ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Augmenting AR/VR with Smell

Team #15

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1 Introduction

1.1 Problem

Augmented Reality (AR) and Virtual Reality (VR) technologies are rapidly growing and becoming more prevalent in our daily lives. However, these technologies have not yet fully addressed the sense of smell, which is a critical aspect of human experience. The absence of scent in AR/VR experiences limits the immersive potential of these technologies, preventing users from experiencing a full sensory experience.

Augmenting AR/VR systems with smell refers to the incorporation of olfactory stimulation into virtual and augmented reality experiences. This technology aims to provide a more immersive and realistic experience for users by integrating scent cues into the virtual environment. This field of research is also referred to as "Olfactory VR" or "OVR".

The sense of smell is an important part of human perception, and it plays a crucial role in our daily experiences. The sense of smell is incredibly powerful, with research showing that it is 10,000 times more sensitive than any other sense, and humans can discriminate more than 1 trillion olfactory stimuli [1], [2]. The olfactory system is responsible for detecting thousands of different chemical molecules that are vaporized and floating in the air, and the olfactory bulbs and limbic system are strongly connected, leading to the imposition of emotions and memories, and modification of conscious thought and learning [1]. Despite the potential benefits of smell augmentation in AR/VR systems, there is a research gap in tracking and analyzing chemical data [1]. To address this gap, this project proposes a case study to design and implement a practical plan for smell augmentation in maintenance diagnosis, with the aim of evaluating feasibility, identifying challenges, and summarizing initial results of overlaying information through smell augmentations. By incorporating scent cues into AR/VR environments, users can be transported to a different world and can experience a heightened sense of realism. For example, users in a virtual forest could smell the scent of pine trees, while users in a virtual bakery could smell the scent of fresh bread.

There are several challenges associated with integrating smell into AR/VR systems. One of the main challenges is replicating scents accurately and consistently. Unlike visual and auditory cues, scents are complex and difficult to reproduce. Additionally, the delivery of scent cues must be carefully controlled to ensure that users are not overwhelmed or nauseated.

Despite these challenges, the potential applications for augmented AR/VR systems with smell are vast. This technology has the potential to be used in a variety of fields, including entertainment, education, healthcare, and marketing. For example, olfactory VR could be used to simulate a medical environment to help train medical professionals or to treat patients with phobias or anxiety disorders. It could also be used to create immersive marketing experiences for products such as perfumes or food.

1.2 Solution

According to the problem we mentioned in the above section, and based on research in Olfactory VR, we propose a device that augment AR/VR experiences with smell, enabling users to experience a full sensory experience.

To achieve this objective, we will need to incorporate hardware and software components that can simulate various scents in real-time, in response to events in the AR/VR environment. Our proposed solution will consist of a scent-emitting device and software that can track and simulate scents based on the user's location and orientation in the AR/VR environment.

