

Design and evaluation techniques for odor mixing

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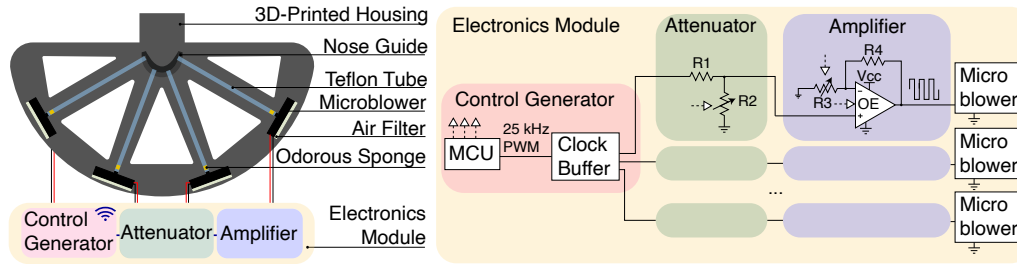


Fig. 1. Design of the odor delivery device. (left) The form factor includes an odor delivery face display and an electronics control module. (right) The electronics module contains three stages of circuitry: a control generator, an attenuator, and an amplifier. The control generator provides a reference PWM signal and distributes it to the microblower control channels. The attenuators and amplifiers manipulate the PWM signals to achieve the appropriate amplitudes for the desired flow rates.

Although smell influences many daily activities, researchers and practitioners have yet to thoroughly understand smells and the interactions involved in smell mixtures. We present work focused on artificially synthesizing odor mixtures, the evaluation techniques to measure the fidelity of such technologies, and the rich application scenarios that materialize with this capability. We highlight our system implementation and design considerations for an olfactory wearable for odor mixing. Then, we outline an approach to assess odor mixing behavior and efficacy, and finally, we discuss possible studies to contextualize the usefulness of our technology.

CCS Concepts: • **Human-centered computing** → *HCI design and evaluation methods*;

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1 INTRODUCTION

Smell and olfactory sensations play an important role in everyday perceptions. Yet fields in entertainment, education, and research have only scratched the surface in using scents for their applications. Many focus on single scent technology, and underutilize odor mixing for complex scents. In general, odor mixing poses significant challenging problems

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that stem from the complex biological perception, non-linear odor production, complex control schemes, and lack of standardization and methodologies. Advancing such technology can provide nuanced scents to portray complex, real-world odors. This can educate learners, e.g., about hazardous wastewater identification, and increase their immersion in virtual worlds. We propose a system to study odor mixing, discuss olfactory-based verification techniques, and examine integration into use cases that benefit from mixed scents. This paper outlines our theoretical and practical approach to design such a system.

2 RELATED WORK

Olfactory Displays: Researchers are actively exploring designs for olfactory displays and developed different smell-based virtual environments. Maes et al., [1, 20] demonstrated on-face wearable form factors. Nakamoto et al. [14] created a multi-channel olfactory display that invokes different smell combinations. Obrist et al. [7] developed integrate a stationary olfactory display with vehicles. Researchers have also demonstrated several VR HMD attachments providing both mono and stereo smell sensations [3, 4, 8, 9, 11, 12, 20]. These attachments led to olfactory virtual environments with different implementations to model the odors. Bahremand et al. [3] demonstrated an olfactory hardware-software system that diffused odorants at varying strengths. Nakamoto and others [13] utilized computational fluid dynamic models to model the virtual flow of odorants. Lastly, Simon et al. [15] demonstrated an olfactory display that attaches to a VR controller. Commercially, attempts at building olfactory displays include OVR [16] and Aroma Shooter [2].

Odor Mixing: Replicating odor mixtures faces the complex and variable nature of odor perception. Frank et al. [10] sought to determine the ability to detect odors in a mixture, while Thomas-Danguin et al. [19] investigated mixing from a psychological perspective. Towards replication, Nakamoto et al. [14] mixed odors through a desktop-based olfactory display. Their user study demonstrated that the machine mix was indistinguishable from a pre-mixed solution. Other work fine-tuned odor mixing using an electronic nose feedback loop and a machine learning model [17]. [6] also applies machine learning to predict the odor perception of a mixture by feeding it mass spectrometry data.

3 DESIGN

To study odor mixing, we design an apparatus (Figure 1) to programmatically deliver odor mixtures in a comfortable, scalable, and mobile system. A microcontroller configures the microblowers to pump air proportional the their control signals. The resulting airflows then carry odors from scented sponges towards the user’s nose.

