Olfactory Display Using Visual Feedback Based on Olfactory Sensory Map

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Abstract. Olfactory sensation is based on chemical signals whereas the visual sensation and auditory sensation are based on physical signals. Therefore olfactory displays which exist now can only present the set of scents which was prepared beforehand because a set of “primary odors" has not been found. In our study, we focus on development of an olfactory display using cross modality which can represent more patterns of scents than the patterns of scents prepared. We construct olfactory sensory map by asking subjects to smell various aroma chemicals and evaluate their similarity. Based on the map, we selected a few aroma chemicals and implemented a visual and olfactory display. We succeed to generate various smell feeling from only few aromas, and it is able to substitute aromas by pictures nearer aromas are drawn by pictures more strongly. Thus, we can reduce the number of aromas in olfactory displays using the olfactory map.

Keywords: Olfactory display, Multimodal interface, Cross modality, Virtual Reality.

1 Introduction

Researches on olfactory displays are evolving into a medium of VR as well as visual and auditory displays. However, there are some bottlenecks in olfactory information presentation.Visual, auditory and haptic senses come from physical signals, whereas olfactory and gustatory senses come from chemical signals. Therefore, researches on olfactory and gustatory information are not so well on the way of researches as that of visual, auditory and haptic information.

Olfaction is most unexplained among five senses, and even the mechanism of reception and recognition of smell substances is unknown. Thus, “primary odors”, which can represent all types of scents, are not established. It means that the policy on mixing and presenting smell substances does not exist. Thus, it is difficult to present various scents using olfactory displays.In addition, olfaction is more unstable and variable than vision and audition. It is known that we can identify scents of daily materials only fifty percent of the time. For example, only half can answer “apple” when they sniff apples. [1,2]

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1.1 Olfactory Display

Olfactory displays can produce high realistic sensation which cannot be given by vision or audition. We illustrate olfactory displays developed so far by two following examples.

"Let's cook curry" by Nakamoto, et al. [3] is an olfactory display with interactive aroma contents, "a cooking game with smells". It presents smells of curry, meat, onion and so on by player's control. Wearable olfactory display" by Yamada, et al. [4] generates a pseudo olfactory field by changing concentration of some kinds of aroma chemicals using position information.

However, they produce only combination of prepared element odors, selected aroma chemicals, in each preceding studies. Therefore element odors cannot represent smells which do not belong to the element odors. It means conventional olfactory displays have limitations to represent various smells.

In order to implement practicable olfactory displays which can produce more various smells than before, it is required to reduce the number of element odors and produce feelings of wide range of smells from those few element odors.

We focused on instability and variability of olfaction. Using the band of olfactory fluctuation, there is a possibility that we can make people feel a smell different from the presented smell by using some techniques when a certain smell material is presented. If we are able to make people feel other smell than actual element odors, we can treat element odors the same as "primary odors" and we can generate various olfactory experiences from the element odors.

2 Concept

2.1 Drawing Effect to Olfaction by Visual Stimuli

Olfaction has more ambiguity than vision or audition. For example, it is difficult to distinguish the name of flowers or foods only by scents, unlike by visual images. [2] Thus, olfaction is easily affected by knowledge of smell and other sensation. [5][6]

In addition, olfactory sensation interacts with other various senses, especially visual sensation. That is, it is thought that olfaction can be used for the information presentation more effectively by the interaction with the cue of other sensation than olfaction. [7][8][9]

In this paper, we tried to generate various "pseudo olfactory experience" by using the cross modal effect between vision and olfaction. When the visual stimulus which contradicts the presented olfactory stimulus is presented, the visual stimulus influences olfaction. It is able to produce the olfactory sensation corresponding to not the smell generated actually but the visual information by presenting an image conflicting with the produced smell. We defined this cross modal effect between vision and olfaction as "drawing effect" on olfaction by vision.

This drawing effect leads visual images to give pseudo olfactory sensation not presented actually. For example, Nambu et al. [10] suggest the possibility of producing the scent of melons from the aroma of lemons, which is unrelated to the scent of melons, by showing a picture of melons. In this case, the picture of melons draws the aroma of lemons toward the pseudo scent of melons. When we apply the drawing effect to the olfactory display, we need the index what condition intensifies the drawing effect.

