Towards Enabling Complex Touch-based Human-Drone Interaction

Yang Chen, Hamed Alimohammadzadeh, Shahram Ghandeharizadeh, and Heather Culbertson

***Abstract*— In this paper, we introduce an innovative approach to multi-human robot interaction, leveraging the capabilities of omnicopters. These agile aerial vehicles are poised to revolutionize haptic feedback by offering complex sensations with 6 degrees of freedom (6DoF) movements. Unlike traditional systems, our envisioned method enables haptic rendering without the need for tilt, offering a more intuitive and seamless interaction experience. Furthermore, we propose using omnicopter swarms in human-robot interaction, these omnicopters can collaboratively emulate and render intricate objects in real-time. This swarm-based rendering not only expands the realm of tangible human-robot interactions but also holds potential in diverse applications, from immersive virtual environments to tactile guidance in physical tasks. Our vision outlines a future where robots and humans interact in more tangible and sophisticated ways, pushing the boundaries of current haptic technology.**

I. Motivation

Many of these haptic drone interactions have been incorporated with VR, using the drones to display touch feedback that matches what the user is seeing through a head-mounted display (HMD) [1], [2]. These systems can be separated into active and passive feedback. Passive feedback involves sensations provided to the user based on their collisions with objects in the virtual environment [3]. More common are active feedback systems with which the user interacts directly using their hands [4]. These drone systems have been created to display a variety of haptic sensations, including vertical force [2] and lateral force [5]. They have also been designed for use in several applications, such as a joystick and slider controller [6] and for presenting clothes during virtual shopping [1]. The majority of these systems used only a single drone at a time to provide one point of contact to the user. The BitDrones system [7] present the idea of using a group of drones to provide haptic feedback, but this feedback has not been tested. Wiredswarm provides forces directly to the user's fingers using multiple drones attached by cables, but can only provide forces in tension, not compression like most standard haptic systems [8]

Overall, related works showed the usage of drones to make the VR experience more immersive. However, there are key limitations to these systems, including limited force output to the user, non-generalizability to three-dimensions, and inability to provide shape of displayed objects. In this paper, we propose methods for addressing these limitations by using multiple eight-rotor drones, which we refer to as Omnicopters [9]due to their holonomic nature.

The authors are with the Department of Computer Science, University of Southern California, Los Angeles, CA 90089, USA. {chen716,halimoha,shahram,hculbert}@usc.edu

II. Vision

Prior human-drone haptic interactions have been implemented using quadrotors [?]. However, displaying static forces and forces in multiple degrees-of-freedom is complicated with a quadrotor because they are non-holonomic. For example, their need to tilt while providing a lateral force[10] limits the static stability of forces applied to the user's hand. Therefore, in this paper we explore the use of a holonomic drone with eight rotors to create these haptic interactions.

A. Omnidirectional Unmanned Ariel Vehicle

The Omnicopter is an advanced drone model with eight rotors arranged in a unique configuration that enables the generation of forces and torques in all three dimensions without the need to tilt or reorient itself. This non-traditional arrangement of propellers provides the Omnicopter with a distinct advantage over other drone models, allowing it to simultaneously navigate in all directions and maintain stability [9].

The dynamics of the Omnicopter are more complex than conventional quadcopters due to the additional degrees of freedom. However, this complexity gives rise to the drone's improved agility and control precision. The thrust force and direction of each rotor can be individually controlled to effect any desired movement or orientation in 3D space. By varying the speed of individual rotors, the Omnicopter can create a resultant thrust vector in any direction. This capability is a direct consequence of its design, which uses a combination of positive and negative pitches in its rotor configuration.

The use of multiple Omnicopters for haptic feedback in VR can provide the user with a more immersive experience by simulating the 3D shape and texture of virtual objects in a physical environment. Thus, the Omnicopter's unique capability of generating 3D thrust without having to tilt, paired with its advanced control system, makes it a promising technology for scaling up touch-based drone-human interaction.

