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# Demonstrating Nebula: Dynamic Multi-Scents in 6DoF Virtual Reality

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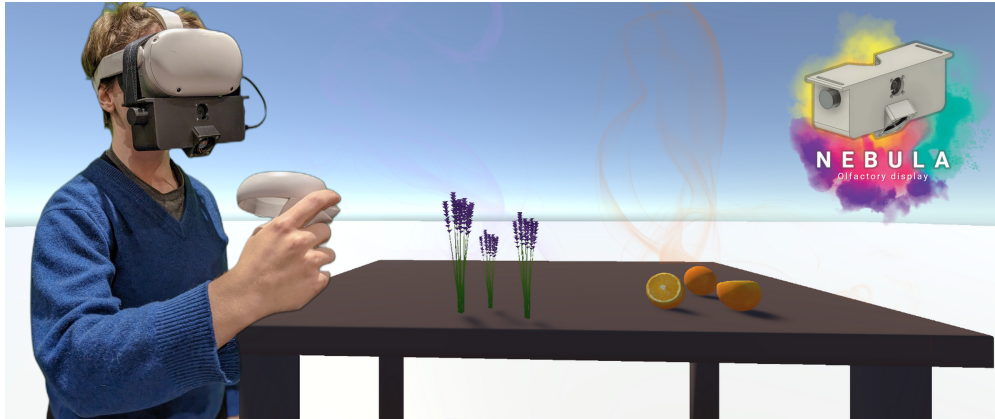


Figure 1: Nebula can diffuse two odors simultaneously in 6DoF VR and is compatible with standalone HMDs. Our demonstration showcases the interactive capabilities of our device, with scents of orange and lavender.

## ABSTRACT

Nebula [4] is an open-source<sup>1</sup> olfactory display compatible with autonomous HMDs and capable of diffusing scents at different diffusion rates. It relies on ultrasonic atomizers controlled via pulse-width modulated signals. Although designed to diffuse two odors simultaneously, it has only been evaluated and tested for the diffusion of a single odor so far. In this demonstration, we propose to showcase its capacity to diffuse two odors within a 6 DoF (degrees of freedom) immersive scenario.

**Index Terms:** Human-centered computing—Interaction devices;

## 1 INTRODUCTION

The integration of multisensory cues in virtual reality experiences raises a growing interest in the scientific community. Recent surveys [7, 8] indicate that expanding beyond visual stimuli to include auditory, olfactory, or tactile cues appears to significantly enhance VR user experience, in several aspects. Notable ones are increased degrees of presence and immersion for VR users. More and more affordable techniques have been recently developed to capture, create, and render multisensory stimuli enabling the creation of *multisensory digital twins* [5].

Among those senses, olfaction has great potential due to its influence on emotions, mood, and memory. Still, olfaction remains under-utilized in the domain of virtual reality, mostly because few HMD-compatible olfactory displays are readily available or easy to reproduce. In this context, Nebula [4] has been recently proposed as a low-cost, open-source, olfactory display compatible with any HMDs (e.g., HTC Vive Pro, Meta Quest 2, Varjo XR3). Nebula

is based on a nebulization process and is capable of diffusing scents at different levels of perceived intensity. Until now, this device has only been tested and evaluated for the diffusion of one single odor. However, its design theoretically allows the diffusion of two odors simultaneously (by inserting a second set of reservoir, micro-controller, and atomizer inside the device). For this demonstration, we implemented this two-odor version and created a corresponding immersive scene to showcase this multi-scent diffusion capability.

## 2 BACKGROUND

The scientific community’s interest in olfactory stimulation in virtual reality has grown stronger over the years. As odor diffusion techniques and technologies have evolved, diversified, and become more affordable, and as access to VR technologies has become easier, a multitude of studies on olfactory stimulation in VR have emerged. Advances in chemistry have also made it possible to artificially create olfactory component, such as Calone 1951 -and derivatives-, the first synthetic olfactory compound created by Pfizer in 1966, reminiscent of the smell of the marine environment. Several forms of olfactory component conditioning exist, and this plays a key role in olfactory diffusion systems. The most widespread form in virtual reality research is the liquid state, whether with an aqueous or alcoholic base. The gas form is not widely used as corresponding devices are complex to set up.

