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Scent Presentation Expressing Two Smells of Different Intensity Simultaneously

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Abstract

Studies aiming at increasing the sense of reality by using scents with the picture medium, such as movies, have lately attracted much attention. In the picture medium, multiple objects with different scents are seen at the same time. Therefore, it is thought that by controlling the presentation of scent in accordance with the various scented objects seen, the viewer will experience a greater sense of realism. This realism will be further heightened by expressing through scent the distance relation between the multiple objects, that is, stronger scent for objects in the foreground and weaker scent for those in the background. However, this requires a technique that can not only present multiple scents which must be perceived simultaneously, but also express a distance relation between them. In this study, by using pulse ejection which emits scents for only very short periods of time and by measuring the olfactory characteristics for various scent presentation patterns by changing the relative amount and presentation frequency of the two scents, we succeeded in enabling around 90% of users to sense the distance relation between two scents. The proposed method for presenting scent depicting multiple objects shown simultaneously in the picture medium is expected to further enhance the sense of reality.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Information Interfaces and Presentation]: User Interfaces—User-centered design

1. Introduction

The transmission and communication of information tends to be limited to visual and audio media. However, the transmission of information via all five senses (sight, hearing, touch, smell and taste) has lately attracted much attention [yus07]. Olfactory information recognized by the olfactory organs differs from the information recognized via the other four senses. The sense of smell powerfully affects humans since olfactory information is directly transmitted to the cerebral limbic system that governs emotions. In addition, olfaction is thought to be an effective means by which to convey information that will enhance the sense of reality, as occurs with the use of three-dimensional vision and sound [Hir07]. It is expected that the addition of scent to the transmission of audio-visual information in particular will further enhance the sense of reality.

In the picture medium, such as movies and television, multiple objects with different scents are seen at the same time. Therefore, it is thought that by controlling the presentation of scent in accordance with the various scented objects seen, the viewer will experience a greater sense of realism. Sensing multiple objects through olfactory information is affected by the relative positions between the objects. For example, in the case that not only a foreground object, but also the space surrounding it (e.g. the background of a forest) is scented, it is thought that we experience the scent of the foreground object strongly and that of the background weakly. Thus, in a multimedia context aiming at enhancing the sense of reality, it is necessary not only to present multiple scents at the same time, but also to express the distance relations between them.

In this study, we developed a scent presentation technique that expresses the relative distance between a foreground (strong) and a background (weak) scent that corresponds with the relation between two items presented in the picture medium. In order to develop such a technique, we needed to address the problem of olfactory adaptation associated with conventional olfactory presentation methods. Conven-

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tional methods continue emitting scent at high density for a long time to enable everyone to experience the scents easily. However, this creates the problem of scent lingering in the air and leads to adaptation, which makes it impossible for users to experience the many separate scents that correspond with the many changes of objects and sounds appearing in the picture medium. Therefore, we approached this problem by using pulse ejection, a method which emits scents for only a very short period of time. Pulse ejection was realized using a display [SOBO08] that provides high-precision emission control of scent.

2. Related Work

Trials on the transmission of olfactory information together with audio-visual information are currently being conducted. Work first started in the 1950s when Heilig developed Sensorama [urlb], the first virtual reality (VR) system that presented olfactory information together with audio-visual information. The recently developed virtual space system, Friend Park [SHO*01], provides users with an increased sense of reality by generating the aroma of a virtual object or environment, where the aroma is defined as the area in which a scent can be perceived. Kaye's article [Kay04] describes some systems that add scent to web content, and computer controlled olfactory displays such as iSmell [WJS*04] and Osmooze [urla] are utilized in these systems. Another type of display, the air cannon olfactory display that generates toroidal vortices of scent in order to present it in restricted space, has been proposed in [YNTT03].

Nakamoto et al. [NNHM01] designed a smell synthesis device that presents the scent of a virtual object remotely. The system analyzes the smell to be transmitted and presents the analyzed data as the composition ratio of the scent elements. On the receiver side, a feedback control changes the ratio of the scent elements owned by the receiver to reproduce the target scent.

A wearable olfactory display with a position sensor has also been developed [YTHH04]. By controlling the density of odor molecules, it can present the spatiality of olfaction in an outdoor environment. The olfactory information transmitting system consists of the aforementioned display, a sensing system using three gas sensors, and matching database. The user can experience a real sense of smell through the system by translating obtained olfactory information.

