FlyingHand: Extending the Range of Haptic Feedback on Virtual Hand using Drone-based Object Recognition

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Figure 1: We proposed a system that allows user to employ a drone with the environment exploration task. (a) The control room where user could issue commands to the drone. (b) The drone would fly and capture the image of the target object. Then, (c) users could use virtual hand to explore remote environment that is captured from the front camera of a drone. At the same time, the image captured by the drone would simulate tactile feedback through ultrasound array.

ABSTRACT
This paper presents a Head Mounted Display (HMD) integrated system that uses a drone and a virtual hand to help the users explore remote environment. The system allows the users to use hand gestures to control the drone and identify the Objects of Interest (OOI) through tactile feedback. The system uses a Convolutional Neural Network to perform object classification with the drone captured image and provides a virtual hand to realize interaction with the object. Accordingly, tactile feedback is also provided to users’ hands to enhance the virtual hand body ownership. The system aims to help users assess space and objects regardless of body limitations, which could not only benefit elderly or handicapped people, but make potential contributions in environment measurement and daily life as well.

CCS CONCEPTS
• Human-centered computing → Mixed / augmented reality; Interaction devices;

KEYWORDS
Virtual hand illusion, body ownership, haptic perception, human-drone interaction

ACM Reference Format:

1 INTRODUCTION
The range in which human could feel and examine the world is sometimes limited by the body size and movement capabilities, especially for aging or disabilities groups. When a certain individual wants to examine the surrounding environment, the most intuitive way is to walk around, use the eyes to view and use the hands to feel the objects in the environment. However, there are countless scenarios, where users are either inconvenient to move or the environment itself is not suitable or reachable for users to explore. For example, it would be hard for a user to examine an object located on the high-shelf without a ladder.

Virtual Reality (VR) has brought up the virtual body extension applications to reach and explore the virtual world. By fitting users’ actual hand to the existing hand model in virtual reality, users could explore the environment by extending the length of the arm virtually [9, 10]. However, this virtual body extension technique is still limited in terms of exploration range and its body ownership. Thus, it is only applicable in surrounding environment exploration while users treat the virtual hand as an auxiliary device. Users could not take advantage of the technique either when they want to reach
a further location, or when they want to get more texture details from the interaction object.

To extend such limitation, in this paper, we proposed a Head-Mounted Display (HMD) integrated systems that allows users to reach an unreachable world without physically moving its presented. A drone and the virtual hand act as extra eyes and hand for users, where the drone will see the object and the virtual hand would help the users to examine and feel the target objects. The design mainly aims at making the drone control part as intuitive as possible, while improving the body ownership of the virtual hand. The systems consist of three separate parts. First, the user could use hand gestures to control the drone and image captures of the target object (Figure 1(a)). In parallel, the drone location is tracked and synchronized into the HMD (Figure 1(b)). Second, the image captures would then be sent back to a system and perform classification with a trained Neural Network. Third, the user could virtually manipulate the target object with the virtual hand while perceiving according haptic feedback (Figure 1(c)).

To summarize, our paper make the following contribution.

- A system that introduces drone control and tactile feedback to the virtual hand, allowing users to manipulate and perceive both virtual and haptic feedbacks.
- Performed a user study on the drone control as well as the virtual hand body ownership

2 RELATED WORKS

2.1 Drone for Environment Monitoring

Intelligent and interactive robots could play a great role in environment monitoring and measurement. Teymourzadeh et al. adapted the spider robot with multiple sensors [8]. The legged robot proved high efficiency in path planning and exploration tasks. However, the ground robots’ exploration range and accuracy are yet limited as their sensors are assembled at a low viewpoint. Compared with ground robots, drones’ viewpoints are less restricted as they could fly over the obstacles and provide real-time data from high above. Drone also have the capabilities for environment monitoring, it’s provided a relatively high flexibility and adaptivity [7]. Delmerico et al. proposed a drone to help ground robots make real-time path planning and localization [2, 6]. Karjalainen et al. showed that participants preferred a drone companion in a home environment [4]. During the experiment participants treated drones as life assistants that could help them accomplish certain tasks. In addition, J. Cauchard et al suggested that hand gesture commands are intuitive when interacting with drones [1].