1.3 Visual Aid

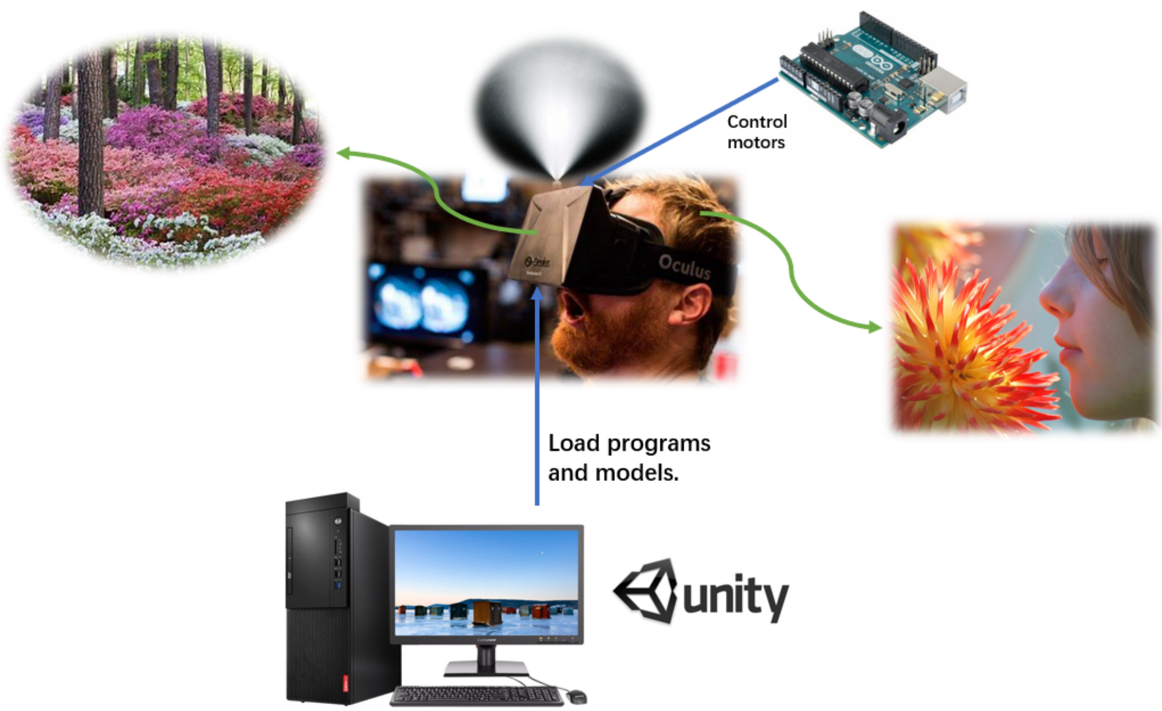

Figure 1: Visual Aid

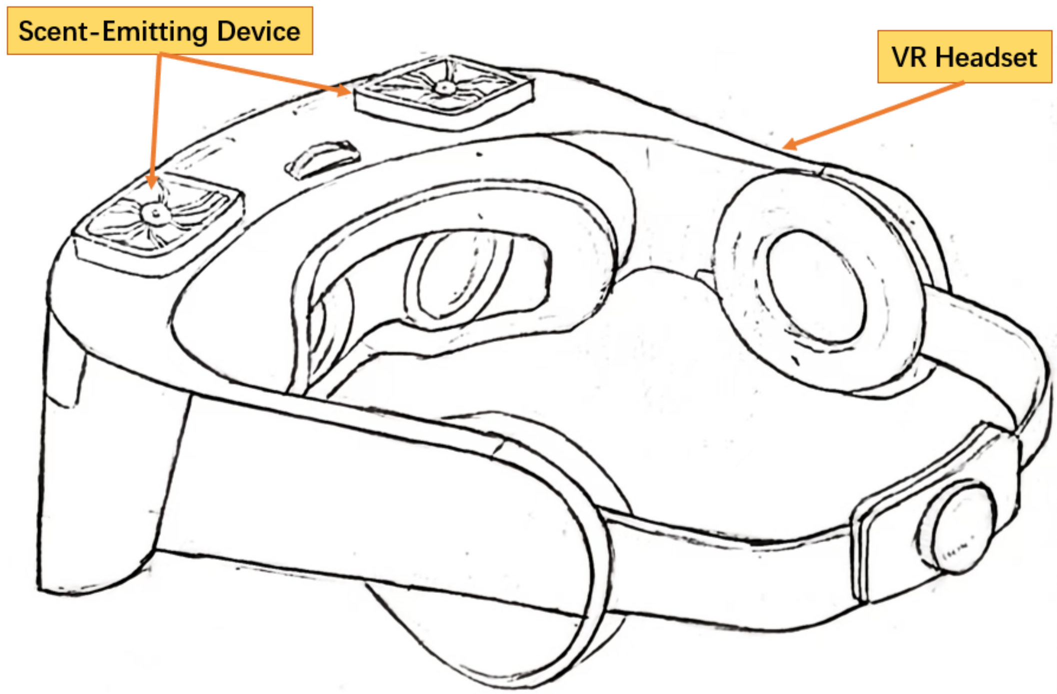

Figure 2: Sketch of Our Device

1.4 High-level requirements list

- The scent-emitting device will need to be able to emit various scents for normal operation, that is, walk or adjust view with normal speed in our constructed virtual world for a period of at least 1 hour without adding new materials.
- The scent-emitting device should emit proper scents in 300 milliseconds after the sensor capturing the user's location and orientation. This also includes time a scent simulation software needs to calculate the intensity and duration of scent emissions. To be more specific, as the major delay may happen in data transmission stage, the time for scent simulation software to calculate scent species, intensity and duration should be under 100 milliseconds.
- As a wearable electronic device, we want our device to be portable and lightweight, so the weight of our proposed device will not exceed 0.8 kilograms, making it easy for users to carry around during AR/VR experiences.

2 Design

2.1 Block Diagram

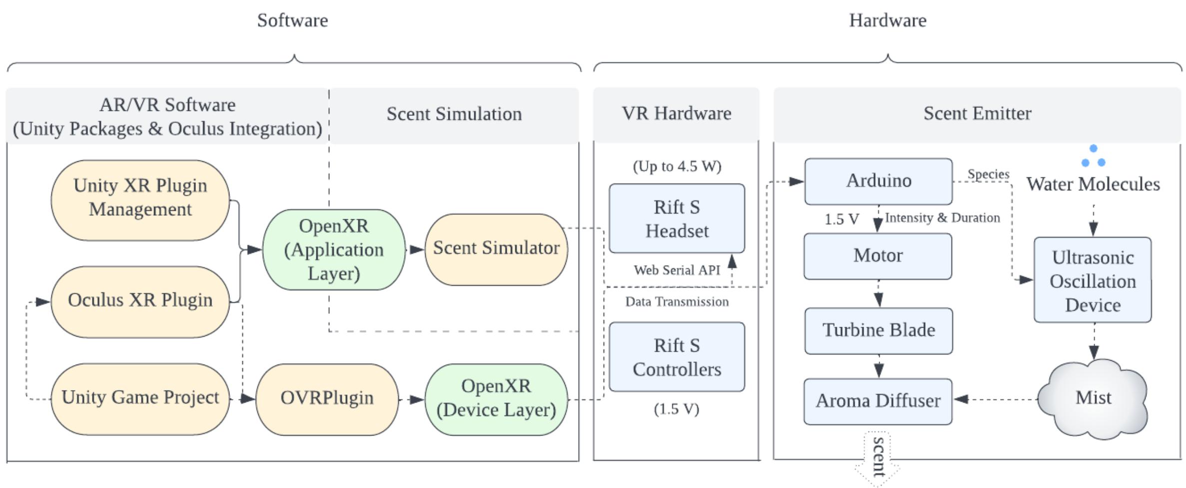

Figure 3: Block Diagram

The system consists of software and hardware parts. In the AR/VR software part, we will build a demo project using Unity and connect its plugin with Oculus. We will also design a scent simulator to simulate and control the process of real-time scent emitting according to the user's experience. The scent emitter is streamed by an Arduino with dual motors and an ultrasonic oscillation device, which will be powered by a small battery of about 1.5V. The motors will drive the turbine blade, which can help spread the scent. To be specific, the intensity and duration of the scents will be translated to the rotation speed and duration of the blade. Ultrasonic oscillation device is used to break up the molecular structure of the different perfumes to produce a naturally flowing mist, and can quickly be absorbed by the air.

2.2 Subsystem Overview

1. **AR/VR software**

   Based on Unity, this subsystem is responsible for creating virtual scenes for users. The AR/VR software enables us to build engaging scenarios, tell users interactive stories, and transport people to new worlds by building virtual reality experiences, which allows our device to fulfill the most important high-level requirement–immersive experience. This subsystem also needs to pre-process users' movement information and head orientation collected by AR/VR hardware, and transmit the information to scent simulation software for further calculation. Our software is designed to be effective and accurate, which also meets the second high-level requirement listed in the previous section.

