Pulse Ejection Presentation System of Odor Synchronized with the User's Breathing

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Abstract - Trials on the transmission of olfactory information together with audio/visual information are currently being conducted in the field of multimedia. However, the continuous emission of odors at high concentrations creates problems of olfactory adaptation and odors lingering in the air which do not match the changes in images over time. To overcome such problems, we applied olfactory pulse ejection to emit odor for very short periods of time. Humans perceive an odor when they breathe in and inhale smell molecules in the air. Therefore, it is important that the timing of pulse ejection is synchronized with breathing. We have developed a breath sensor which detects inspiration, and in this study, we combined the use of this breath sensor with that of an olfactory display in order to establish a pulse ejection presentation system of odor synchronized with breathing. The results of an evaluation experiment showed that the system has a more than 90% detection rate. In addition, a questionnaire survey of the users revealed that the system provides them with a continuous sense of smell, avoiding the effects of adaptation and lingering odor. The use of the developed system is expected to make easier the synchronization of olfactory information transmitted together with audio/visual information.

Keywords: Olfactory information, Olfactory display, Breath sensor, Synchronization with breathing, Pulse ejection.

1 INTRODUCTION

Information and communication via computers tends to be limited to visual information and audio information. However, in the real world, humans gather external information via the five senses of sight, hearing, touch, smell and taste, allowing them to react appropriately to local circumstances. Accordingly, the conveyance of such information and its communication via the five senses has lately attracted much attention among researchers in the field of multimedia [1]. 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 it is directly transmitted to the cerebral limbic system that governs emotions and memories [2]. Thus, olfactory information serves highly important functions in daily life.

In this study we focus on the development of an ejection control technique for odors, aiming at increasing the application of olfactory information and communication in the field of multimedia. Already in this field, trials are underway to supplement image media such as movies with odors. Any experimental system must control the odor presentation in accordance with the changing images and sounds presented to users. Existing systems have not yet overcome the problem of emitting too much odor over a continuous period, and fine control is necessary in order to avoid various problems such as olfactory adaptation and lingering odors in the air making it difficult to synchronize odors with the ever changing images and sounds.

In efforts to resolve these problems, we attempted to reduce the amount of odor emitted by using pulse ejection for a duration of just 100 msec. In general, it is known that humans can detect odors only when they inhale. So, in order to apply the pulse ejection, it is important that odor presentation is synchronized with breathing [3]. Therefore, we also developed a breath sensor that acquires breath data in real time and can detect the beginning of inspiration. We next combined the developed breath sensor with an olfactory display to create a pulse ejection presentation system of odor that was synchronized with the user's breathing. To examine the performance of this system, we carried out an evaluation experiment and a questionnaire survey with users. This paper presents details of the newly developed system and discusses the evaluation results [1].

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 [4], the first virtual reality (VR) system that presented olfactory information together with audio/visual information. The recently developed virtual space system, Friend Park [5], provides users with an increased sense of reality by generating the odor of a virtual object or environment. Kaye's article [6] describes some systems that add odor to web content, and computer controlled olfactory displays such as iSmell [7], [8] and Osmooze [9] are utilized in these systems. Another type of display, the air cannon olfactory display that generates toroidal vortices of odor in order to present it in restricted space, has been proposed in [10].

Nakamoto et al. [11] designed a smell synthesis device that presents the odor of a virtual object remotely. The system analyzes the smell to be transmitted and presents the analyzed data as the composition ratio of the odor elements. On the receiver side, a feedback control reproduces the target odor by changing the ratio of the odor elements for the receiver.

[1]This work was supported by SCOPE (the Strategic Information and Communications R&D Promotion Programme) of the Ministry of Internal Affairs and Communications in Japan.

A wearable olfactory display with a position sensor has also been developed [12]. 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 a matching database. The user can experience a real sense of smell through the system by translating obtained olfactory information.

