ABSTRACT
A new wearable haptic system is proposed for interactive immersive Virtual Reality (VR) installations. The core of the system is a common cooling CPU fan attached to a user hand, tracked in 3D, and operated from a host computer. The proposed system is suitable for entertainment applications where immersed VR users interact with fuzzy, cloud-like or jelly-like objects, producing soft and gentle tactile sensations upon contact with user hands.

1. WEARABLE HAPTIC FAN
The force-generating element of the proposed system is a CPU fan from a desktop computer. The fan model shown in Figure 1, weighs 40 grams. It is able to operate at 3-12 V range, exerting force of 0.18 N, estimated by suspending the spinning fan on a string and measuring the angle from vertical direction. This value is an order of magnitude smaller than that of traditional haptic devises. However, the winning parameter is the working volume, which is limited only by the tracker. In the prototype, shown in Figure 1, Flock of Birds from Ascension is used, capable of tracking within 4 feet radius in standard mode.

1.1 Hand poses and haptic responses
Because the fan is firmly attached to the palm, the motor should be activated only if the hand touches an object surface in palm-forward pose. If the hand penetrates the surfaces in edge-forward pose, no force should be exerted, and the hand will cut through the object freely.

1.2 Distortions in magnetic tracking
A fan is an active device that distorts magnetic tracking. In order to estimate the amount of added noise, tests were conducted using a Flock of Birds sensor, placed directly on top of the spinning fan at 2 cm distance. At maximal fan speed, oscillating noise in reported sensor position stayed within 5 mm. When the sensor and the fan were separated, as shown in Figure 1, the noise became negligible.

1.3 Compensating for high motor latencies
The fan motor has a high spin-up latency. In order to minimize discrepancies between visual hand position and delayed haptic response upon contact, hand motions should be smoothed with a wide low-pass filter, simulating moving in a viscous medium. This measure should prompt users to avoid brisk hand movements naturally.

2. SUGGESTED APPLICATIONS
In all examples below, users must be immersed into VR with a head mounted display. The head and at least one hand must be tracked with 6 DOF. Full body avatars are optional, however, the virtual hands must be visualized at all times. Most of these applications are intended for young audiences.

Falling Snowflakes. Large snowflakes are slowly falling on the ground. Players can catch them by placing their hands below the snowflake. When touching the hand, snowflakes produce tactile feedback and 'melt', after prolonged contact.

Making a Snowman. By scooping virtual snow from the ground, players make snowballs. Wider scooping motions result in larger snowballs. To grab and release a snowball, both hands must be used, as in real life. Haptic feedback confirms scooping and grabbing actions.

Haptic Tracing. The goal of this game is to visualize a hidden object, by tracing its surface in 3D with haptic-enabled hands. When a player touches the object, its surface becomes visible at successfully felt locations. Visualization of contact area may be implemented by changing local shading parameters. Well known objects of art, such as famous sculptures, may be used as targets. If the target object is animated, this application turns into a ghost-chasing game.

Figure 1: Wearable haptic system assembled on the left hand: a fan is mounted on the palm (left), a motion sensor is placed on the back of the hand (right).

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