HapticDrone - An Encountered-Type Kinesthetic Haptic Interface with Controllable Force Feedback: Initial Example for 1D Haptic Feedback

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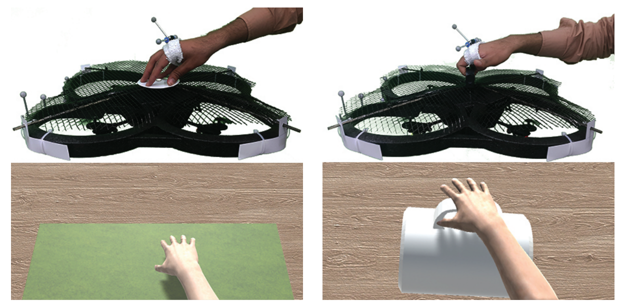
ABSTRACT
We present HapticDrone, a concept to generate controllable and comparable force feedback for direct haptic interaction with a drone. As a proof-of-concept study this paper focuses on creating haptic feedback only in 1D direction. To this end, an encountered-type, safe and un-tethered haptic display is implemented. An overview of the system and details on how to control the force output of drones is provided. Our current prototype generates forces up to 1.53 N upwards and 2.97 N downwards. This concept serves as a first step towards introducing drones as mainstream haptic devices.

ACM Classification Keywords
H.5.2 [User Interfaces]: Haptic I/O

Author Keywords
Haptics; Virtual Reality; Kinesthetic; Encountered; Drone



(a) The user experiencing stiffness of a virtual object, the force is rendered in the upward direction.

(b) The user experiences weight sensation by grasping the handle, the force is applied in the downward direction.

Figure 1. The example applications are implemented using the controllable 1D force feedback from the HapticDrone.

INTRODUCTION
Haptic interfaces allow people to perceive virtual objects through kinesthetic and tactile cues. Generally, haptic devices are classified into either grounded or ungrounded category based on the grounding of the feedback forces. Haptic interfaces that use the ground or earth as a counterpart of the action-reaction principle [6] are considered "grounded". The workspace of these devices is limited to their grounding location. On the other hand, ungrounded haptic interfaces are commonly attached to the user's body, exploiting a body part as a reaction support [1]. In this case, they remain in perpetual contact with the user and only "relative-force" among body parts can be generated. Encountered type devices are a subset of haptic devices that come in both the grounded and ungrounded format [8]. They follow the user's movement and only engage contact when a virtual object is touched. Recently a new wave of grounded devices providing midair haptic feedback are being introduced. They use ultrasonic waves [2] or air [7] to create mid-air haptic displays. These devices generate small amounts of force for tactile stimulation.

Drones have recently been introduced into encountered type haptics to overcome the challenges of classical haptic devices. They are capable of generating considerable force in all directions of movement. Thus can constitute a haptic device with multiple degrees of freedom. Research in the area was started by BitDrones [4], where the user experiences basic touch feedback and interacts with flying "catoms". Kenierim et al. [5] also demonstrated tactile feedback utilizing the impact force of small drones. In [9], Yamaguchi et al. used a drone as an encountered-type haptic device. A flexible sheet of paper was attached to the drone's side, which becomes stiffer due to air flow from the rotors. A user touches the sheet using a stick to feel the force. The main limitations are that the rendered force cannot be accurately controlled and the maximum force is very low (0.118 N) since the rotor's airflow is a fraction of the drone's capabilities.

For drones to leave the confines of novelty and join mainstream haptics they need to become comparable to standard haptic devices. Thus we need controllable and higher magnitude of force output. Furthermore, the design philosophy should be applicable to any drone allowing easier up-gradation with each new iteration. We have achieved these targets and present HapticDrone as the solution.

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HAPTICDRONE

The concept can generate controllable and comparable force feedback for direct haptic interaction with a drone. During free movement without contact with a virtual object, the drone can follow the user's movement in all directions, remaining in the vicinity preparing for contact. To create feedback, the HapticDrone makes direct contact with the user's hand and pushes it to generate force output when needed. As our main goal is to generate tangible amount of controllable force feedback, as an initial proof of concept we have confined force rendering and corresponding applications to 1D (vertical direction) interaction. Virtual reality is chosen to demonstrate the applications as shown in Figure 1. However, the concept can be used in different environments, such as teleoperation, augmented reality, computer aided design and video games.