2. **Scent simulation software**

   This subsystem is responsible for calculating which species of scents our device needs to emit based on our users' position in the virtual world. This scent simulation software gets the pre-processed data from AR/VR software and uses our efficient and effective software to decide which scent to emit, how long the scent last, and how strong the smell is. This information will then be transmitted to the scent emitter subsystem for the release of real scent.

3. **AR/VR hardware**

   This subsystem provides the hardware basis for AR/VR software and is responsible for motion capture and model rendering, which uses Rift S as the key hardware component. It consists of a VR headset and two controllers. Through the headset, the user (as the camera inside the project) can see virtual scenes. The headset can track the direction of users' sight. The controllers are used to track the position of the hands and control the experience inside the VR environment. This allows our device to fulfill one important high-level requirement–immersive experience. The data collected by the sensors will be transmitted to AR/VR software subsystem for virtual scene generation and movement information pre-processing.

4. **Scent emitter**

   This subsystem is responsible for emitting the scent based on data from scent simulation software. This scent emitter is designed to be integrated with our headset. It consists of a scent cartridge, an Arduino module with multiple motors, ultrasonic oscillation devices, and an aroma diffuser. The overall hardware is portable and light, which fulfill the high-level requirement listed in In scent cartridge, different scent is protected in individual bags to preserve the smell. After scent species, intensity, and duration information is calculated in scent simulation software, these data will be transmitted to Arduino via web serial API. The Arduino can then control the ultrasonic oscillation devices to generate high-frequency electron oscillation, which breaks down the water molecules into mist and control the motor to drive the turbine blade inside the aroma diffuser to help spread the scent. This subsystem allows the users to have an immersive AR/VR experience that incorporates smell as a key sensory input.

2.3 Subsystem Requirements

2.3.1 AR/VR software

Requirements	Verifications
1. The demo should run smoothly and consistently with at least 90 Hz frames per second(FPS) to provide visually comfortable and immersive experiences to users.	1. Use benchmarking tools, such as *Oculus Tray Tool* or *SteamVR Performance Test*, to measure the frame rate of the VR demo while it is running. 2. Conduct user testing: Invite potential users to test the VR demo and provide feedback based on their experience.
2. The software must be designed to work seamlessly with the latest lineups of Oculus VR devices.	1. Ensure that the design is compatible with Oculus' software development kits(SDKs) and tools to guarantee that the software is optimized for Oculus devices and takes advantage of their features and capabilities. 2. Create and validate our demo software using an Oculus Rift S, and if feasible, test it on other Oculus device models.
3. The demo needs to include adequate examples to be considered a comprehensive and general implementation of incorporating scent into VR systems.	The demo should offer at least 3 different scenes/objects, such as a bakery or a bouquet of roses, to incorporate different scents for the users to interact and experience with.

2.3.2 Scent simulation software

Requirements	Verifications
1. The simulator should be able to calculate the appropriate intensity and duration of the scents emitting based on the diffusion equation.	1. Through careful experiment and referring to the Odor Detection Threshold (ODT) which is the minimum concentration of an odorant that can be detected by humans, and Oder Intensity Standard Curves (OISC)[3], we can make sure that the scents can be emitted within an acceptable and comfortable range. 2. Use specialized equipment: Use specialized equipment, such as gas chromatography-mass spectrometry (GC-MS), to verify that the simulator accurately calculates scent intensity and duration.
2. The real-time result should be delivered correctly to the emitter.	Use Arduino's Universal Serial Asynchronous Receiver Transmitter(USART) protocol to transmit real-time signals to the PC for debugging.

2.3.3 AR/VR hardware

Requirements	Verifications
1. The VR headset should be equipped with Bluetooth technology or a USB port to connect with the scent emitter.	As our Oculus Rift S device relies on a PC, it is essential to ensure that the PC is equipped with Bluetooth capability and can effectively communicate with the Arduino Uno R3 for seamless performance.