AROMA [BCN04] tries to introduce the olfactory modality as a potential alternative to the visual and auditory modalities for messaging notifications. Experimental findings indicate that while the olfactory modality was less effective in delivering notifications than the other modalities, it had a less disruptive effect on user engagement in the primary task.

The addition of a scent to image media such as movies has been proposed by a number of researchers. Okada et al. [OA03] measured the viewer's mental state by his/her brainwaves, and analyzed the relation between the scent and the viewer's feelings while watching. A movie that adds olfactory information to the audio-visual information has been created, but because the synthetic perfume did not accord with the image and the scent was not deodorized, the movie could not be widely distributed. In addition, the "scent communication mobile" [kao], a mobile phone service, now delivers scent via the Internet, so-called "scent communication".

However, the scent presentation techniques of previous works were designed merely to create the sense of experiencing a scent, and they used higher densities and longer presentation times of scent than actually necessary, and thus were hindered by the problem of olfactory adaptation due to scent lingering in the air. To this end, we describe in the next section our proposed technique that makes it possible to experience multiple scents at the same time and which expresses the distance relation between objects as presented by the audio-visual information.

3. Proposed Scent Presentation Technique to Express Distance Relations between Foreground and Background

We are focusing on the development of a scent ejection control technique that will make communication via olfactory information widespread. In the area of the multimedia, the addition of scents in accordance with audio-visual contents was found to have marked effects on content understanding; however, multiple objects, each of which have scent, frequently appear on the screen at the same time. For example, in the case of a movie scene where someone eats an apple in a forest, both the apple and the forest have distinct scents. If both scents are presented at the same time and we can sense them both simultaneously, it should enhance the sense of reality because we can sense, by olfaction, that there are two objects present. As mentioned earlier, it is also important to convey the distance relations between objects for an enhanced sense of realism, where we would expect to experience the smell of the foreground apple strongly and the background of the forest weakly.

We previously succeeded in enabling a user to sense two scents in a single breath by using pulse ejection [SOK*08], and in the present study, we sought to develop the scent presentation technique further to express the distance relation between objects presented in the foreground and background. The pulse ejection method used is shown in Figure 1. The olfactory display used in this study [SOBO08] can control scent ejection for units of 100 msec. Therefore, we define "pulse ejection" in the following experiments as scent ejection for a 100?msec period (delta t shown in Figure 1.

In order to create the sense that there are two objects at the same time, it is necessary to experience two scents in

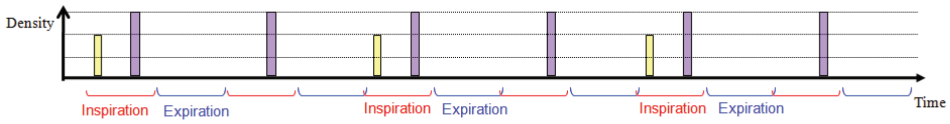

Figure 2: *Proposed method.*

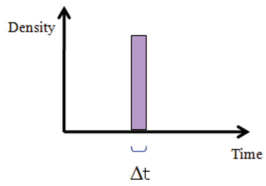

Figure 1: *Definition of pulse ejection.*

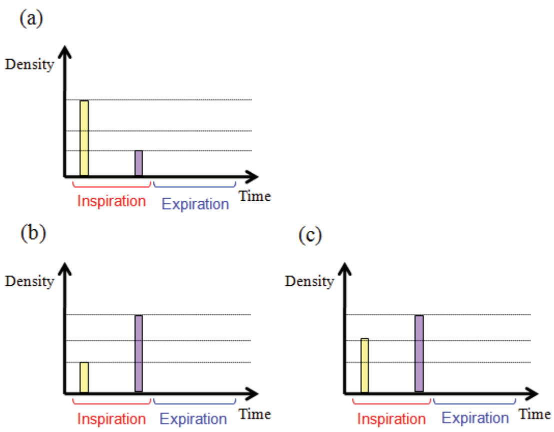

Figure 3: *Pulse mode method of scent presentation.*

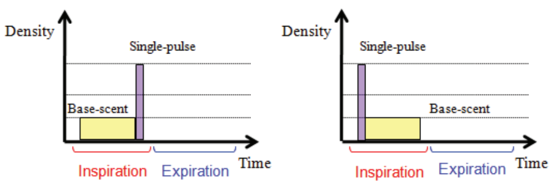

Figure 4: *Base mode method of scent presentation.*

as short a time as possible. We thus define the foreground and background distance relation as "the intensity relation between two scents perceived in a single breath when presented simultaneously". The foreground scent is expressed by a strong scent, and the background scent by a weak scent. Figure 2 illustrates the proposed method.