Comfort: Comfort is necessary for long-term adoption and use. A device that integrates smoothly into the human form will encourage more research into odor mixing. Since the odor delivery device is loaded near the face, it is essential that it is lightweight and compact. Therefore, the housing is 3D-printed with lightening holes. Furthermore, it only holds carefully selected, necessary, and lightweight components, such as the small microblowers, embedded sponges, and surface-mount electronics. The rest of the device’s mass is in the electronics housing, which a user can carry elsewhere on the body.

Scalability: We prioritize scalability to the expansive selection of odors and the endless combinations for recipes. Because many odor recipes and mixtures are unknown, we designed our device with the flexibility to easily add odor channels. An odor channel can be added by taking another attenuation and amplification circuit and plugging it into the electronics module with a microblower. No further design or customization is required. The maximum number of odor channels is limited by the number of channels in the clock buffer, which for our case is twelve. However, a researcher can simply add in another clock buffer, which will double the upper limit without much added work. The

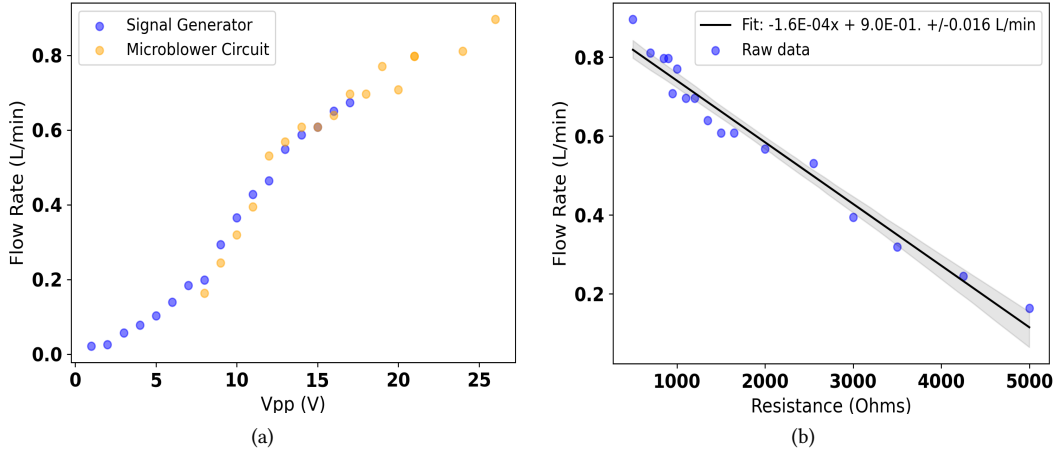


Fig. 2. Device characterization plots. (a) Flow rate versus control amplitude for two signal sources: a desktop signal generator and our driving circuit. The overlap region shows minimal variations in performance. (b) Flow rate versus potentiometer resistance. This was conducted for one odor channel, and shows the relationship between the two can be estimated with a linear trend.

form factor is also scalable because its semicircle shape and light weight supports the capability to expand the housing, increase the number of microblowers, and add devices to the sides of the face.

Mobility: Mobility adds to an odor mixing device’s comfort and ease-of-use factor while also expanding its application scenarios. For example, a mobile olfactory system with a VR headset enables visual and exploratory use cases. Moreover, a mobile device will make it easier to travel to diverse locations and populations, which is vital since olfaction varies with geographical locations and cultural backgrounds. Wireless electronic control allows real-time designer programmability while remaining mobile. For this reason, the microcontroller has Bluetooth and WiFi modules, allowing researchers to connect their portable laptops from afar. This, combined with its already compact form factor, makes the system mobile.

4 SYSTEM EVALUATION

We propose a series of measurements using a flow meter (Omron, D6F-P0010A2) and photoionization detector (Aurora Scientific, 200B) to characterize the apparatus, and its capability to present mixed odors with controllable concentrations.

Device Characterization: To better understand the odor delivery device, we compare it to a desktop signal generator, and define a relationship between its input and output. Verifying the fidelity of our hardware, we measure the output flow rates of an odor channel when the microblower is connected to a signal generator and to our system. The results (Figure 2a) show minimal variations in resulting flow rates from the two signal sources. After we verify the hardware, we define an empirical model by measuring the electronics output flow rate as the user input resistance changes (Figure 2b). The resulting fit provides a linear equation to estimate the system’s behavior.

