

# AirHook: Simulating 3D Spatial Wind Around Ears to Enhance Presence in VR

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**Abstract:** As a sensory experience proven to enhance presence in Virtual Reality, realistic wind simulation relies on a bulky mechanical setup or the form factor of a Head-mounted Display. We present AirHook, an ear-worn airflow display that renders multi-directional and dynamic wind in 3D space with a compact design and no interference with the VR headset.

## 1. Introduction

Virtual Reality (VR) applications are noted for their strong potential to create sensory experiences beyond physical constraints. Given wind’s role as a natural cue in everyday life, researchers have proposed physical wind-display systems to enable its seamless integration into the virtual environment. They successfully proved the wind’s positive effect on human awareness of the virtual space and sense of presence across scenes featuring weather phenomena [1], [2], outdoor activities [3], [4], [5], and games [6], [7].

Most prevailing wind systems [4], [8], [9] employ room-scale arrays that coordinate multiple fan units to synthesize continuous changes in wind direction, intensity, and flow patterns, yielding realistic sensations. However, high requirements of space and cost for the installation of such systems limit their broader adoption. To mitigate these constraints, other approaches reduce reliance on room-scale infrastructure and bring wind cues closer to a small but highly sensitive skin area, the face, by attaching small fans [3], [6], [10] or directed air nozzles [7] to the Head-mounted Display (HMD). The challenge is that on-HMD wind displays can conflict with the headset’s form factor, and the HMD blocks part of the facial skin from airflow, thereby narrowing the range of perceivable airflow directions.

Building on established research showing the ear’s marked sensitivity to airflow [7], [11], we developed AirHook that can simulate multi-directional wind at the ear region. It adopts an ear-hook-style form factor, which become a natural basis for wearability as well as an ideal location for non-interfering placement with HMD. Taking advantage of

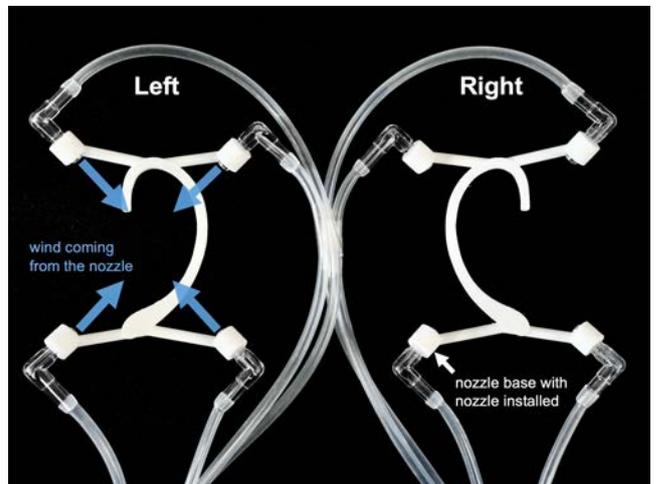


Fig. 1 Ear-mounted part of AirHook, including a pair of 3D-printed ear hooks with air nozzles installed.

the ear’s protruding anatomy, AirHook delivers omnidirectional airflow cues while remaining compact. Moreover, the ear-mounted design allows easy synchronization of airflow presentation with head orientation sensed by the HMD.

## 2. Implementation

AirHook consists of two parts: an ear-mounted display (Fig. 1) and a remote case for supplying and controlling the wind source.

### 2.1 Ear-mounted Display

The wearable display is a pair of 3D-printed symmetric ear hooks that rest on the auricles, following an ear-hook earphone design (Fig. 1). Each ear hook measures approximately  $65 \times 30 \times 4.4$  mm and weighs 11.5 g.

Each hook carries four cylindrical nozzle bases (OD 9.6 mm, ID 5.6 mm), joined by a 4-mm-diameter cylindrical support. The bases lie in a plane orthogonal to the interaural axis and are aimed along the diagonals of the horizontal or vertical axes. We chose diagonal rather than cardinal

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**Fig. 2** A VR user feeling the virtual wind when wearing AirHook.

orientations to avoid upper helix regions that are largely covered by hair. Each nozzle base is tilted  $20^\circ$  inward to increase skin contact area. Eight L-type connectors serve as terminal nozzles, press-fit into the bases and coupled to silicone tubing (OD 4 mm, ID 3 mm), each routed to one air pump in the remote case. With 1.8 m tubing, the system provides approximately 1.6 m of movement, and the range can be further extended using I-type connectors.

## 2.2 Wind Source and Control

The AirHook system employs eight 12V vacuum air pumps (AP520B-120), each driven by one MOSFET Driver Module (XY-MOS) via pulse-width modulation (PWM) to independently regulate airflow intensity. The electronics are split into two mirrored groups, consisting of four pumps and four driver modules per group, to display airflow for each side of the ears. Each group is controlled by one Arduino Uno board and powered by an AC adapter (12V/2A).

All electronic components above are mounted in a polyethylene case for easy transport and quick setup, which can be placed on the floor or a table during use. Soundproofing urethane foam sponges are inserted above and below the electronics to damp vibration noise from the running pumps.

In the VR scenes built on the Unity3D platform, the world-frame wind is transformed into a head-centered frame using the HMD's orientation. In this head frame, wind direction and intensity are assigned to each nozzle based on its relative location to the head center. These are then converted into PWM values and sent via Arduino for the nozzle actuation.

## 3. Demonstration

We prepared two passive-viewing VR scenes, respectively rendering environmental wind and motion-induced wind. The first scene takes participants to a forest where gentle winds pass through and blow leaves away, while the second scene includes a rollercoaster experience where participants sit in a mine cart running on a wooden track.

Participants are seated and wear the AirHook, AirPods

Pro with noise canceling enabled, and a Meta Quest 3 Headset under the researcher's guidance, as shown in Figure 2. They experience the two scenes in sequence, each for about one minute. During the VR experience, participants feel 3D spatial wind around their ears, which is rendered consistently with the accompanying audiovisual cues and continuously changes directions.

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