2.3.4 Scent emitter

Requirements	Verifications
1. The emitter should be driven by an inexpensive, efficient, and user-friendly microcontroller (MCU), enabling easy setup and operation.	The emitter will be streamed by an Arduino Uno R3 as the microcontroller board based on the ATmega328P.
2. The dual motors demonstrate exceptional stability even while powered by a single 1.5V battery.	Conduct stress tests on the dual motors by applying 200% -500% load on them while they are operating on a single 1.5V battery. The dual motors should work as expected when facing instabilities.
3. The emitter consists of 2-4 small scent cartridges with scent cartridges installed. Besides the special scents, the emitter should also be able to clear the scents (deliver pure air or water mist) between the transition of different scents to avoid accidental mixture.	1. Design and conduct extensive unit test cases for every possible scenario. 2. To ensure accurate delivery of scents/water mist, we plan to utilize specialized equipment, such as gas chromatography-mass spectrometry (GC-MS), to verify the precise chemicals being emitted at each time step.
4. Real-time cues from the API through the OpenXR should be delivered to the Arduino using Web Serial to trigger scents.	Utilize Arduino's USART protocol to send real-time signals to the PC, allowing for comparison with signals received through the API.

2.4 Tolerance (Risk) Analysis

We believe that the scent simulation software poses the greatest risk to the successful completion of the project because as people are sensitive to scents, slight deviations in the intensity and duration of scents may highly influence people's immersive VR/AR experience. For example, when our user uses our device and enters our constructed scene, he may see a huge orchard. When he is fifty meters far away from the orchard, he is supposed to smell a light fruity scent. And the intensity of this scent should be slowly increased as he moves closer. In the real world, the smell has no clear boundary. That is, people should not feel separated when they are exposed to multiple kinds of scents. For example, if the user stands between tuberose and Hyacinthus orientalis, he may smell a mixture of two scents. If he walks closer to tuberose, then he may smell stronger scents from tuberose, but the scents from Hyacinthus orientalis should not disappear. Both characteristics of scents mentioned above require high accuracy of our scent simulation software, and low accuracy may make users feel strange and unreal, and thus negatively influence the immersive experience. So our research on scent would involve disciplines of thermodynamics, transport phenomena, and psychophysics to predict the odor of mixtures of scents, evaporation/release of scents, diffusion and performance of scents, which will be applied in our scent simulator.

Besides, in our design, the scent-emitting device is integrated with the headset, which means the distances between the nose and emission point also need to be considered. As such, it could additionally pose a challenge to meeting our expectations for performance. To ensure success, our team evaluates the feasibility through mathematical analysis and simulation. As we plan to model a garden, we will use the scent of flowers.

By carefully researching, we found that most of these scents have diffusion coefficients between $1.8m^2/h$ and $4.0m^2/h$, Therefore, in simulation, we set diffusion coefficients to be $2.5m^2/h$, and focus on two dimensions. The steady-state diffusion equation is:

$$\nabla \cdot (\Gamma \nabla \phi) + S_\phi = 0$$

where Γ is the diffusion constant. According to the above equation, we can get the diffusion equation for two dimensions:

$$\frac{\partial}{\partial x}(\Gamma \frac{\partial \phi}{\partial x}) + \frac{\partial}{\partial y}(\Gamma \frac{\partial \phi}{\partial y}) + S_\phi = 0$$

Our simulation is based on this formula. Here is the simulation result:

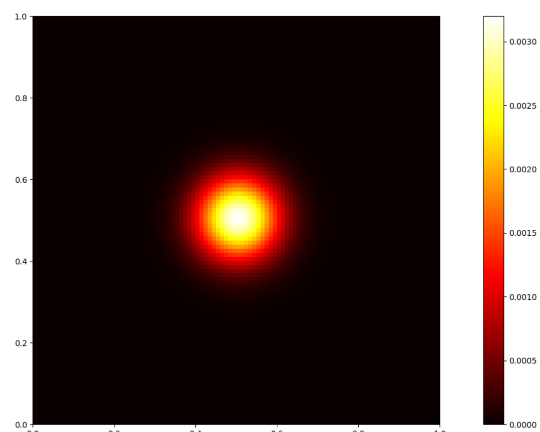

Figure 4: Python Simulation Result

Besides, Teixeira et al.[4] built a relatively complex perfume diffusion model in their research work, which also shows that those scents can be transmitted in a short time. As our scent-emitting device will be about twenty centimeters above the nose, this distance should be enough for diffusion.