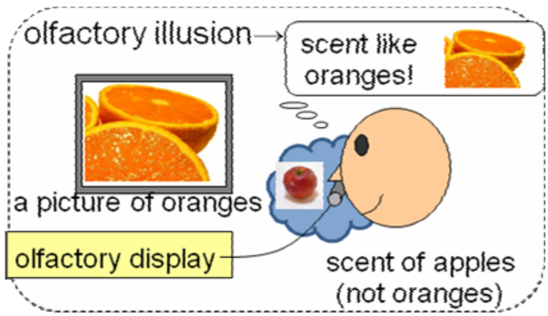

Fig. 1. Concept of Visual-olfactory Display

2.2 Olfactory Display Using Sensory Maps

It is thought that the strength of the drawing effect depends on the kind of the presented scent. That is to say, it is forecast that the drawing effect is generated easily between smells with high degree of similarity of the scent, while the drawing effect is not generated easily between scents with low degree of similarity of the scent. Then, we propose to use the degree of similarity of the smell, or the distance between scents, as an index in the drawing effect to the smell.

The method of evaluating the degree of similarity of the scent includes a method using similarity according to the language and similarity of the chemical characteristics.[11] However, there is not a fundamental research on the degree of similarity of the scent based on human's olfactory sensation yet. Then, we tried to construct a new olfactory map based on smell evaluation, which is more approximate to olfactory sensation than past olfactory maps.

The distance between scents can be evaluated more accurately and easily than before by making the olfactory map based on olfaction. Then, it becomes possible to operate the drawing effect to olfaction by vision more efficiently if we can prove that the closer the content of the olfactory source and the content of the picture aimed at, the stronger the drawing effect occurs.

3 Construction of an Olfactory Map

It is difficult to take out a common part of multiple people's smell senses and to make it into the common map because olfaction has more individual variations than other senses. [12] Two kinds of approaches are thought for making an olfactory map.

The first approach is making a personal olfactory map. It is required to measure distance, to make the map, and to prepare appropriate aromas for each user but the olfactory display completely suitable for each user can be achieved.

The second approach is evaluating the distance between scents by many people, extracting a common part of olfaction not influenced to the individual variation and making the map. The advantage of this approach is to be able to obtain the data of the distance between smells in which one map has generality. Therefore, when the individual variation of the result is not extremely large, it can be said that it is more advantageous for the development of an olfactory display suitable for practical use to use the approach of this common olfactory map.

It is necessary to consider two points, secure reliability to the smell evaluation and application to multiple people with individual variation of olfaction, to make a common olfactory map by using sense of smell. We discuss the method for making the olfactory map satisfying the points and evaluation to the map.

3.1 Method for Constructing Olfactory Maps

The procedure of constructing an olfactory map is as follows. First, we prepared 18-kinds of fruit flavored aroma chemicals: lemons, oranges, strawberries, melons, bananas, grapefruits, yuzu (Chinese lemons), grapes, peaches, pineapples, lychees, guavas, mangoes, apples, green apples, kiwis, apricots, plums. We confined the kinds of aroma chemicals among fruit flavors because we can compare the similarity between two aromas in the same category (fruits, flowers, dishes, etc.) easily than between two aromas in different categories. Then, we soaked test papers into each aroma chemicals and used them as smell samples.

Seven subjects evaluated the degree of similarity of two smell samples by five stages from among them. For example, if a subject feels that the scent of oranges and the scent of melons are very similar, the similarity is “4”. Then, we calculated smell distance between two smell samples as “5 minus similarity”. Correspondence table between the similarity and the distance is illustrated in Table 1. This trial was done to the combination of all of the 18-kinds smell samples.

Table 1. Relationship between score of similarity and distance of smell samples

Score of Similarity	Mention of questionnaire	Score of Distance
1	Different	4
2	Less similar	3
3	Fairly similar	2
4	Very similar	1
5	Hard to tell apart	0

The relation of the distance of the 18-kinds of smell samples is shown as 18 dimensions square matrix. We analyzed the distance matrix by Isometric Multidimensional Scaling (isoMDS) and mapped the result into a two dimension olfactory map.