B. 3D Cursor Rendering

We propose a system consisting of an omnicopter swarm and a touchpad device to render the haptic interaction. The touchpad runs a standard 3D editing software and enables 3D model view selection, while the swarm renders virtual objects as viewed on the touchpad. Each Omnicopter has three modes of operation: 3D rendering Mode, View Selection Mode, and Editing Mode. The choice of these modes was motivated by desktop 3D design software workflows[11], [12], [13]. Note that this is not an exhaustive list of operating

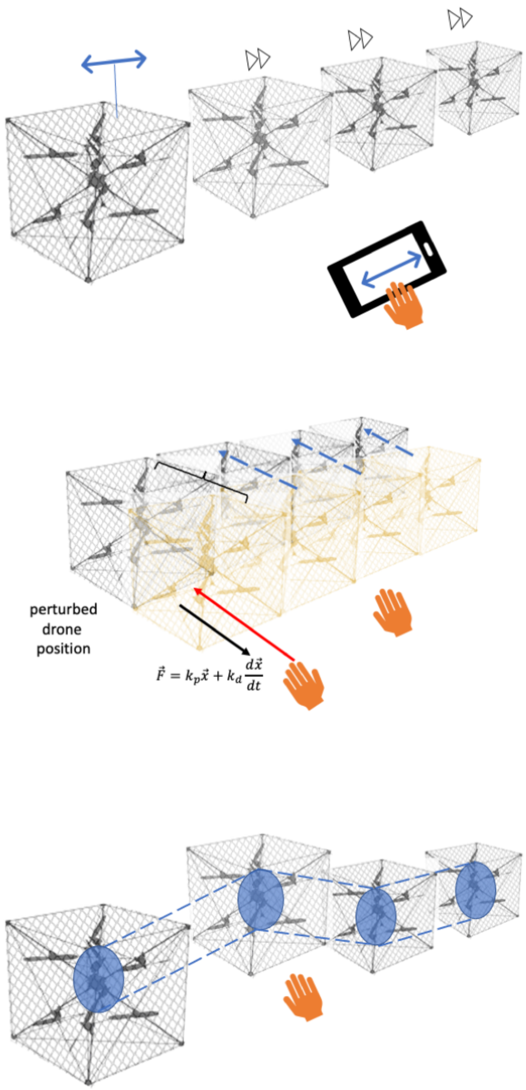

Fig. 1. From top to bottom: Force Rendering mode, zoom-in mode, and editing mode.

modes and the system can be extended to include additional modes for more complex interactions.

1. View Selection Mode: This mode involves dynamic changes in the drone swarm's formation in response to the user's selection of the view for the virtual object using the touchpad. For instance, if the user wishes to zoom into a particular portion of the virtual object, the swarm adapts accordingly, rendering the contour shown on the display. As the user's field of view zooms in, the drones adjust their positions to reflect the most significant contour changes within the zoomed area. The adjustment is proportional to the zoom level, ensuring an accurate and immersive representation of the model.

2. 3D Rendering Mode: In this mode, the multi-Omnicopter swarm works collectively to render a 3D model representing the virtual object's most significant contours. Each drone in the swarm represents a piece of the model, together creating an immersive and tangible representation of the virtual object. When the user touches the virtual object rendered by the omnicopters, they will move together and render the calculated force in the direction opposite of the user's touch (Fig. 1).

3. Editing Mode: In this mode, the user can effortlessly modify the position of individual drones by pushing them, which in turn alters the rendered contours of the original 3D virtual object. The new positions of the drones reflect the user's changes, enabling direct manipulation of the virtual object. For example, a user moves the position of a drone in a swarm that is rendering a pipe, the slope of the pipe changes as seen in (Fig. 1). This mode allows users to interact more deeply with the virtual object, modifying its shape, size, and orientation as desired.

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