In addition, hypothesizing that a lower frequency of presentation would make it difficult to sense two scents presented at the same time, we decided that each scent would be presented either at least once in two breaths.

To express the distance relation, we needed to alter the density of the two scents presented in a single breath by highlighting the foreground scent, by increasing its density, while reducing the relative density of the background scent. So, to determine a suitable difference in density between the two scents and a suitable order of presentation that would enable the user to experience the two scents and the distance relation, we developed two methods of scent presentation in a single breath.

The first method involved two pulse ejections where the relative intensity of the stimuli was changed by varying the ejection amounts of the first and second pulses. This method is hereafter referred to as the "pulse mode" method. Figure 3 shows examples of this method, where (a) shows the pattern presenting the higher density scent first, and (b) and (c) show the patterns presenting the higher density scent second. Figure 3-(b) shows a greater difference in density between the two scents, and (c) a lesser difference.

Since we considered that using the pulse mode might mean that the lower density scent is little sensed, we developed a second presentation method (Figure 4) in which the presentation of the lower density scent is long and the higher density scent is presented by pulse ejection. Here, we refer to the weak scent with long presentation as the "base scent", and the strong scent presented by pulse ejection as the "single pulse", and we call this method the "base mode" method. In addition, the base scent has the lowest of the densities tested. Figure 4 shows examples of the base mode method in which we use the pattern of presenting the base scent either (a) first or (b) second.

Based on the results of our previous study in which a human subject was able to detect scents easily for 1200 msec from the beginning of inspiration [OKS*08], here the interval between the two pulse ejections in the pulse mode method was set to 1000 msec and the presentation time of the base scent was set to 1100 msec.

Finally, in order to eject scents that evoke a specific distance relation, it is necessary to consider the olfactory characteristics that enable humans to experience pulse ejection. Therefore, in the next section, after clarifying the detection threshold, we examine in Experiment 1 how two scents in a single breath are experienced with the pulse mode and the base mode method by carrying out a subjective evaluation. We then apply the results in Experiment 2 in order to express the distance relation over six consecutive breath cycles.

4. Experiments

In our previous study [KSBO08], we confirmed that no scent lingers in the air when the wind velocity control of the olfactory display is set at more than 1.2 m/sec. Here, we set the wind velocity control at 1.8 m/sec, which is the maximum setting of this olfactory display, in order to reduce the delay from emitting scent from the olfactory display's exit hole to reaching the nose of the user. We used three kinds of natural fragrance: lemon, cinnamon and heliotrope.

4.1. Detection Threshold

The experiment to determine the detection threshold was conducted using pulse ejections of the three scents with 11 subjects (8 male, 3 female) who were students in their 20s majoring in information technology. We instructed subjects to breathe in accordance with a sonant cue, to sniff the scent patterns presented in accordance with their breath cycle, and then to answer whether they were able to detect the specific scents presented. Using the paired comparison method [syu05], we measured the detection threshold of the scent. The olfactory display presented a scented and an unscented ejection to each subject, and we instructed subjects to indicate which of the two was the scented ejection. We started the trial from the ejection amount that the subjects could sense easily, and it was decreased until the subject selected the distracter. As a result, the average detection threshold of the 11 subjects was an ejection quantity of 11 of the 127 phases of lemon scent, 8 of the 127 phases of cinnamon scent and 6 of the 127 phases of heliotrope scent. In our previous study, we determined that the perceived intensity of each of the scents is about the same at each detection threshold [SOBO08]. In addition, it is known that the perceived intensity of a stimulus is proportional to the logarithm of the physical magnitude of the stimulus [KNT03]. Therefore, we defined three phase levels of scent ejection, from 1 to 3, as shown in Table 1, to use in the experiment. Ejection level 1 was set to double the ejection quantity of the detection threshold, and the ejection levels were increased stepwise logarithmically from ejection level 1 in three levels. Table 1 shows the ejection quantity of 127 phases of the three scents corresponding with the three ejection level phases.

