Tactile Drones - Providing Immersive Tactile Feedback in Virtual Reality through Quadcopters

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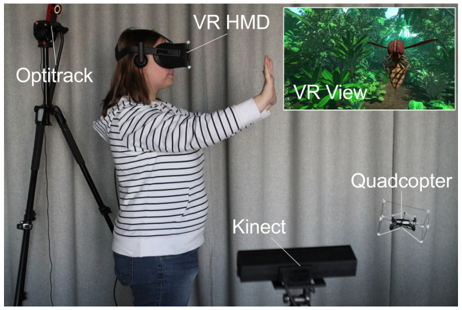

Figure 1: User immersed in virtual reality using our TactileDrone system. While tactile feedback is generated by a quadcopter, it is perceived as a hit from a bumblebee.

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Abstract
Head-mounted displays for virtual reality (VR) provide high-fidelity visual and auditory experiences. Other modalities are currently less supported. Current commercial devices typically deliver tactile feedback through controllers the user holds in the hands. Since both hands get occupied and tactile feedback can only be provided at a single position, research and industry proposed a range of approaches to provide richer tactile feedback. Approaches, such as tactile vests or electrical muscle stimulation, were proposed, but require additional body-worn devices. This limits comfort and restricts provided feedback to specific body parts. With this Interactivity installation, we propose quadcopters to provide tactile stimulation in VR. While the user is visually and acoustically immersed in VR, small quadcopters simulate bumblebees, arrows, and other objects hitting the user. The user wears a VR headset, mini-quadcopters, controlled by an optical marker tracking system, are used to provide tactile feedback.

Author Keywords
tactile feedback; virtual reality; quadcopter

ACM Classification Keywords
H.5.m. [Information Interfaces and Presentation (e.g. HCI)]: Miscellaneous

Introduction and Related Work

Recent technical progress dramatically improved the visual fidelity of head-mounted display (HMD) used for virtual reality (VR). Current VR HMDs, such as the Oculus Rift and HTC's Vive, provide a high-resolution binocular display with a wide field of view. Combined with the latest graphic cards, VR gets a high degree of realism. In addition, external tracking allows to move within a volume and inertial head-tracking maps the viewport on the user's movement. This also reduces motion sickness [6] and, thus, increases realism. Similarly, the accompanying sound provided through speakers or headphones is achieving a quality comparable to real world sound.

While visual and auditory displays provide a very high degree of realism, displays for other senses are lacking behind. For example, the haptic sense is not entirely used in combination with VR HMDs even though tactile feedback can increase immersion [4] and users' performance [10] in VR.Academia and industry created a variety of devices to provide tactile feedback. Most commonly, as used by the Oculus Rift and HTC's Vive, vibrotactile feedback is provided through game controllers the user holds in the hands. Another commercially available approach for specific applications, such as simulating surgeries [3], is to provide force feedback through stationary devices. Research further proposed a range of wearable devices, including gloves with tactile feedback [1], tactile belts [11], which provide vibrotactile feedback around the waist, and tactile vests that provide tactile feedback on the upper part of the body [7].

In recent years, a range of novel methods for providing tactile feedback in VR have been researched. Lopes et al. proposed electrical muscle stimulation (EMS) for providing tactile feedback in VR. They show that realistic physical experiences can be created using EMS [8]. Cheng et al. investigated the impact of providing haptic feedback through "human-actuators" [2] and explored mechanisms to synchronize multiple of them. Researchers further explored air pressure [9] and ultrasound [5] as tactile feedback modality without requiring the user to wear additional body-worn devices. Overall, previous work proposed a large variety of technologies to provide tactile feedback in VR. Each approach has specific limitations, such as carrying additional hardware or limited feedback areas.

In this Interactivity installation, we showcase a novel approach for providing tactile feedback in VR. While users are experiencing VR wearing a HMD, small quadcopters hover around them. The hovering quadcopters accelerate and impact users at the same time when they experience hits in VR. Since quadcopters can cover the complete 3D space, tactile feedback can be delivered all over the body. The interactivity offers different simulations of objects, such as bumblebees or arrows, hitting users.