3.2 Evaluation of Reliability

Reliability to the smell evaluation should be ensured because human sense of smell is unstable. In order to check if people can identify the same aromas as same scents, we prepared a pair of test paper of the same aroma chemicals, and we asked five subjects to evaluate the degree of similarity between the same aromas. We went on the experiment for two kinds of aromas: Lemons and Lyches. Then, we compared the results of comparing the same aromas with the average of the degree of similarity to the combination of all of the 18 kinds of smells.

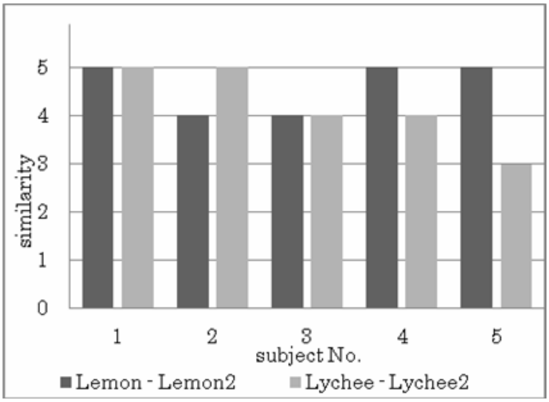

Fig. 2. The degree of similarity between the same aromas. The mean value of degree of similarity between same lemon aromas is 4.6 and the one between lychee aromas is 4.2. Both results differ significantly from the mean value among entire 18-kinds of aroma chemicals (2.07). ($p<0.01$).

There is reliability in the similar level measurement based on the sense of smell because the mean value of the degree of similarity between the same aromas indicated a remarkably high value compared with the entire mean value.

3.3 Making the Common Olfactory Map

We created a policy that it is possible to construct the common olfactory map by integrating and extracting a common part from results of multiple people's olfactory maps. In this section, we constructed a common olfactory map by averaging the result of 7 subjects' olfactory similarity evaluation.

We tried two ways of methods to average subjects' result: the simple average and the binarized average of similarity values. The simple average method is the method calculating the average of smell distance between each aroma and mapping them aroma chemicals by isoMDS. The binarized average method is the method binarizing smell distance before calculating arithmetic average and mapping the results in order to prevent blurring the map by fluctuation of subjects' answers. First we set a proper threshold value from 0 to 5 and divided the similarity values into the smell distance value 0 if the similarity degree value is under the threshold and the distance value 1 if it is over the threshold. We set the threshold between 3 and 4 because the similarity degree of two identical aromas is no less than 4 in 9 trials out of 10 in 3.2 Evaluation.

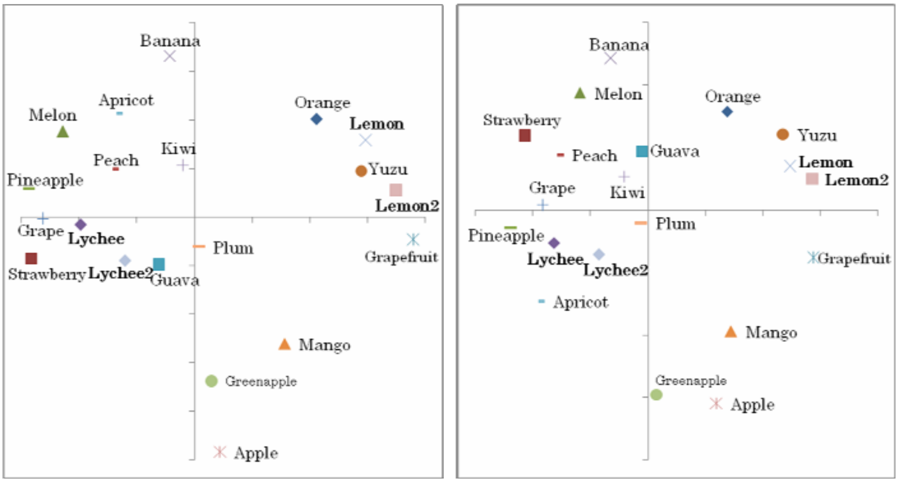

Fig. 3. (A) simple average (left), (B) binarized average (right)

On the simple average map (Fig.3.A), the scent “yuzu” was mapped between “lemon” and “lemon2” (same as lemon) and “guava” was mapped between “lychee” and “lychee2” (same as lychee). It means that the distance between different aromas is closer than the distance between the same aromas. In contrast, on the binarized average map (Fig.3.B), “lemon2” is closest to “lemon” among all aromas, and “lychee2” is closest to “lychee” among all aromas.

