scared during the 0.5 m Drone-only routine and even requested to stop that trial due to concerns about proximity. In contrast, she did not report fear in the MR condition, as she was primarily engaging with the avatar rather than the exposed hardware. P2 similarly characterized MR. Drone as "more fun" and "more interactive," and described the avatar-enhanced drone as a partner, whereas the Drone-only version felt more like a tool or prop.

Both dancers, however, were sensitive to distance and proxemics. P1 clearly preferred 1.0 m as her default distance, describing 0.5 m as "scary," but she suggested that occasional closer passes could be effective if they were brief rather than sustained. He/she also noted that certain motion motifs, such as the zigzag segment, could be emphasized more clearly in the flight path. P2 did not settle on exactly 0.5 m or 1.0 m, instead proposing an intermediate distance that balances safety and interaction. For him/her, 1.0 m provided comfortable safety but sometimes felt too far to sustain engagement at center stage, while 0.5 m violated her personal space.

Regarding the avatar and system design, both participants commended the motion quality and layered texture of the avatar, describing it as intentional and lifelike. At the same time, they independently questioned the color–music mapping, given a piano-heavy, non-upbeat track, both felt that red–orange hues were more suitable for an upbeat song and recommended cooler tones (blue/violet) to better match the musical mood. The onboarding sequence in the MR application was received positively, helping both dancers anticipate the experience and understand the routine structure. Finally, P1 found the music somewhat repetitive and "not really danceable" for her preferred style, whereas P2 considered it appropriate for the intended genre.

Taken together, the pilot indicates that MR. Drone can successfully reframe a drone from a mechanical object into a more expressive, partner-like presence, especially at closer distances, while also revealing important trade-offs around safety, personal space, and cognitive load. These findings motivated concrete adjustments to the main study, including prioritizing 1.0 m as the primary interaction distance, refining the flight path to balance closeness and comfort, revisiting avatar color choices to better match the soundtrack, and simplifying the questionnaire flow to reduce participant burden.

6 Conclusion

In this paper, we introduced MR. Drone, a mixed-reality system that augments a physical drone with an expressive virtual avatar to explore how dancers perceive drones as potential co-performers. Building on insights from co-design workshops, MR. Drone is positioned in human–drone interaction within an embodied performance context, blending physical motion with layered visual behaviors that aim to reduce intimidation and frame the drone as a partner rather than a tool. By integrating real-time Lighthouse tracking, synchronized avatar overlays in Meta Quest mixed reality, and a choreographed semi-autonomous flight path, the system offers a unified platform for studying proxemics, expressiveness, and perception in co-located HDI.

Our pilot study with two dance experts provided crucial early validation of the system's feasibility, clarity of interaction, and safety. Quantitative measures revealed clear perceptual differences across both distance (0.5 m vs. 1.0 m) and condition (MR versus Drone-only), with MR generally improving anthropomorphism, engagement, and emotional valence—particularly at closer distances—while Drone-only at 1.0 m remained perceptually safer and less cognitively demanding. Simulator sickness remained low across all sessions. Qualitative insights further contextualized these findings: participants described the MR avatar as more intentional, partner-like, and creatively stimulating, while the unaugmented drone was viewed as mechanical, intimidating, or spatially intrusive at 0.5 m. Both dancers emphasized the influence of personal space, motion clarity, and audiovisual coherence, offering recommendations that shaped refinements to the avatar design, soundtrack mapping, and flight choreography.

These results demonstrate that MR augmentation can meaningfully reshape how dancers interpret and interact with drones in live performance settings. MR. Drone successfully reframed the drone's presence, softening its authority and enhancing its perceived expressiveness—even with non-responsive, pre-scripted movement. At the same time, the pilot highlighted key trade-offs around cognitive load, spatial comfort, and the importance of maintaining safety without diminishing immersion. These insights informed several adjustments for the main study, including prioritizing a 1.0 m base distance with planned momentary closeness, refining avatar color palettes to better match musical tone, and improving onboarding clarity.

Overall, this work contributes an empirical foundation for mixed-reality augmentation in human–drone co-performance, offering both a technical framework and early evidence that expressive virtual overlays can modulate perception in meaningful ways. By bridging HDI, somatic practice, and XR performance, MR. Drone opens avenues for designing drones not merely as functional machines but as embodied creative partners. Future work will involve a larger, more diverse user study to investigate how augmented drones support co-presence, improvisational reciprocity, and long-term comfort, as well as exploring dynamic, dancer-responsive motion to deepen the sense of shared agency on stage.

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