2.2 Virtual Hand and Body Ownership

Multiple attempts have been performed to help users reach the unreachable world with the help of a virtual hand. Ueda et al. proposed an extended hand interaction that enables users to manipulate home appliance and make human-human communication with a projected virtual hand [9]. The model allows users to use a touch panel to control the virtual hand movement while preserving some hand gestures on the virtual model. Instead of using projection-based visualization, Feuchtner and Muller combines real world environment with the virtual one [3]. The design records the real world objects locations into virtual world while fitting a user’s hand with a virtual hand model. They allow users to manipulate the virtual hand in the virtual environments (VEs), whose results would in turn be updated back to real world to make the physical object move accordingly. However, the systems are still restrained by the space and the body ownership is yet limited. This extension span only suits the need for nearby objects manipulation and the extension of virtual hand more than 150cm may lose the sense of body ownership [5]. Our proposed system introduces drone and tactile feedback to the expendable virtual hand design, which not only improves the application range, but also allows perceived body ownership. Drone exploration makes it possible for users to interact with objects more than 150cm from them, while the haptic feedbacks intensifies users’ feeling that the hand extension is actually one part of their body.

3 SYSTEM DESIGN

3.1 Assumption

We assume the use case of the remote task scenario where the target object is difficult to physically reach by the user such as in the cave or above the shelf. Thus, it requires a remote interaction technique such as drone to explore the scene.

3.2 System Architecture

3.2.1 Hardware Setup. We separate the implemented system into two interaction spaces; the experiment room and control room. The experiment room is consisted of a tracking system (OptiTrack Flex13 cameras) and a drone (Tello Drone by Ryze Tech Inc.). In order to track the system, the drone assembles retro-reflective markers. We implement our virtual hand with the Unity3D software and feed the camera image as the background where the user could observe through an HMD. We assume that the target object used in this study is a sphere and a cube. The sphere has a radius of 1.86cm, and the cube has an edge of 3cm. Both target objects have similar volumes as $26.95cm^3$ and $27cm^3$, respectively. Figure 3 shows the implementation of the experiment room.

The control room consists of a force feedback device (Ultra-haptics Array Development Kits) embedded with hand tracking system (Leap Motion) and an HMD Display (Oculus Rift DK2). All equipment is connected to a PC (Intel Core i7, 64GB RAM, Nvidia Gefore GTX970 4GB RAM) and communicates through Python
While the user reaches the hand more than 45° of the function, the drone transmits the location information and the physical movement. The hand gesture is tracked with Leap Motion tracking and it’s directly mapped to the drone movement. At the same time, the tactile feedback is generated by the Ultrahaptics array according to the virtual hand location and the target object. The control room issue commands to the drone (in the experiment room) through wireless network, and the drone transmit the location information back via the same network.

3.2.2 Controller. In order to make the best use of human body and treat the drone as an extension of user’s hand, we use Leap Motion to issue the control commands to the drone. The movement controls are set by the relative positions of user’s hand and the Leap Motion. For instance, when user place their hand to the left of the Leap Motion, the system will send commands to the drone to move left. Since the movement of drone is slower than how interactively of human gesture, we implement the transfer function \( f \) that indicate the relative thresholds between the command input \( x \) and the physical movement \( f(x) \) of the drone as follows:

\[
f(x) = \begin{cases} 
0 & \text{if } x \in [0, \alpha] \\
\frac{x - \alpha}{\beta} & \text{if } x \in [\alpha, 1]
\end{cases}
\]

where \( \alpha \) controls the beginning of the drone motion and \( \beta \) controls the slope of the function.

To separate the controller between drone and virtual hand, we implement an angle threshold that handles whether moving the drone or the virtual hand. Figure 4 shows the diagram of separate controller for drone and virtual hand. When the user reaches their hand within the 45deg system will send command to the drone, while user reaches the hand more than 45deg the system send the command to the virtual hand. By this interaction metaphor, it allows the user to perceive force feedback from the haptic feedback device that locates on the front of hand tracking.

3.2.3 Estimation of Remote Environments. Since, the camera only feeds the captured images back to the system, it is not possible to estimate the distance between target object location and the drone location. To solve this problem, we estimate the distance from the drone’s position to the target object from our external tracking system. Thus, we can accurately calculate the drone position and the range of virtual hand. As shown in Figure 1(c), we realize the extension of a hand by adopting a relative linear model with the hand model. Taking the actual hand position for each frame \( a \), the virtual hand position \( v \) and the gain \( g \), we update the virtual hand position as follows:

\[
v_t = v_{t-1} + g \cdot (a_t - a_{t-1})
\]

where \( t \) and \( t-1 \) are a current frame and previous frame, respectively. The gain value could be tuned to meet different needs.