4.2. Experiment 1: Expressing the distance relation in a single breath

First, we examined a suitable technique for expressing the distance relation between two scents in a single breath. This experiment was conducted using pulse ejections of the three scents with 22 subjects (18 male, 4 female) who were students in their 20s majoring in information technology. Figure 5 shows the experimentation environment.

Table 1: *Ejection quantity (in 127 phases) of each scent for the three ejection levels.*

Ejection Level	lemon	cinnamon	heliotrope
1	22	14	12
2	44	28	24
3	88	56	48

Figure 5: *Experimentation environment for Experiment 1.*

4.2.1. Experimental method

Before the experiment, we conducted the following confirmation and measured the olfactory characteristics for two scents presented in a single breath.

Preliminary procedure

1. Subjects noted down age, name, gender, physical condition, appetite, and condition of the nose.
2. Subjects were instructed to fix the position of their nose by resting their chin on the stand and smelling the scents slowly in a relaxed state.
3. Subjects became familiarized with the three scents used in this experiment, and then confirmed whether they could detect the kinds of two scents presented in a single breath in the different presentation patterns.

We prepared 6 patterns of pulse mode presentation as shown in Figure 6 (3 combinations of the first scent's ejection level * 3 combinations of the second scent's ejection level - 3 combinations where the two scent's ejection level is the same.) and 2 patterns of base mode presentation as shown in Figure 7 (where the first scent is the base scent, and then where the second scent is the base scent). We used a total of 48 patterns (abovementioned 8 patterns multiplied by 6 combinations of the three scents).

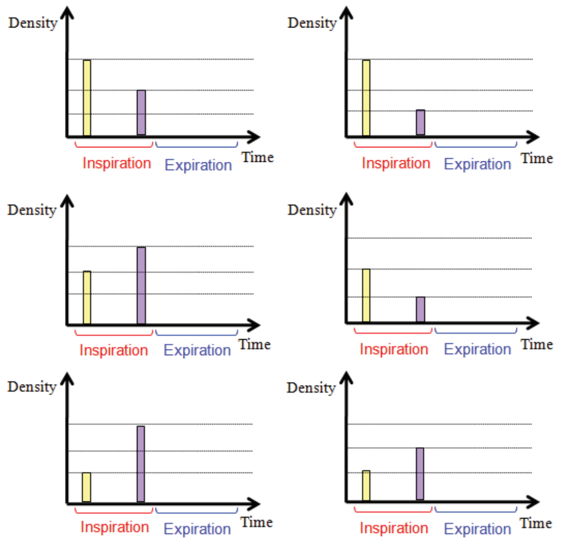

Figure 6: *Ejection patterns used in the pulse mode method.*

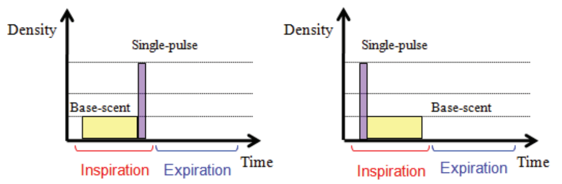

Figure 7: *Ejection patterns used in the base mode method.*

We instructed subjects to breathe in accordance with a sonant cue, to sniff the patterns presented at random in accordance with their breath cycle, and then to answer the questions shown in Table 2. In addition, we previously told the subjects what kind of scent was presented. Table 2 shows the questions in the case of using cinnamon and lemon. We asked the same questions in the case of using lemon and heliotrope, and using heliotrope and cinnamon.

Table 2: *Subjective evaluation in the case of lemon and cinnamon presentation).*

Q1.	How many kinds of scents did you smell?
Q2.	（For those who answered two kinds in question 1) Which of the following did you feel? ①Lemon seemed much more in the foreground (stronger). ②Lemon seemed a little in the foreground (stronger). ③The intensity of the two scent seemed about equal. ④Cinnamon seemed a little in the foreground (stronger). ⑤Cinnamon seemed much more in the foreground (stronger).