The binarized average method can prevent blurring among individuals and blurring between subjects more than the simple average, and suitable for the olfactory map generation. Furthermore, the generated olfactory map makes it possible to categorize aroma chemicals based on each rough character of the smell like citrus fruits and the apples, etc. There is a possibility to implement the olfactory display with which small number of representative aroma chemicals can present various smells by selecting representative aromas from each category.

4 Olfactory Display Using Olfactory Maps

If we prove that “the more similar the content of picture and the content of aroma chemicals are, the more the drawing effect is likely to happen”, we can implement a brand-new olfactory display which can render more kinds and range of smells than the number and range of a few of prepared aroma chemicals.

In this chapter, we describe the prototype of visual-olfactory display system and the experiments to evaluate the effect of the smell distance on the map to the drawing effect.

4.1 Implementation of Visual-Olfactory Display

The visual-olfactory system consists of an olfactory display and notebook PC for showing pictures and control. (Fig.4)

The olfactory display consists of the scent generator, the controller, the showing interface and PC monitor. The scent generator has four air pumps. Each pump is connected to a scent filter filled with aroma chemicals. The controller drives the air pumps in the scent generator according to the command from PC. The scent filters add scents to air from the pumps and then the showing interface ejects air nearby user's nose.

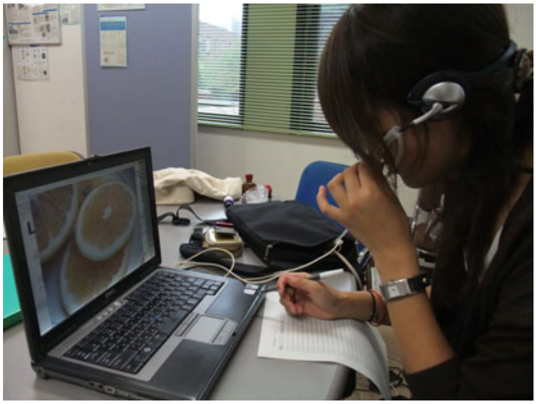

Fig. 4. Prototype system of visual-olfactory display

4.2 Evaluation of the Visual-Olfactory Display

We went on experiments to evaluate the visual-olfactory display for 7 subjects. These 7 subjects are different from subjects of the evaluation 3 in chapter 3.4 in order to prove the validness of olfactory map for people not participating to build the map.

We showed them a picture from 18-kind of pictures of fruits and an aroma from 4-kind of element aromas. The pictures of fruits correspond to 18 aroma flavors used in chapter 3 one by one. Then, we asked them, "What kind of smell you feel by sniffing the olfactory display?" We conducted the experiment in a well-ventilated large room to avoid mixing different aromas and olfactory adaptation.

The four kinds of element aromas were selected from 18-kinds of fruit used in chapter 3. First, we categorized the 18-kinds of aromas into four groups by features of scents. (Fig.5) Then we selected one scent from each group (apple, peach, lemon, lychee) so as to minimize the distance between a key aroma and each another aroma in the same category as the key aroma. Each picture was shown with the nearest key aroma.

If subjects answer that they feel the smell correspondent to the shown picture when the content of the picture and the content of the aroma are different, the drawing effect is considered to occur. Thus, we used the rate of answering the smell of the shown picture as an index of the drawing effect.

In order to prove "the more similar the content of picture and the content of aroma chemicals are, the more the drawing effect is likely to happen", we also conducted another experiment to evaluate the drawing effect between the picture and another aroma which is not closest to the content of picture. We asked subjects to answer what smell they felt when we showed them a picture and the aroma second closest to the picture. The trials were done for 9-kinds of picture. We compared the drawing effect between trials using the closest aroma and trials using the second closest aroma.