AROMA [13] attempts 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 an odor to image media such as movies has been proposed by a number of researchers. Okada et al. [14] determined the viewer's mental state by measuring his/her brainwaves, and analyzed the relation between the odor and the viewer's feelings while watching. While a movie that supplements visual/audio information with olfactory information has been created, it could not be widely distributed because the synthetic perfume did not correspond with the changing images and the odor was not deodorized.

3 PULSE EJECTION PRESENTATION TECHNIQUE

In this study, we propose an odor presentation technique matched with the individual breathing patterns of the system users receiving the olfactory information. To control olfactory time characteristics, the effects of adaptation and lingering odor in the air must be minimized as far as possible. We therefore use pulse ejection to emit odor for just very short periods of time. Such pulse ejection enables the amount of the emitted odor to be reduced overall, and in a previous experiment, we confirmed that the odor did not remain in the vicinity of the user when presented by pulse ejection with the wind velocity above a certain level [15], thus avoiding olfactory adaption due to scents lingering in the air. Pulse ejection is defined as the olfactory ejection moment that stimulates the olfactory receptors repeatedly and transiently [16], as shown in Figure 1. By using an olfactory display which can provide a stable pulse ejection of 100 msec, we can realize high-precision emission control of odor released into the air.

When humans breathe in, smell molecules in the air are inhaled, and when a smell molecule binds to a receptor organ in the nose, we detect an odor. This is the recognition mechanism of an odor [17]. In addition, air intake in humans decreases during each inspiration [18]; Figure 2 shows we can reliably detect odors only during the early stages of inspiration. The synchronization of odor presentation with the beginning of inspiration is thus considered the most effective technique [19], especially since pulse ejection involves instantaneous odor emission, where the odor disappears almost immediately without remaining in the air.

Therefore, to ensure satisfactory recognition of odor, we have developed a pulse ejection presentation system synchronizing odor emission with the user's breathing pattern. This system consists of an olfactory display presenting pulse ejection, a breath sensor acquiring breath data in real time, and a control computer transmitting a signal for scent presentation to the olfactory display. Figure 3 shows a schematic of the developed system.

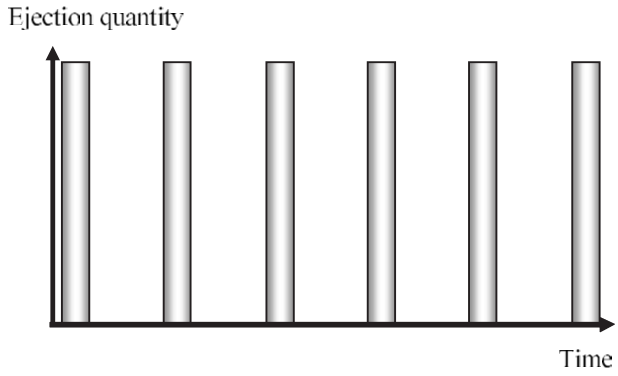

Figure 1: Presentation of bursts of odor via pulse ejection.

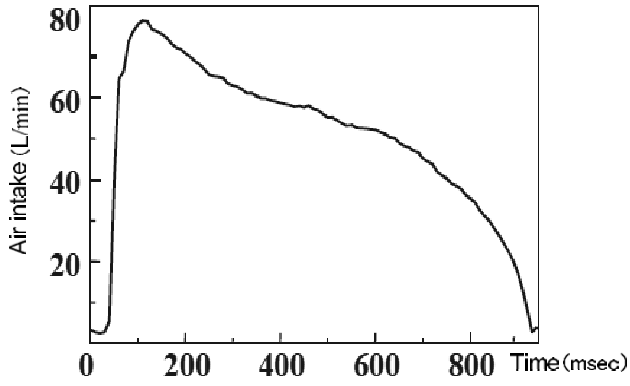

Figure 2: Change in air intake during inspiration over time.

