# HapticPuppet: A Kinesthetic Mid-air Multidirectional Force-Feedback Drone-based Interface


Martin Feick
DFKI, Saarland Informatics Campus
Saarbrücken, Germany
martin.feick@dfki.de

Anthony Tang
University of Toronto, iSchool
Toronto, Canada
tonytang@utoronto.ca

Antonio Krüger
DFKI, Saarland Informatics Campus
Saarbrücken, Germany
antonio.krüger@dfki.de



**Figure 1: Concept. (A) HapticPuppet drone providing haptic feedback when a user is pressing a virtual button in AR. (B) Demonstrates how the system can be used for exercising. (C) A VR user kicks a ball and feels the impact. (D) A collocated partner dance, and the remote setup using two HapticPuppets. (E) Shows a user's hand augmented with five attachment points.**


## ABSTRACT

Providing kinesthetic force-feedback for human-scale interactions is challenging due to the relatively large forces needed. Therefore, robotic actuators are predominantly used to deliver this kind of haptic feedback; however, they offer limited flexibility and spatial resolution. In this work, we introduce HapticPuppet, a drone-based force-feedback interface which can exert multidirectional forces onto the human body. This can be achieved by attaching strings to different parts of the human body such as fingers, hands or ankles, which can then be affixed to multiple coordinated drones - puppeteering the user. HapticPuppet opens up a wide range of potential applications in virtual, augmented and mixed reality, exercising, physiotherapy, remote collaboration as well as haptic guidance.



## KEYWORDS

Haptics, Directional Kinesthetic Force-Feedback, Drones, VR, AR

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## 1 INTRODUCTION

Kinesthetic (haptic) force-feedback is crucial for many applications to improve realism and immersion in mixed reality environments [7], to improve remote collaboration by substituting a distant users' interactions [6], or to guide blind or visually impaired people [3, 4]. Here, two main classes of haptic systems exist (1) grounded devices i.e., they are stationary, allowing to generate large forces but are somewhat limited when dynamic re-positioning is required and (2) ungrounded systems, that always remain at a human's body and thus, can usually not provide stronger (counter)forces. However, both approaches often lack the ability to apply directional forces to any desired limb when users are freely moving around in 3D space. This is especially challenging, because it requires intelligent use of 3-dimensional space and high accuracy to avoid physical contact with users. As a result, bulky actuation mechanisms are unsuitable for such demands.

We propose HapticPuppet, a kinesthetic force-feedback interface which is designed to offer three clear advantages (1) in idle mode, users can freely move in 3D space with complete absence of force feedback and as little wearable human augmentation as possible, (2) it supports rapid 3-dimensional re-positioning to avoid collisions and ensures quick adaptation to new contexts and requirements, and (3) it can generate directional forces alongside complex trajectories mid-air. To achieve this, users may wear a single or multiple attachment points on various parts of their body (see Figure 1). Drones can connect to these attachment points via strings and hence, are capable of actuating (puppeteering) these limbs. This set of features enables HapticPuppet to be used as a haptic interfaces for a wide variety of applications and use case.

## 2 HAPTICPUPPET & RELATED LITERATURE

The HapticPuppet concept is inspired by related work in field of supportive systems for visually impaired people, where the distinct sound and airflow of drones is used to provide navigational cues [3]. Soto et al. [4] presented DroneNavigator, an interface consisting of a controller stick and strings attached to a quadrocopter offering haptic guidance. [9] developed GuideCopter, a drone-based haptic interface that uses strings attached to fingers and the forearm. In a study, they investigated how force and pulling-directionality need to be designed to effectively communicate navigational cues. The authors report that they achieved high accuracy, and even outperform current audio-based devices. Therefore, we opted for the promising string approach to establish a connection between to free-floating drones and the human. Using strings attached to fingers has also been demonstrated in the context of VR, enabling high fidelity whole-hand haptic feedback for virtual objects [5]. Especially in the VR space, drones have been used to provide haptic feedback for objects [2], interactions [8, 11] or haven been utilized to generate counterforces [1]. Yet, to the best of our knowledge, there exist no approach that uses drones for full-body actuation.

## 3 TECHNICAL IMPLEMENTATION

We designed and implemented the user augmentation kit, a HapticPuppet drone as well as the basic software pipeline to control a single drone in the environment using optical tracking.

### 3.1 User Augmentation & Attachment Points

We 3D printed attachment points in different sizes that can be attached to various positions on the human body. As illustrated in Figure 1, we currently offer fingers, wrists, arms and ankles, but our approach is not limited to this. Later, we also imagine attachment points that can be affixed to users chest, head or legs. Depending on the application and users' preferences one or multiple attachment points can be worn.