Considering that the user will not have much movement in our demo, we studied how the concentration of scents changes over time in the 1D case. Considering constant mass evaporation rate of scent:

$$\mu_i^{mass} = k_i M_i C_i^g$$

where k_i represents the mass transfer coefficient concerning the film contributions from both gas and liquid. The gas concentration changes as:

$$C_i(z,t) = \mu_i^{mass} \int_{t_i}^{t} \frac{1}{2\left[\pi\Gamma_i(t-\tau)\right]^{1/2}} \left[exp(-\frac{(z-z_0(\tau))^2}{4\Gamma_i(t-\tau)}) + exp(-\frac{(z+z_0(\tau))^2}{4\Gamma_i t-\tau})\right] d\tau$$

3 Ethics and Safety

3.1 Ethics

Our device has a few potential ethics concerns that must be considered during the design and implementation process. As an extension of VR/AR system, our device will emit gases, which involves cultural sensitivity. Different cultures have different attitudes towards scent, and certain scents may be considered offensive or inappropriate in some cultures. Concerning the IEEE Code of Ethics, term 3, "to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist"[5], we will be mindful of these cultural differences and ensure that scent cues are not offensive or inappropriate.

Besides, as with any emerging technology, there is always the risk of the technology being misused for nefarious purposes. For example, scent cues could potentially be used to manipulate users or deceive them in some way. Therefore, we will follow the IEEE Code of Ethics, term 6, "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations"[5], and we will only authorize our technology to organizations or companies with valid and legal certificates.

Furthermore, we agree to build a peace, beautiful and loving VR world avoiding any bloody scenes. This will follow ACM Code of Ethics and Professional Conduct, which says "Examples of harm include unjustified physical or mental injury, unjustified destruction or disclosure of information, and unjustified damage to property, reputation, and the environment"[6]. Our team agrees that violent and bloody scenes is harmful to people especially to children, so we will not put any of these elements in our device.

In addition to the above, our team pledges to follow the IEEE Ethics guidelines[5] and the ACM Ethics guidelines[6] as closely as possible.

3.2 Safety

There are several potential safety hazards with our project. When emitting gases, it is possible to trigger allergic reactions or other health issues for some users. It may also potentially have a psychological impact on them. For example, certain scents could trigger memories or emotions that users may find distressing. To avoid the physical or mental health issues, we will only use harmless and safe gases. We will follow the standard value of poisonous and harmful gases[7] to check the scents. To ensure that scent delivery is carefully controlled, we plan to list the gases we use, and ensure our users know them well before using our device.

Besides, as VR/AR masks need to be worn on the head, our device may cause visual fatigue, wrist or neck strain. For some users, the long time experience on VR/AR devices may even lead to headache, pure photosensitive epilepsy or hearing damage. Unfortunately, this is the potential risk that exist for all VR/AR devices. To minimize the damage, our team plans to display warm tips for every users before they entering our constructed virtual environment.

In addition to the above, our team pledges to follow ECE445 safety guidelines on course website. First, we promise that no one will work in the lab alone. Second, we will complete a mandatory online safety training in order to be allowed to work in the lab. Third, we promise that before working with high voltages, we will first complete additional safety training. Forth, when charging or utilizing certain battery chemistries, we promise to read, understand, and follow guidelines for safe battery usage. Finally, when involving electric current running through a human subject, our team promise to read through and understand these guidelines for Safe Current Limits.

References

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