4 OLFACTORY PRESENTATION SYSTEM

4.1 Olfactory Display

Figure 4 shows the olfactory display developed jointly with Canon Inc. used in the experiment. The inkjet display is able to produce a jet which is broken into droplets by small holes in the ink tank. As the concentration of odor emitted from the display is constant, the display adjusts the perceived strength of the odor by altering the ejection quantity. The display has the following features.

- Twelve kinds of odor tanks

  The display can utilize 3 cassettes, each of which can store one large tank and 3 small tanks, which enables the display to present, in total, 12 kinds of odors utilizing 3 large tanks and 9 small tanks.

- Olfactory ejection moment

  Ejection can be controlled for a period of 100 msec.

- Ejection quantity control: 256 phases (large tank), 128 phases (small tank)

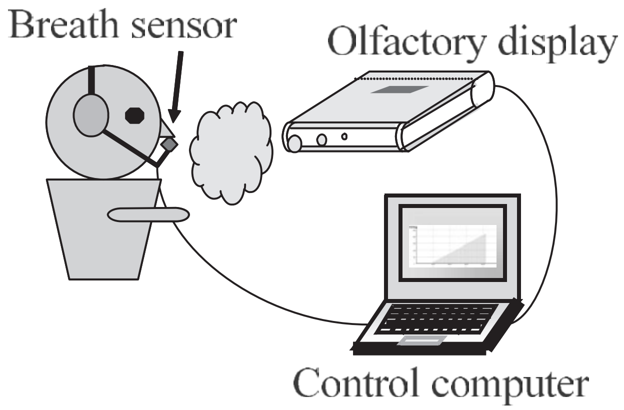

Figure 3: Pulse ejection presentation system synchronized with breathing.

Figure 4: Olfactory display.

There are 256 minute holes in the cassette connected to the large tank and 128 in the cassette connected to the small tank. The user can control the ejection quantity by changing the number of holes used.

- Wind velocity control: 10 phases

  The display is equipped with a fan that can produce 10 phases of wind velocity control in the range of 0.8 m/sec - 1.8 m/sec.

- Creation of an olfactory scenario

  The user can create a scenario in which olfactory ejection occurs multiple times and can control the amount of odor ejected by altering the tank number, quantity of ejection, ejection start time and ejection end time.

For all experiments described below, the display emitted 100 msec pulse ejections of lavender odor. The ejection quantity of the odor was set to 10, which was determined in a preliminary experiment as the value that all users could detect, of the 256 phases. Wind velocity was set to 1.8 m/sec of the display maximum.

Figure 5: Breath sensor.

4.2 Breath Sensor

To acquire breath information, we developed a breath sensor (Figure 5) which senses temperature change in air inhaled through the nose. The temperature detection element is the NTC (Negative Temperature Coefficient) thermistor which is widely used as a temperature detection element and has a negative temperature characteristic that resistance falls when temperature rises. In this study, we used the NTC thermistor [20] manufactured by Honeywell Inc. An Op-Amp amplifies each item of sensing data, an A/D converter (AMTEC Inc.) converts it to a digital signal, and the value is transferred to a computer.

The data transfer rate of the output voltage level acquired from the breath sensor is 10 sample/sec and the analysis software ”TracerDAQ” (AMTEC Inc.) records the data. Figure 6 shows a wave pattern of the recorded breath data from which the beginning of inspiration is detected. Since the temperature of the thermistor falls when air flows during inspiration, the resistance and the output voltage fall. Conversely, the output voltage rises during expiration. Thus, the timing when the wave pattern of breath data begins to fall is judged as the beginning of inspiration.

Characteristics such as breathing intervals differ from person to person, and each user must therefore calibrate the breath sensor before use.

4.3 Pulse Ejection Presentation System of Odor Synchronized with Breathing

Next we developed a pulse ejection presentation system that is synchronized with breathing. The user wearing a breath sensor sits in front of the olfactory display and is presented with odor (Figure 7). The system acquires the user’s breath data via the breath sensor and transfers the data to a control computer. The control computer runs a program to monitor breath data constantly and to detect the beginning of inspiration. At the point the program judges to be the beginning of inspiration, a signal for odor presentation is transmitted to the olfactory display, which then presents odor to the user. The above represents the process of smell presentation by the pulse ejection presentation system.