Concept

We propose using caged quadcopters equipped with different tips that can hit the user at different body parts. Thereby, the quadcopters are steered according to objects in the VR that virtually hits the user. When an object hits the user in VR, a quadcopter hits the user at the according location in reality. Since quadcopters can be equipped with different tips, different types of feedback can be simulating in VR. Thus, we are capable of providing full-body tactile feedback that does not require the user to wear additional devices besides the VR HMD.

To enable accurate tactile feedback at a specific body location, the position and orientation of quadcopters as well as of the user must be tracked. While the user experiences a VR scene, quadcopters are hovering in around him or her.

Figure 2: Exemplary VR scene, where users experience a bumblebee.

Quadcopters are enclosed in a cage to protect the user from rotating propeller and to deliver tactile feedback on impact. If a VR scene requires tactile feedback at a particular body position, a single quadcopter accelerates in the direction of the respective body part. When a virtual object hits the user, the physical position of the accelerated quadcopter hits the specific body part. This enables a spatial synchronous representation of tactile, visual, and auditory feedback. Using a quadcopter to provide tactile feedback allows creating different types of feedback by changing the speed, weight, and tips of the quadcopter. For this Interactivity installation, colliding objects are represented as stinging bumblebees, arrows, and hurling particles.

Implementation

Our implementation of *TactileDrone* is divided into three components comprising tracking, VR scenes, and feedback control.

The HMD and the quadcopters are tracked by an OptiTrack Flex 3 motion capture system[1]. The system offers the low latency and high accuracy tracking that is necessary for immersive VR experiences and also enables high-precision control of the quadcopters. As the system requires knowledge about the position of the user's body to fly the quadcopters to specific body parts, a Microsoft Kinect 2 tracks the user's pose. The Kinect is calibrated to stream the locations of the body part in the same coordinate systems as the OptiTrack.

The tracked HMD's position is used by the VR component to render a Unity 3D[2] scene based on the users' head pose. Additionally, this component manages virtual objects and notifies a feedback control component about the time and position when tactile feedback is required. An Oculus Rift[3] is used to display the VR scene. Since quadcopters cause a noticeable noise level, we replaced the built-in speakers by active noise canceling headsets.

The feedback control component keeps track of the quadcopters and feedback requests. Depending on the feedback requests, a flying trajectory is computed according to the position and pose of the user. A quadcopter is steered accordingly using a PID-controller. A Parrot Rolling Spider[4] enclosed in a cage is used to provide the tactile feedback. The Rolling Spider is a Bluetooth-enabled quadcopter, able to carry up to 10 grams of payload and capable of accelerating up to 18 $\frac{km}{h}$. This corresponds to a theoretical energy of 0.8125 Joule when impacting the user. While the impact energy is strong enough to provide noticeable feedback, it also ensures safe operation. Figure 1 shows the installation of *TactileDrone* with all components and a user experiencing a VR scene.

TactileDrones

TactileDrone is a single-user virtual reality experience that engages with visual, auditory and tactile senses. The user wearing the HMD can explore an ancient Mayan city located in a jungle. The VR experience comprises three passages. While freely inspecting the scene, several large bumblebees are appearing (see Figure 2) and flying around the user. Then one of the bumblebees is bouncing into the user. The tactile feedback is generated by one of the quadcopters which is controlled to hit the user accordingly. In the second part jungle creatures armed with bow and arrow enter the scene. They start to shoot arrows towards the user. Again, one quadcopter equipped with a tip is bouncing into the

[1] www.optitrack.com/products/flex-3 - last access 2017-02-15
[2] www.unity3d.com - last access 2017-02-15
[3] www.oculus.com - last access 2017-02-15
[4] http://global.parrot.com/usa/products/rolling-spider - last access 2017-02-15

user visually represented by an arrow that hit her or him. Finally, the creatures are leaving and the experience ends with the city collapsing. Bricks, wood, and skulls hurl towards the user. For that, a quadcopter flies into the user with higher speed.

Conclusion

This Interactivity installation proposes a new way to provide immersive tactile feedback in VR. Quadcopters impact the user when an according virtual object in a VR scene hits the user. The quadcopters are enclosed in a cage to protect the user from rotating propeller and to provide the feedback on impact. The quadcopters are tracked using an optical motion capture system and the user's pose is determined using a Microsoft Kinect. The position of the quadcopters and the user are combined to deliver tactile feedback at specific body parts by controlling quadcopters according to the presented VR scene.

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