Planned Odor Characterization: To understand how the microblowers and odor sponges produce an output mixture, we plan to perform measurements with a photoionization detector (PID). The PID can sample the air flow from the microblowers and generate a voltage proportional to the vapor concentration. Thus, we define the relationship between flow rate and odor concentration: $c = C_0x$. c is the target odor concentration in $[\frac{mol}{min}]$, C_0 is the concentration in the sponge’s headspace in $[\frac{mol}{L}]$, and x is the flow rate in $[\frac{L}{min}]$. From the function of the PID and this equation, we need to graph the PID voltage response as a function of channel flow rate, and perform instrument calibration,

which interprets the voltage responses as concentrations. With this, we are able to verify the relationship among the microblower flow rates, the odorous sponges, and the final concentrations.

After investigating different magnitudes of control signals, we plan to conduct measurements varying their durations. This will provide insight into the system’s temporal dynamics, such as latency and its response to pulses or ramps.

The measurements outlined thus far have focused solely on single odor outputs. To understand how the system mixes odors, we aim to measure a binary mixture with the PID. There will be three total rounds of measurements that will include channel A with odor A, channel B with odor B, and clean air, which ensures constant flow rate. The first round will measure the PID response as a function of the flow rate of A, and the second round will do similarly with that of B. The third round will be the PID response as a function of the flow rates of A and B, where each trial will vary the flow rate of A and B, but the total flow rate will remain constant. We hypothesize an odor mixture is a superposition of the concentrations of its constituent components, and thus, predict the resulting plot will show the PID responses from the individual odors summing to produce the PID response from the mixture.

5 PLANNED PERCEPTUAL EVALUATION

With the validated device, we plan to conduct user studies to analyze our system’s perceptual accuracy, granularity, and contextual use.

User Study 1: Since many existing scent-based technologies create odors using premixed, liquid mixtures, such as essential oils and perfumes, this study seeks to compare the perceptual accuracy by which our system-mixed odors, or odors mixed in the vapor phase, can emulate premixed odors, or odors mixed in the liquid phase. To this end, this study is a duo-trio test, where the user attempts to discriminate the odd sample out of three. The number of times users are successfully able to discriminate between a system-mixed and premixed odor will determine our system’s ability to accurately and predictably recreate existing scents.

User Study 2: Everyday objects may emanate dozens of volatile compounds that all contribute to that object’s scent to varying degrees. This study seeks to understand how well the system can represent the different ratios that may be required in odor recipes. The researcher presents the user with odor A and odor B, and tells them as such. Next, they present the user with a mixture of A and B, and ask them to select if it is A or B. This process is repeated for different proportional mixtures of A and B. We predict that as the odor mixture becomes predominantly A or B, the number of times the user responds correctly will increase. Similarly, as the mixture becomes more equally proportioned between A and B, the selection will become difficult and the number of correct responses will fall towards 50% of the time.

User Study 3: We would like to explore application scenarios with our device’s odor mixing capabilities. We will examine how our system produces complex odors on the fly in the realm of water contamination and the temporality of strawberries.

Consumers judge drinking water through its smell, taste, and appearance, and water facilities often use consumer feedback to detect water quality issues. The check-if-apply list [5] provides a standardized way for consumers to describe their drinking water by checking one or several of the provided descriptor options. For our user study, the researcher will present the user with system-mixed and premixed mixtures with different water contaminants. For each sample, the user will use their sense of smell and the check-if-apply list to describe the mixture. The final descriptors chosen for each water sample will determine if the user used the predicted descriptors for each sample.

Many current olfactory displays use essential oils as their odor sources, but this often leaves scents to be of one note. For example, a virtual environment with strawberries will display a strawberry essential oil as a scent. However, to the best of our knowledge, there are no essential oils for different kinds of strawberries or for strawberries that are unripe

or rotten, which could be useful to show temporality in a virtual space. We seek to investigate our system’s capabilities in displaying this temporal relationship. Using strawberry gas chromatography-mass spectrometry (GC-MS) data [18], we have developed odor recipes for unripe, ripe, and rotten strawberries using a set list of chemical compounds. Similar to the water contamination study described above, users will describe the scents of the strawberry odor recipes. The descriptors chosen will provide insight into the effect of our odor recipes for the different stages of strawberries.

6 CONCLUSION

Real-time odor mixing enables complex artificial odor synthesis that includes nuances indicative of real-world sensations. A system and procedure to accurately execute this function pose exciting implications for future olfactory solutions. Such scenarios may look like training users for water quality monitoring or granularly changing an object’s scent over time for more realistic virtual environments.

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