Skoltech Summer Research Internship in Aerial Robotics

Topic – High-Fidelity Haptic Rendering of Soft Objects in VR using UAVs

Collaborators – Joint research: Skoltech, MIT, Imperial College London, Bilkent University

IEEE SMC 2022 Conference Paper - https://doi.org/10.48550/arXiv.2209.10503

Keywords – Human-Drone Interaction; Haptic Interfaces; Multi-agent Systems; Virtual Reality

Summary –

I contributed to *DandelionTouch*, a novel VR haptic feedback system using a swarm of drones to deliver tactile sensations to the user's fingertips. The drones followed the user's hand movements in real-time and provided vibrotactile feedback when interacting with virtual objects. We presented a peer-reviewed paper at **IEEE SMC 2022**, which received the **Best Student Paper – Runner-up Award**.

Challenge –

The core objective was to achieve high-fidelity, low-latency haptic feedback in an unbounded VR environment without the use of bulky wearable devices. This required building a drone-based haptic interface track user hand motion, deliver tactile cues, and avoid collisions while maintaining spatial formations in close proximity to a human.

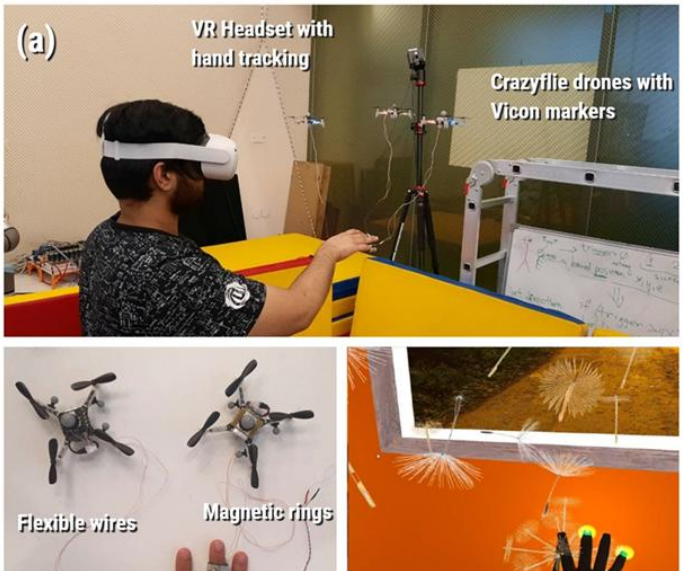

Figure 24: DandelionTouch Concept: (a) The user receives tactile feedback when interacting with different agents in the VR environment. (b) Vibromotors are delivered to the user's finger by drones. (c) The user interacts with virtual objects through DandelionTouch.

Approach –

My contributions focused on three major components:

1. **Swarm Impedance Modeling (Python)**: Implemented the impedance control equations governing the drone formation, based on mass-spring-damper dynamics.

2. **VR Simulation and Collision Detection (Unity 3D)**: Built the VR environment with physics-based hand tracking and real-time collision detection to trigger haptic feedback.

3. **Unity–ROS Bridge**: Linked Unity and ROS via ROS# and TCP sockets to synchronize user motion, drone behavior, and haptic responses in real time.

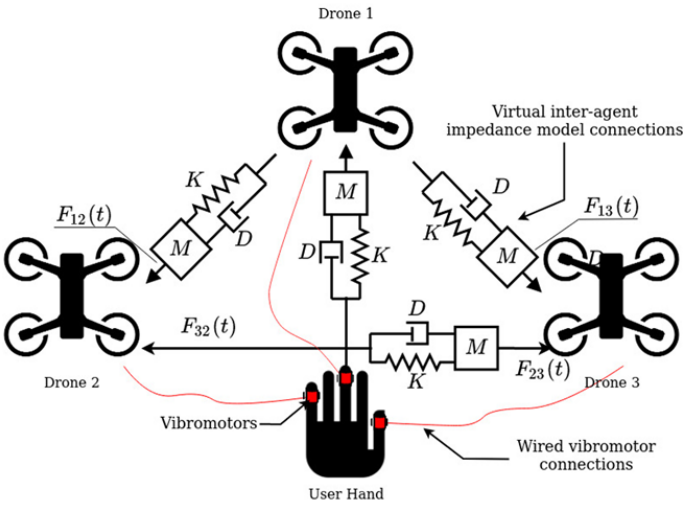

Figure 25: The topology and parameters of impedance links to achieve safe flight and compliant interaction.

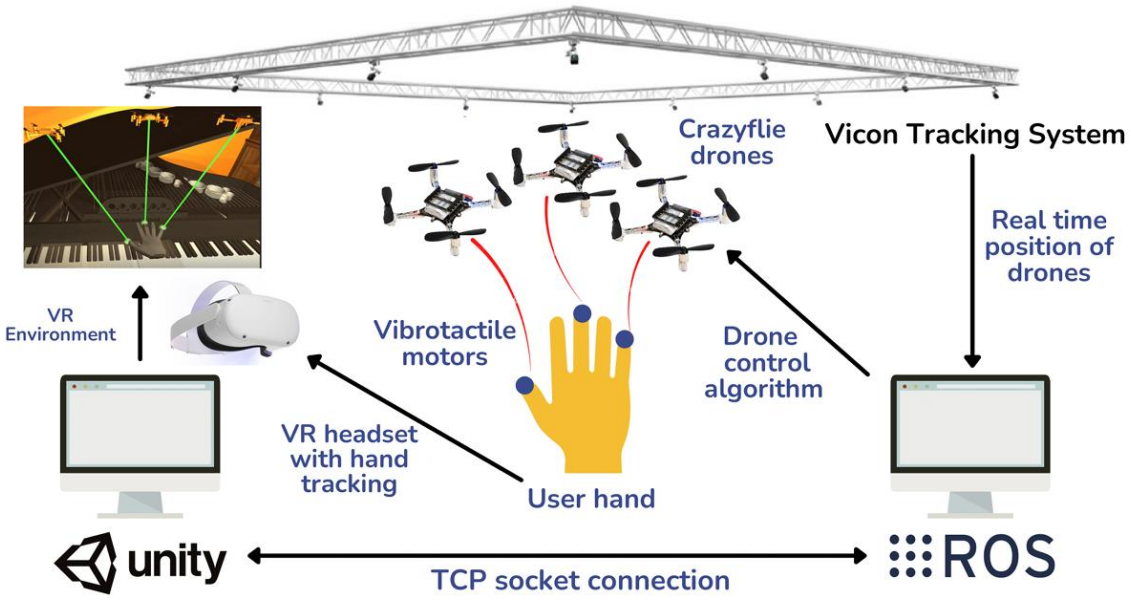

Figure 26: Overview of the DandelionTouch. User interacts with objects through VR framework with motion capture. Then ROS framework controls the swarm behaviour to follow the user's hand and deliver feedback of interaction.

Bio-Inspired Concepts –

The impedance-based swarm control was inspired by **biomechanical models** of compliance and stability seen in human motor control. The **mass-spring-damper** model mimics how biological limbs adjust force and stiffness when interacting with physical environments. The **distributed swarm behavior** is analogous to collective motion in insects and birds, achieving formation maintenance and collision avoidance through local force-like interactions. The vibrotactile patterns simulated skin-level tactile cues such as **texture and stiffness**, reflecting neurosensory encoding in biological touch.

Figure 27: Real-life testing: (a) The experimental setup of the human perception of various vibrotactile patterns. (b) The virtual environment with surface sample for pattern recognition.