The Parrot AR Drone 2.0™ quadcopter is used as a test bed to evaluate the HapticDrone concept. To provide complete safety, the default cover was augmented with a lightweight aluminum mesh (89g). Oculus Virtual Reality headset was used in conjunction with Unity 3D for the applications. Tracking the drone, the user and the HMD is accomplished using the OptiTrack V120 Trio from Natural Point with IR markers. The AR Drone SDK commands are embedded in a custom python application, which controls the drone's movements based on the location and application data.

In order to precisely control the exerted force, the relationship between thrust command value and the rendered force magnitude has to be formulated. We applied the method of system identification by treating the drone as a black box. Under a given static mass of the drone, the velocity command is directly proportional to the force. An experimental procedure was conducted to find the resulting force in the upward and downward direction. The input speed was incrementally increased (41 intervals) and rendered force values were recorded as the output. The dynamic range is shown in Figure 2. The maximum stable upwards and downwards force is 1.53 N and 2.97 N respectively. For comparison, a grounded device, the Geomagic Touch [3] can produce 3.3 N of force.

To create an encounter type interaction, the drone has two flying modes. It follows the user's hand in *non-contact mode* keeping a certain distance until a virtual object is encountered, whereupon, it makes contact (mode switching) and renders a force based on the application in *contact mode*. In *non-contact mode* a PID loop is employed catering for the added weight of the safety cover. The *contact mode* uses the force mapping function to interact with the user based on the application.

EXAMPLE APPLICATIONS

As our system is a proof of concept prototype and only has 1D controlled force feedback, we have confined our applications to this dimension. In the future, combining the other degrees of freedom provided by the drone, we can create more interesting and complex scenarios.

Programmable Stiffness Rendering

The user can touch virtual objects and experience their haptic value of stiffness (k) as shown in Figure 1 (a). The drone's upwards force is used to create the feeling of resistance. The drone follows the users hand movements in non-contact mode, waiting for interaction. When the user touches one of the virtual objects, the drone enters contact mode and applies force to the user's hand. The force changes linearly based on the stiffness model ($f = kx$) and the penetration depth (x) on the virtual object is calculated from the tracking data. If the calculated force exceeds the maximum exert-able force (1.53 N), the algorithm saturates to the maximum force. The application is programmable for more sophisticated models.

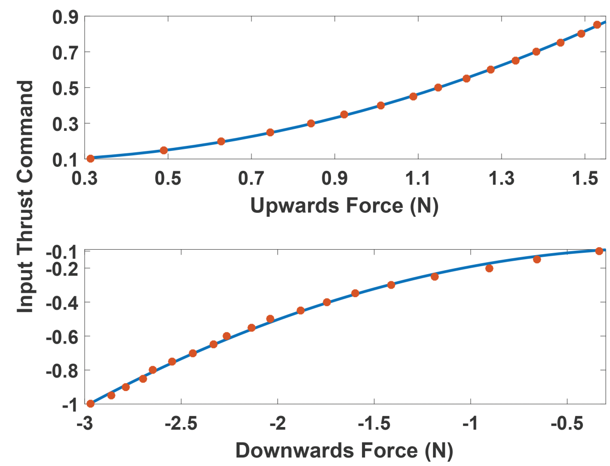

Figure 2. The force mapping function, showing the dynamic range of the drone. The results are used to control the force in the stiffness and weight rendering applications.

Haptic Weight Augmentation

This application allows the user to experience the weight of a virtual object, as shown in Figure 1 (b). The drone's downwards force is used to create the perception of heaviness. A handle is attached to the drone for this application. The weight of an object and gravity can be changed. In non-contact mode, the drone moves itself based on the position of the virtual object. When the user slips their hand into the handle and lifts the object from its rest position, the drone enters contact mode. It applies force according to the simulated weight of the object. It can create a maximum gravitational force of 2.97 N.

CONCLUSION

In this research, we detailed the HapticDrone concept. As an initial study, we have developed controlled force rendering in one dimension, with the goal to extend to full degrees of freedom in the future. Furthermore, we proved that drones are capable of creating respectable amounts of force feedback (1.53 N upwards 2.97 N downwards), comparable with mainstream haptic devices. The concept can be applied to any quad-copter turning it into a safe, untethered, encountered-type haptic device.

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