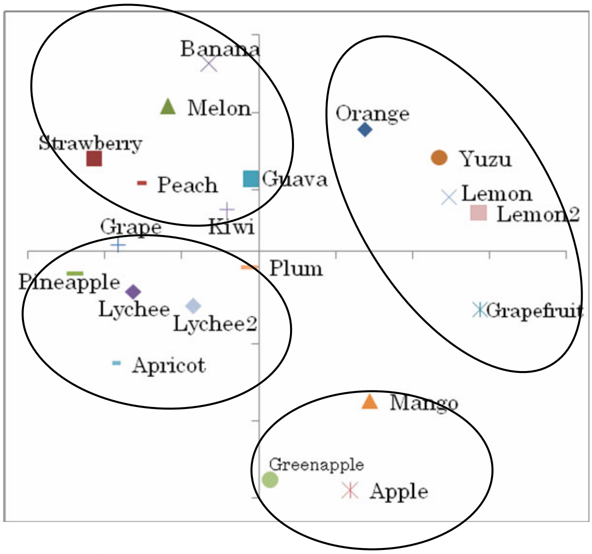

Fig. 5. Categorization of aroma chemicals

Each subject answered the scent of the picture in an average of 13 of 27 trials (36%) per person showing a picture and an aroma. This is statistically higher than the rate to answer the scent of the aroma, 11%. ($p<0.01$) The number of description of answer for 27 trials per person was as many as an average of 13 kinds although we used only four kinds of aromas.

Moreover, we compared the rate to answer that the smell is like the content of the picture by olfactory distance on the map. The rate was 44% when the picture and the aroma were close, while 27% when the picture and the aroma were distant. It means the close pair helped subjects to answer the smell influenced by the picture statistically significantly. ($p<0.01$) (Fig.6)

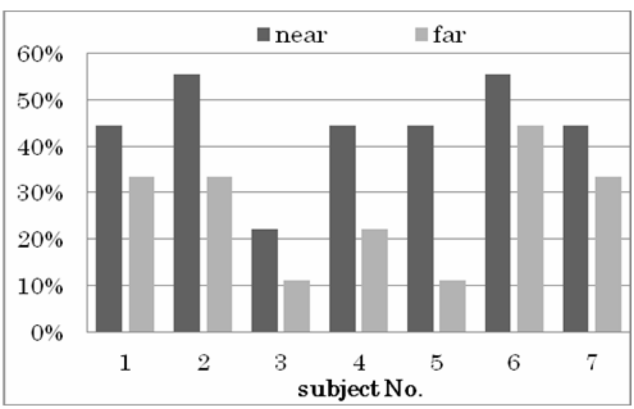

Fig. 6. Comparison by Distance

5 Conclusion

There were much more answers that it smelled corresponding to the destined image than the answer that it smelled corresponding to the aroma chemical actually presented. Besides, the kind of a free answer included many kinds of smells. These results confirmed that we can generate several times more kinds of pseudo smells than the number of prepared aroma chemicals.

In addition, the fact that a similar set of a picture and an aroma increases the rate of the drawing effect of the picture to the aroma proved the hypothesis that the closer the picture and the aroma on the olfactory map were, the stronger the drawing effect was. As well as the smell distance, positional relationship of smells in the map is available for a criterion of selecting element odors.

However, the rate answering the smell of the destined picture was 44%, which was not enough high to use the drawing effect for olfactory displays actually. This is attributed to the difficulty to identify the picture and the name by free answer. For example, guavas are not popular for Japanese subjects so that they are thought not to be able to recall the name of guavas by visual cue, and it is difficult to tell the picture of lemons and grapefruits apart.

It proved to be possible to construct the olfactory map based on olfactory sensation according to the sensory evaluation of the smell similarity of two or more people. The common olfactory map suitable for people with various olfactory sensation patterns can be used as well as the language based olfactory map. Using the common olfactory map, we achieved an olfactory display presenting various smells virtually from a few aroma chemicals. It becomes possible to achieve olfactory virtual reality with a simpler system by reducing the number of aroma sources. Moreover, it is thought to be possible to make olfactory maps among other kinds of smells like flowers or dishes as far as the smells have visual cues in order for the olfactory cue.

The technique changing smell feeling by visual sensation without changing the aroma chemicals itself makes it possible to achieve high quality olfactory VR more easily.

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