3.2.4 Image Classification for Haptic Mapping. Once the drone finds the target object, it takes an image and transmits back to the PC through a network. Then, we apply a color filtering to remove the background noise and feeds its sequences to the Convolutional Neural Network (CNN) to derive classification of a target object. We use the CNN with 5-layers architecture, each consisting of a 2D convolution layer and a 2D max pooling layer. We sampled a total of 12400 images for training set, and 2000 images for validation set. We found the accuracy of 98.64% and 96.5% for training set and validation set, respectively.

4 EVALUATION

4.1 Procedure

We conducted a user experiment to evaluate the effectiveness of the proposed method to perceive body ownership and the usefulness of the proposed drone control method. The evaluation is separated into two parts: First, the participants were asked to control the drone with their hand gestures to move forward and backward. The participants observed the drone movement via the HMD, Second, the participants were asked to use the virtual hand to touch the target object.

We conducted a qualitative evaluation with 11 participants (10 males and 1 female, from 20 to 29-year old). Only one participant had an experience with force feedback device, and two participants had the experience with HMD. All participants had or corrected to normal vision.

4.2 Questionnaire

Once participants finished the experiment they asked to fill a questionnaire to give us general feedbacks on the experience with the proposed system. The questionnaires have been designed as follows:

Q1: I felt my hand movement was causing the movement of the drone...
we found that the tactile feedback provides great experience enhancement when users interact with the target object, which reflects to the higher score in Q3. The body ownership of the virtual hand could be thus concluded to have improved with the introduction of tactile feedback. However, with the limited degree of freedom of the tactile representation of the device, it is noticed that the user might lose the body ownership once the distance between the actual hand and tactile feedback is different.

4.3 Result
Figure 5 shows the subjective score obtained for each question. We confirm that our subjective questionnaire has a good reliability using the Cronbach’s alpha test ($\alpha = 0.702$). Overall, the questions were better ranked for Q1 “I felt my hand movement was causing the movement of the drone” (avg. 4.0), Q3 “I felt my hand movement was causing the movement of the virtual hand” (avg. 4.36) and Q4 “I felt the virtual hand was part of my body” (avg. 4.09). We analyze the user preference using the one-way ANOVA Friedman-Test, but, cannot find the significant difference among the questions.

4.4 Discussion
The experiment result shows that the proposed method is easy to control the movement of the drone (Q1). However, the movement direction control is realized by exerting forces to the drones. For example, when a user issues the command “backward” to a drone that being “forward”, the flying mechanism needs to slow down the forward speed first before moving in the other direction. Thus, the users feel a latency when manipulating the drone, which reflects to the lower score in Q2.

For the improvement of body ownership using proposed method, we found that the tactile feedback provides great experience enhancement when users interact with the target object, which reflects to the higher score in Q3. The body ownership of the virtual hand could be thus concluded to have improved with the introduction of tactile feedback. However, with the limited degree of freedom of the tactile representation of the device, it is noticed that the user might lose the body ownership once the distance between the actual hand and tactile feedback is different.

5 APPLICATIONS
From the experimental result, we confirm that the proposed system improves the experiences of body ownership with virtual hand. We envision the application of this system, which could be a virtual experience of museums as is shown in Figure 2. This application could erase the distance limit between visitors and museums. The visitors could rent a museum drone remotely, which has the classification ability to identify the unique codes of different paintings and sculptures. The users could use their hands to control the drone fly around the museum and stop at the sculpture of their interest. Then, the visitors could manipulate and examine the details of the arts with their virtual hands, while receiving tactile feedback based on the arts details. The design also allows anyone to access any museum anywhere, without any capacity issues. A new running style of museums could be opening in regular hours for physical visitors, and in closed hours for drone visitors.

6 CONCLUSION
An HMD integrated system has been proposed to help users explore and feel the surrounding and remote environment. The system allows users to treat drone as extra eyes and hands, by controlling it with hand gestures remotely. Neural Network technique has been applied to analyze drone captured information. Users could get haptic feedback on their palms based on the drone captured data, which helps them to get a sense of the remote objects.

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