In the case that the subject answered one kind of smell for question 1 shown in Table 2, we considered that he/she could not detect the scents. We measured the detection ratio from the ratio of the answer when he/she answered two kinds. For question 2, we also measured the average score the subject assigned on a scale of -2 to +2, as shown in Table 3.

For example, when high intensity lemon and low intensity cinnamon were presented in a single breath, a higher score indicated a stronger sense of the distance relation, and when low intensity lemon and high intensity cinnamon were presented, a lower score indicated a stronger sense of the distance relation. In the latter case, the score was normalized by inverting the sign, where a higher score indicated a stronger sense of the distance relation. The same applied to other combinations of scents. We conducted the above trial for all presentation patterns with all subjects. For preventing olfactory adaptation, there were approximately 30-sec intervals between the trials, and subjects were instructed to take a break for around 5 minutes after every 8 trials, as shown in Figure 6 and Figure 7.

Table 3: *Intensity scores for the two kinds of scent emitted.*

Score	Judgment of the anteroposterior defference
+2	Lemon seemed much more in the foreground (stronger).
+1	Lemon seemed a little in the foreground (stronger).
0	The intensity of the two scent seemed about equal.
-1	Cinnamon seemed a little in the foreground (stronger).
-2	Cinnamon seemed much more in the foreground (stronger).

4.2.2. Results

Table 4 and Table 5 show the average score (standard deviation) and detection ratio for the 22 subjects for the pulse mode method and the base scent method, respectively.

Table 4: *Average score (standard deviation) and detection ratio using the pulse mode method.*

First \ Second	Level 3	Level 2	Level 1
Level 3		**0.72**(1.1) 90.2%	**1.30**(0.79) 74.2%
Level 2	**0.59**(1.05) 100.0%		**0.53**(1.01) 87.9%
Level 1	**1.30**(0.89) 94.7%	**0.54**(1.06) 90.9%	

Table 5: *Average score (standard deviation) and detection ratio using the base mode method.*

First \ Second	Single-pulse	Base scent
Single-pulse		**1.55**(0.69) 52.3%
Base-scent	**1.20**(1.01) 99.2%	

The vertical axis of Table 4 and Table 5 shows the first scent presentation method, and the x axis shows the second one. For example, the area for level 1 on the top and level 3 on the left shows the average score (standard deviation) and detection ratio in the case of presenting the level 1 pulse first and the level 3 pulse second. The higher the average score (-2 - +2), the stronger the perception of the distance relation, and the higher the detection ratio(0% - 100%), the stronger the perception of both scents.

The results were analyzed using a two-way ANOVA (kind of scent, kind of presentation pattern). There was no significant difference for kind of scent ($F(2,22)=0.64$, $P > 0.05$), but a significant difference for kind of presentation pattern ($F(7,22)=27.02$, $P < 0.01$). For all 8 kinds of presentation pattern as shown in Table 4 and Table 5, differences were assessed using the Steel-Dwass method [ste].

No significant difference was found for the pattern using level 2 ($P>0.05$). Moreover, no significant difference was found for the pattern not using level 2 (the pattern using level 1 and level 3 as shown in Table 4 and the pattern using single-pulse and base scent as shown in Table 5 ($P>0.05$)). However, there was a significant difference for all combinations of the first pattern and the second pattern ($P<0.05$). This shows that there is large individual variation in the sensation of scent for the pattern using level 2 density since the standard deviation is large, that is, there is no connection of result when using level 2 density. Two scents which are presented on one breath when there is 1 level of difference are not universally perceived by all subjects because of a tendency for the differences in perceived distance to be assessed subjectively. It is therefore necessary to present the two scents where the stimulus difference is more than 4 times different (i.e., more than 2 levels of difference) in order to express the distance relation.

In addition, the detection ratio results indicate that it is difficult to detect two scents by using the scent presentation technique which presents the high density scent first and the low density scent second, irrespective of using the pulse mode or base mode method. It is thought that the second weaker stimulus is difficult to sense because of olfactory adaptation caused by first stronger scent stimulus. In addition, we previously explained to the subjects that stronger scents express much more in the foreground and weaker scents express much more in the background.

We conclude that the scent presentation method which presents the first scent at level 1 density and then the second scent at level 3 density is suitable for expressing the distance relation in a single breath cycle.