One of the first wearable olfactory device for VR was proposed in 1999 by Dinh et al. [3]. Participants were wearing an oxygen mask connected to a canister of coffee grounds and a pump. Later, Yamada et al. [12] proposed two prototypes: the first one was based on gas phase odors and used air pumps generating airflow passing through cotton infiltrated with perfume material; the second one was intended to be less cumbersome and used liquid phase odor by injecting droplets directly near the user’s nose. More recently, Ranasinghe et al. [10] proposed a multisensory VR device integrating olfaction, thermoception and wind. Tsai et al. [11] considered ultrasonic atomizer, as Nebula. The use of other technologies for diffusing scents can be found in the literature. For instance, Kato and Nakamoto [6]

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<sup>1</sup><https://github.com/Plateforme-VR-ENISE/Nebula-Core>

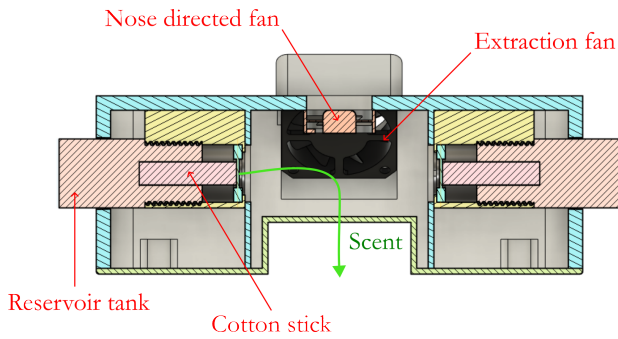


Figure 2: Section of the olfactory display CAD model.

and Nakamoto et al. [9] developed devices that rely on a surface acoustic wave (SAW) atomizer combined with an FPGA. While the portable devices presented above diffuse a single odorant at a time, recent work from Bahreman et al. [1] proposed a new device called *The Smell Engine*, capable of dynamically mixing several odorants in their vapor phase, along with a framework to operate it in Unity. De Paiva Guimarães et al. [2] proposed a low-cost olfactory display, battery operated, integrated into a Google Cardboard. The diffusion is based on an ultrasonic atomizer.

The devices presented above considered a variety of technologies and demonstrated good performance. However, most of them are difficult or impossible to reproduce due to their complexity and/or missing details from the relevant publications; some of them also rely on expensive (or not easily accessible) components. In this context, we proposed Nebula [4], an open-source reproducible device compatible with any HMDs (including autonomous ones).

### 3 NEBULA: AUTONOMOUS OLFACTIVE DISPLAY

Nebula is an olfactory display designed to diffuse multiple scents in a virtual environment using an ultrasonic atomization process. This process creates a scented mist, i.e. micro-droplets suspended in the air carrying the scent, by rapidly oscillating a metal surface with micro-perforations ( $\sim 80\mu\text{m}$ ) in direct contact with a water-based liquid. In our design, the scented liquid is held by a cotton stick located in a reservoir (see Fig. 2).

By controlling the speed of the atomizer oscillation, we can control the diffusion rate of the device. As such, the scent intensity can be adjusted dynamically in a virtual experiment with minimal latency. The device can receive the commands using serial communication through a USB port, we specifically developed a Unity plugin to facilitate the dispatch of control orders. This effectively makes the device compatible with any HMDs, including autonomous headsets with a USB port available (tested on Meta Quest 2 and Meta Quest Pro).

Nebula is designed with accessibility in mind. The case is fully 3D printable and the electronic components can easily be bought online, reducing the cost to approximately 60\$. Additionally, we created a GitHub repository containing (1) the electronic hardware schemes, (2) the STL files for 3D printing, (3) all the firmware and software source code including the Unity program allowing to reproduce the conducted psychophysical study.

The original paper shows the device capable of diffusing a single scent. The controllability of the diffusion rate for this initial design was validated on three diffusion rates (no diffusion, weak diffusion, and strong diffusion) through objective measurements and a user study on sixteen participants. Although this study was focused on validating the diffusion of a single scent, the device is capable of containing a secondary reservoir for another scent. With this demonstration, we aim to showcase this multi-scent diffusion capability.

## 4 EXPECTED EXPERIENCE FROM DEMONSTRATION

Participants can try out Nebula in a simple VR scene (see Fig. 1) where a lavender flower and an orange are laid out on a table. They are free to move in the virtual environment and they can either move closer to the odor sources or pick up the sources to bring them close to their nose. By doing so, Nebula triggers a diffusion that is congruent with the nature of the source and whose intensity is relative to distance between the head and the source. This demonstration runs on a standalone Meta Quest 2 to showcase the autonomous capabilities of Nebula, enabling its use in a wide range of contexts.

### ACKNOWLEDGMENTS

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