Presentation of Odor in Multi-Sensory Theater

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Abstract. This paper discusses an approach to implement and evaluate odor display, with the goal of using it in multi-sensory theaters. A display system that mixes odors with an arbitrary ratio was developed, and a sensor system that is capable of measuring the concentration in a relatively short time period using a sample and hold function was devised. Experiments clarified the time delay and attenuation of the concentration in the transmission of an odor from the display to a user, and the feasibility of utilizing a quantitative mixture of odors was confirmed.

Keywords: Underlying & supporting technologies: Multimodal interfaces, Olfactory Display, Multi-sensory Theater.

1 Introduction

Many investigations have been conducted with the aim of integrating various sensations into a virtual environment. Such investigations have included the feedback of haptic and vestibular sensations, in addition to visual and auditory sensations. The presentation of these sensations is expected to increase the similarity to a real environment and hence improve the reality of a virtual environment. The sensation of odor is one of the sensations that we use in daily life. The sensation informs us of both preferable and abhorrent situations such as the presence of flavorful food or smoke from a fire, and it contributes to our safety and enriches our lives.

The authors are working on a project involving the development and application of a multi-sensory theater. The goal of this project is to attain a higher sensation of reality by integrating haptic, wind, odor, and body motion presentations. The study reported in this paper is part of our effort to develop an olfactory display for the theater environment.

A difficulty when dealing with the sensation of odor from an engineering viewpoint is that the measurement of odor is not necessarily easy. Although semiconducting gas sensors are commercially available at a moderate price, they are often difficult to use because no quantitative calibration method has been established, and their response is relatively slow. This study also investigated fundamental techniques to use such sensors.

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2 Related Work

The sensation of odor is a chemical sensation involving the perception of chemical substances. An artificial presentation of this sensation is realized by emitting odorants that are perceived by the receptors. However, at present, it is impossible to synthesize arbitrary substances in real time. An easy approach is to use substances prepared in advance; it is expected that a wide variety of odors could be generated by mixing smaller sets of odorants. However, the relationship between a set of odorants and the possible variations in the sensation of odor is unclear.

Many studies have dealt with the presentation of odor by mixtures of odorants. Pioneering research in this field was done by Hiramatsu et al., who examined the transmission of odor by estimating the mixing ratio of elemental odorants [1]. Tanikawa et al. developed a device that mixes vaporized odorants using air flow control [2]. Yokoyama et al. implemented a portable odor display, and carried out an experiment on a searching task using odor[3]. Yanagida et al. proposed a method of conveying odor using the vortex rings generated by an air cannon[4]. In a project by NICT, downsizing an odor display was investigated, and a device that was 20 × 20 × 20 mm in size was developed[5]. Kadowaki et al. investigated the characteristics of human odor perception, including the adaptation to stimuli, and applied the knowledge gained to the development of an odor display[6].

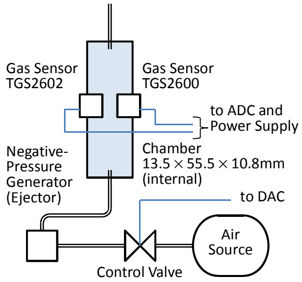
Most of the devices described above were designed to present odors directly to the nose of a user. However, in the case of a multi-sensory theater, it is not necessarily appropriate to attach or wear a device around the user's face because this could hinder the free motion of the user. Therefore, our study investigated an approach to convey odor to the user by an air flow. This approach has the drawback that the diffusion and time delay in the conveying process are not negligible. In addition, to evaluate this approach, precise measurement of the odor concentration in the transient state is necessary.

3 Experiment System

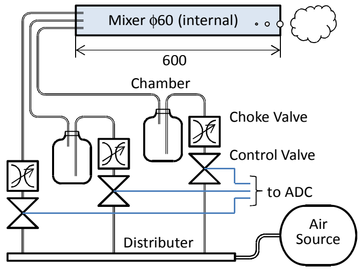
This section describes the sensor and display systems that were implemented in the following experiments.

3.1 Sensor System

A drawback of applying a semiconducting gas sensor to a human interface is its relatively slow response. This makes it difficult to measure the intensity of an odor in real time. Our study proposed a sample-and-hold type sensor unit that samples the air with the odorant and holds it in a small chamber until the outputs of the sensors become stable. A negative-pressure generator (i.e., ejector) was used to introduce the external air into the chamber. This generator was turned on and off from the computer by switching the air supply (Figure 1 (a) (c)).



(a) Structure of Sensor Unit



(b) Structure of Display System

(c) Sensor Units

(c) Mixing Chamber of Display System

Fig. 1. Sensor and Display Systems

The volume of the chamber was approximately 8 mL, and the flow of the suction was approximately 100 mL/s. Two sensors of different types were attached to the chamber, whose metal cover was removed to improve the response. The resistance of the sensor device decreases according to an increase in the concentration of the gas (or odor) around the device; the resistance R and concentration C have approximately the following relationship:

$$\log(C/C_0) = K \log(R/R_0), \tag{1}$$

where suffix 0 indicates the values in plain air.