4.3. Experiment 2: Expressing the distance relation in consecutive breaths

In this next experiment, we presented two scents in a single breath over six consecutive breaths and measured the human olfactory characteristics related to this. The experiment was conducted using pulse ejections of three scents with 20 subjects (17 male, 3 female) who were students in their 20s majoring in information technology.

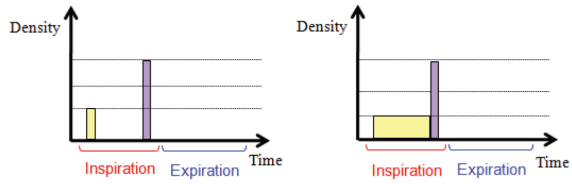

Figure 8: *The two scent ejection patterns used in a single breath.*

4.3.1. Experimental Method

Prior to Experiment 2, the preliminary procedure was conducted in the same manner as described for Experiment 1 in Section 4.2.1.

In this experiment, the patterns presented in a single breath corresponded to the pattern which showed a high score and high detection ratio in Section 4.2.2. In other words, we used the pattern of the pulse mode method in which the level 1 pulse was presented first and the level 3 pulse was presented second, and the pattern of the base mode method in which the base scent was presented first and the single pulse was presented second, as shown in Figure 8.

In addition, we prepared two patterns in which the presentation frequency was changed: one in which the same pattern in a single breath was presented 6 times consecutively as shown in Figure 9 (ratio of number of times of scent presentation between the first scent and the second scent is 1:1), and the other in which the second scent in a single breath was presented two times more than the first scent as shown in Figure 10 (ratio of number of times of scent presentation between the first scent and the second scent is 1:2).

Each of these patterns was presented in the pulse mode and the base mode. In addition, in the preliminary experiment, we had used the abovementioned pattern when the ratio was 2:3, but since the results were very close to those of the pattern for the ratio of 1:1, it was omitted from the main experiment.

We used a total of 24 patterns (the above 4 patterns as shown in Figure 9 and Figure 10 multiplied by 6 combinations of the three scents). We instructed subjects to breathe in accordance with a sonant cue, to sniff patterns presented at random in accordance with their breath cycle, and to answer the same questions as shown in Section 4.2.1.

For preventing olfactory adaptation, there were approximately 30-sec intervals between the trials, and subjects were instructed to take a break of about 5 minutes for every 4 trials, as shown in Figure 9 and Figure 10

4.3.2. Results

Table 6 shows the average score (standard deviation) and detection rate for 20 subjects. The vertical axis of Table 6

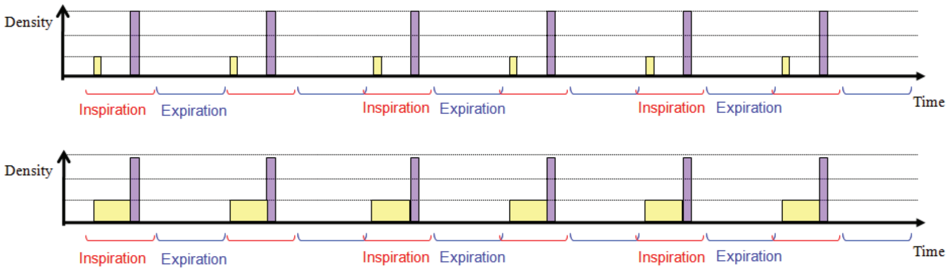

Figure 9: *Ejection pattern when the ratio of the number of times of scent presentation between the first scent and the second scent is 1:1).*

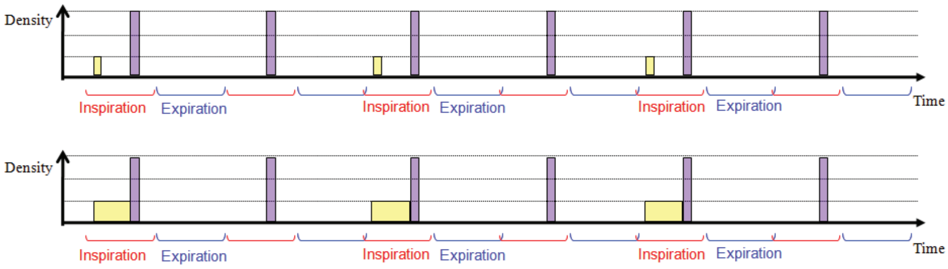

Figure 10: *Ejection pattern when the ratio of the number of times of scent presentation between the first scent and the second scent is 1:2).*