The attachment points are 3D printed on a Prusa i3 MK3S+[1] using a mix of PETG/PLA materials. Generally, a single attachment point consists of 3 parts: a base, a unidirectional bearing and a hook to attach the string. We chose this design because it limits the number of drones needed to provide directional forces and for the most part prevents tangling of the strings (see Figure 1 E - 5).

The string material depends on the use case and the desired sensation that a designer wants to create. To this end, we successfully worked with polyamid and nylon thread.

### 3.2 HapticPuppet Hardware

We built a custom drone which we designed to produce maximum torque given its rather small size of 95mm (wheel base). It is based on the Beta95X[2] frame and utilizes 4 x 1106 brushless motors (4500KV), Gemfan 2540 3-blade propellers and is operated with a F4 brushless flight controller and ESC V2.0 (BLHeli32) running Betaflight[3] 4.2.0 firmware. It weights 72 grams and powered by a 450mAh 4S 75C lipo battery allowing for 6–7 minutes flight time under normal conditions. For remote control, we use a AC900 receiver and a FrSKY[4] Taranis lite. The RC radio transmitter was flashed with the OpenTX[5] 2.3.10 firmware.

### 3.3 Position Control System

Our setup uses 12 Optitrack Flex 13 cameras[6] attached to an aluminium frame, covering a tracking space of 5m x 5m x 2.5m. The drone is outfitted with retro-reflective markers enabling accurate position and orientation tracking which is streamed via Motive[7] and NatNet SDK to a host machine. Here, we use a Proportional Integral Derivative (PID) controller[8], allowing us to position the drone in 3D space. To this end, we technically only support single drone setups.

## 4 APPLICATIONS & USE CASES

Here we outline four potential uses cases which are shown in Figure 1, demonstrating the wide application space of HapticPuppet.
**Augmented Reality (A):** HapticPuppet can give the purely virtual objects and environment a "physical" tangible form. This way, it can enhance interactions and hence, deliver a more realistic, intuitive and compelling AR experience. There exist sheer countless potential use cases, however we decided to show a simple but very common interaction - pressing a button mid-air. Since AR allows users to still see the real-world, designers might want to opt for transparent polyamid thread. Additionally, it is possible to hide levitating drones in the environment that cannot stay out-of-sight, using visual overlays [10].
**Rehabilitation/Exercising (B):** HapticPuppet enables users to perform physical exercises with static or dynamically changing resistances. One key advantage over resistance rehabilitation bands is, that only one device is required, enabling a wide range of potential exercises that can be performed. Moreover, the airflow caused by the drones' propellers, which is usually seen as one of the major drawbacks, may be utilized for active cooling of the person while exercising. This opens up an interesting design space that hopefully inspires future use cases.
**Virtual Reality (C):** In VR, users are visually immersed into a virtual environment and similarly to AR, HapticPuppet can add rich haptic sensations to improve the overall experience. Here, we show a foot-based interaction i.e., a user kicks a ball, because providing kinesthetic force-feedback to the feet still seems underexplored in VR research.
**Remote Collaboration (D):** Physically connecting remote people is still a grand challenge. HapticPuppet is designed to contribute to this area by enabling a local user to feel movements of a remote person and thus, allowing them to synchronize their actions. This can be used to learn new movement patterns to, for instance, train a golf or tennis swing with a remote expert. On the other hand, one could also image to simulate a local surrogate of the distant user, so that their presence can be felt e.g., while dancing. This could, of course be enhanced by adding a visual avatar using AR/VR as illustrated in Figure 1 (D).

[1] https://www.prusa3d.com/
[2] https://betafpv.com/
[3] https://betaflight.de/
[4] https://www.frsky-rc.com/
[5] https://www.open-tx.org/
[6] https://optitrack.com/
[7] https://www.optitrack.com/software/motive/
[8] https://github.com/m-lundberg/simple-pid

## 5 LIMITATIONS & NEXT STEPS

One key challenges with the current implementation remains the precised positioning of the drones in 3D space, i.e., preventing oscillation, drifting and similar effects, as well as the coordination of multiple drones simultaneously [11]. Additionally, there exist inherit limitations to the use of quadrocopters such as their noise, airflow when not matching the interaction, and the fact that they could be potentially harmful to users. In the latter, we either want to use cages for the drones [2] or even switch to blade-free drones [12] in the future.

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