Two sensor units were created; in the following experiments, they are referred to using the letters A and B. Moreover, the types of sensors are represented by the numerals 00 and 02 for TG2600 and TG2602, respectively. For example, the TG2602 sensor on unit A is described as A02.

3.2 Display System

A display system that mixes odorants was developed (Figure 1 (b) (d)). This system was designed for use in a multi-sensory theater. However, it could also be used as an odor generator for the evaluation of the sensor units. The principle of the system is similar to that of the device by Tanikawa et al.[2]; the odorants are vaporized in chambers to achieve saturated state, and the air in each chamber is pushed out by infusing air into the chamber. Then, the extruded air is mixed with plain air. The air flows are controlled using pressure-control valves and choke valves. Generally, the choke valves have the characteristic that the amount of flow Q is proportional to $\sqrt{P}$, where P is the differential pressure before and after the valve. Because the air flow is relatively small, the loss of pressure after the valve is negligible. Hence, it can be assumed that the pressure at the exit of the valve is equal to that of the atmosphere.

The plain air that is mixed with the extruded air is also used to convey the odor to the user, in addition to attenuating the concentration. Because the flow of the plain air has a much larger volume, the change in the total volume by mixing in the extruded air is negligible. Hence, the concentration of the odor presented to the user, C, is considered to be proportional to the flow volume Q.

In the following experiments, the pressure control range was limited to 0.1–0.4 MPa. The choke valve was tuned so that the concentration of the output odor did not exceed the measurement range of the sensors. Because no quantitative measure for the odor concentration was available, we defined our own standard based on the display system, where the concentration of the odor at the output of the mixing chamber at the maximum air pressure (0.4 MPa) was defined as $C = 1.0$.

3.3 Odor Source

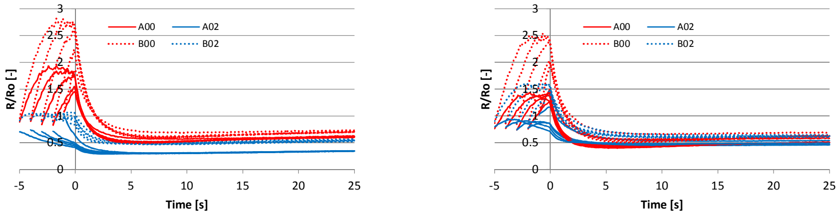
Two odor sources were used: "Queen Rose" (denoted as QR) and "Mix Berry" (denoted as MB). These are essential oils that are commercially available.

4 Measurement of Odor

The measurement method using the sample-and-hold-type sensor unit was investigated.

4.1 Sample and Hold Characteristic

The suction duration and hold time required for the sensors to become stable were important factors for the sensor unit. To determine these factors, the changes in the sensor outputs during the sample and hold operations were observed. The suction duration was changed from 1 to 5 s. Figure 2 shows the results; all of the data were aligned at the end of the suction on the temporal axis. From these results, it is clear that there were large changes in the values during the suction, which were probably caused by a temperature change in the sensor device. The sensor values became stable after about 10 to 20 s; moderate changes in the values are considered to be caused by the odor leaks from the chamber. During this stable period, the value differences caused by the effect of the suction duration were relatively small. Considering these features, the ideal suction duration and hold time were determined to be 1 s and 20 s, respectively. This measurement sequence was used in all of the subsequent experiments.



(a) Queen Rose (QR) (b) Mix Berry (MB)

Fig. 2. Changes in Sensor Values during Suction Operation

4.2 Sensor Calibration

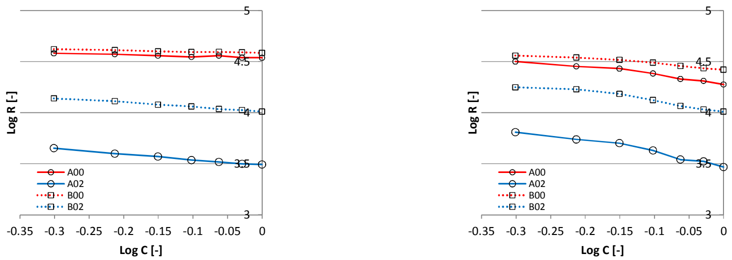
It is known that the sensors used in our implementation have different sensitivities depending on the gas (i.e., odorant). In addition, the individual differences between sensor devices, even with the same model number, are not negligible.

Hence, the measurement parameters for every combination of sensors and odors had to be measured and recorded. The following relationship between the concentration of odor C and the sensor resistance R was assumed:

$$\log(C) = a \log(R) + b, \tag{2}$$

where a and b are parameters that take different values for different combinations.

The measurement results for the sensor resistance while changing the air pressure P are shown in Figure 3. As stated above, the odor concentration was assumed to be proportional to $\sqrt{P}$. Through fitting of lines to the plot using the least squares method, parameters a and b were obtained, as given in Table 1.