Table 6: *Average score (standard deviation) and detection ratio for each ejection pattern.*

	1:2	1:1
Pulse mode	**1.46**(0.74) 91.7%	**0.96**(1.32) 95.0%
Base mode	**-0.56**(1.05) 98.3%	**-0.92**(1.32) 97.5%

shows the scent presentation method in a single breath, and the x axis shows the presentation frequency of the first scent and the second scent. For example, the area shown as 1:2 on the top and the base mode on the left presents the average score (standard deviation) and detection ratio in the case that the base scent was presented first, the single-pulse was presented later and the ratio of the number of times of scent presentation between these scents is 1:2. The higher the average score (-2 - +2), the stronger the perception of the distance relation, and the higher the detection ratio(0% - 100%), the stronger the perception of both scents.

The results were analyzed using a two-way ANOVA (kind of scent, kind of presentation pattern). There was no significant difference for kind of scent ($F(2,22)=1.72$, $P > 0.05$), but there was a significant difference for kind of presentation pattern ($F(7,22)=58.46$, $P < 0.01$).

For all 4 kinds of presentation pattern, differences were determined using the Steel-Dwass method [ste]. Significant differences were found for all 4 kinds ($P<0.05$).

To begin with, we focused on the presentation method in a single breath. There was a significant difference between the pulse mode and the base mode ($P<0.05$), with the score using the pulse mode being higher than that using the base mode. This shows that subjects could sense differences in the distance much more readily with use of the pulse mode. We also focused on the presentation frequency. There was a significant difference between the pattern in which the ratio of the number of times of scent presentation is 1:1 and that in which it is 1:2 for both the pulse mode and base mode methods ($P<0.05$), with the score for the second pattern being higher than for the first pattern. This shows that subjects could sense differences in the distance more readily with use of the pattern in which the ratio of the number of times of scent presentation was 1:1.

One possible reason why the pulse mode is superior to base mode concerns the ejection amount. Only the difference in the density affected the sense of distance relation in a single breath. However, it is thought that difference in the ejection amount also has a large effect in the case of consecutive breaths. The fact that the pattern of the ratio of 1:2 is superior to that of 1:1 supports this. Another possible reason concerns the architecture of the base mode. This mode had no interval between the base scent and single-pulse, and thus it is thought that there was a slight mixing of the two scents. This had little effect in a single breath, but had a larger effect in consecutive breaths.

We conclude that the scent presentation method which presents the scents by pulse mode when the ratio of the number of times of scent presentation between the first scent and the second scent is 1:2 is suitable for expressing the foreground-background distance relation in multiple breath cycles.

5. Conclusion

Studies designed to enhance the sense of reality by presenting scents to correspond with the picture medium, such as movies, has lately attracted much attention. Such a medium often shows multiple objects at the same time and there is a distance relation between these objects. Any use of scent to enhance the audio-visual media needs to express this distance relation between multiple scents presented simultaneously. We approached this problem by using pulse ejection to emit scents for only a very short period of time. Users were able to sense two scents at the same time in a single breath. We also confirmed that they could sense the distance relation between a scent in the foreground (strong) and one in the background (weak) by changing the scent intensity (density) and the presentation frequency of the two scents using the "pulse mode" method and "base mode" method. We subsequently confirmed that they could sense the distance relation using the pulse mode method over six consecutive breaths cycles under the following conditions:

- When the difference in density between two scents is more than 4 times.
- When the low intensity scent is presented before the high density one.
- When the frequency of presentation of the first scent is half that of the second one.

The proposed scent presentation technique, which was determined based on the results of this study, enabled around 90% of the subjects to sense the foreground-background distance relation with respect to the scents presented.

This study demonstrated a scent presentation technique that simultaneously expresses two smells of different intensity. Future work remains to determine if a visual stimulus with this technique allows people to understand distance due to smell intensities without discomfort. The proposed method for presenting scents depicting multiple objects shown simultaneously in the picture medium is expected to further enhance the sense of reality.

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