(a) Queen Rose (QR) (b) Mix Berry (MB)

Fig. 3. Responses of Sensors to Odor Concentration

Table 1. Calibration Parameters

Sensor	Queen Rose (QR)		Mix Berry (MB)	
	a	b	a	b
A00	-0.147	4.53	-0.760	4.29
A02	-0.545	3.49	-1.153	3.49
B00	-0.119	4.58	-0.483	4.43
B02	-0.438	4.01	-0.870	4.02

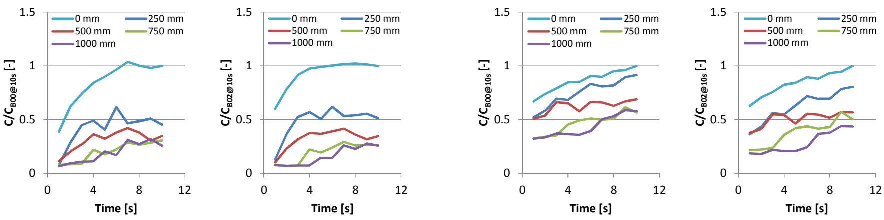
5 Presentation of Odor

Controlling the timing and concentration is essential for the presentation of odor in a multi-sensory theater. To clarify the characteristics of the display system, the following two experiments were carried out.

5.1 Time and Distance

It takes time to convey an odor to a user because the user is located at some distance from the display system. In addition, the odor diffuses in the air during the conveyance. The delay and attenuation were evaluated by measuring the transitional changes in the concentration at various distances. The distance from the exit of the display system to sensor unit A was changed to 250, 500, 750, and 1000 mm, whereas sensor unit B was placed at the exit (i.e., 0 mm). The air was sampled at 1 to 10 s in steps of 1 s. Actually, because the sensor unit requires a hold time of 20 s, the same emission sequence was repeated for every sample time and distance combination.

The concentration values were computed using the parameters obtained in Section 4.2. Because this experiment had the goal of determining the transmission in air, the values were normalized using the concentration at the exit; the value from sensor unit B at 10 s was used as the standard for this normalization. The results are shown in Figure 4. They suggest that at 1000 mm from the display, the timing of the increase in concentration was delayed by about 6 s, and the concentration was attenuated by from 1/2 to 1/5.



(a) Queen Rose (QR) (b) Mix Berry (MB)

Fig. 4. Changes in Concentration Depending on Time and Distance

5.2 Mixture of Odors

As stated previously, the display was designed with the ability to mix odors at any given ratio. This mixing function was confirmed by an experiment using the sensors. The relationship of Equation 2 was not applicable to the case of a mixed odor. Hence, a different model was assumed, as follows.

$$D = D_0 + h_{QR} C_{QR} + h_{MB} C_{MB}, \tag{3}$$

$$\log(R/R_0) = k \log(D/D_0). \tag{4}$$

The reduction in the resistance of the sensor device is caused by the reducing character of the gas (or odor). In the case of a mixed gas under a low concentration condition, the reducing ability is considered to have an additive nature. In the above equation, D_0 and D are the reducing abilities of the plain air and the air with the gas, respectively; h_{QR} are h_{MB} are parameters that represent the reducing abilities of the QR and MB odors, respectively. All of the parameters are considered to have different values for individual sensors.

In the experiment, the extruding air pressure for QR and MB was changed to 0.1, 0.2, 0.3, and 0.4 MPa, and the resistances of sensors A and B were recorded. Using the resulting data, the parameters in Equations 3 and 4 were estimated. The estimation error was defined as

$$E = \log(R/R_0) - k \log(D/D_0), \tag{5}$$

and the least squares method was used to minimize the square error. The resulting parameters are listed in Table 2. Using these parameters, the measurement results can be mapped into a concentration space whose axes represent the intensities of QR and MB (i.e., C_{QR}-C_{MB} space). The plot is shown in Figure 5. It should be noted that the additivity magnitude relation is preserved to some extent; especially in the area where C_{QR} is not large, there is no fold back in the plotted mesh.

Table 2. Fitting Parameters

Param.	Sensor	
	A00	A02
h_{QR}	9.66×10^{-5}	5.22×10^{-4}
h_{MB}	1.66×10^{-3}	6.31×10^{-4}
D_0	3.58	2.61×10^{-3}
k	476.26	1.55

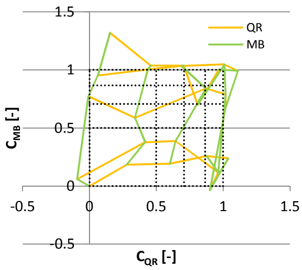


Fig. 5. Mapping into Concentration Space

6 Conclusion

This paper discussed our investigation for the presentation of odor in a multi-sensory theater. A display system that mixes odors and conveys them to users using air flow was developed. A sensor system with a sample and hold function was implemented for the evaluation of the display. Experiments clarified the characteristics of the time delay, concentration attenuation, and quantitative mixture of the odors.

Future work will include a more precise investigation into the spatial distribution of odor. Because a user is allowed to move his/her head in a theater, the distribution must be designed to cover the area of this head motion. Other tasks will involve further improvements in the sensor unit and sensing method. In particular, a reduction in the hold time is required for efficient measurement.

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