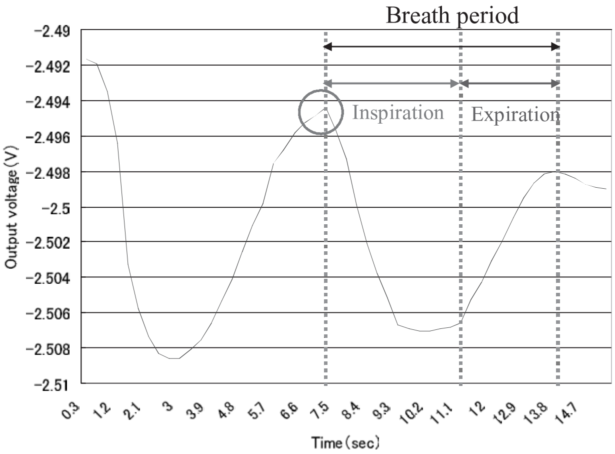

Figure 6: Breath data measured with the breath sensor.

Figure 7: User wearing the breath sensor.

5 EXPERIMENT

5.1 System Verification

To verify whether the developed pulse ejection presentation system detected inspiration and presented odor accurately, we conducted a verification experiment with 20 participants (17 males, 3 females, aged in their 20s).

In each experiment, the system monitored around 10 of the participant's breath cycles and presented lavender odor for 100 msec by pulse ejection at the beginning of each inspiration. Participants were instructed to click a mouse when they began to inhale. After the experiment, we verified the performance of the pulse ejection presentation system by comparing the timing of odor presentation as determined by the system with that of the clicking of the mouse button. Each participant performed the experiment two times.

We defined the correct detection rate and the false detection rates as follows and then calculated the rates using data obtained in the verification experiment.

$$Correct\ detection\ rate\ (\%) = NSDC \div NPI \times 100 \quad (1)$$

$$False\ detection\ rate\ (\%) = NSDW \div TNSD \times 100 \quad (2)$$

$NSDC$: $Number\ of\ times\ system\ detected\ inspiration\ correctly$
NPI : $Number\ of\ inspirations$
$NSDW$: $Number\ of\ times\ system\ detected\ inspiration\ wrongly$
$TNSD$: $Total\ number\ of\ times\ system\ detected\ inspiration$

The correct detection rate of this system was determined to be 93.9%, and the false detection rate was 11.3%. As a result, the developed system was confirmed to detect the beginning of inspiration with a probability of more than 90% and to be capable of presenting odor synchronized with breathing. The correct detection rate is able to increase close to 100%, but at present the false detection rate increases with it. Because of this increase in the false detection rate, there is wasteful ejection and an excess quantity of odor is emitted. Depending on the purpose of system usage, it will be necessary to adjust the balance between the correct detection rate and the false detection rate.

5.2 Questionnaire Survey on Feelings Regarding the Odor Presented

We provided 22 participants (16 males, 6 females, aged in their 20s to 60s) an experience of odor presentation using the developed pulse ejection presentation system, and then administered a questionnaire survey in order to determine the users' feelings about the odor presented.

In the experiment, while wearing the breath sensor, participants were exposed to lavender odor that was presented for 100 msec by pulse ejection. The odor was emitted when the system detected the beginning of inspiration and was repeated for 10 breath cycles. As the average time of each breath is 5 seconds [21], it took about one minute to complete the experiment with each participant, and the ejection time of odor was just 1 second in total. After each participant smelled the odor, he/she responded to the following questionnaire items.

Question
What did you notice about odor presented by the pulse ejection presentation system?

The answers presented for the respondent to choose from were as follows:
① Noticed it continuously
② Noticed it on every breath
③ Noticed that the strength of the odor alternated between strong and weak
④ Noticed that the strength of the odor gradually got stronger
⑤ Noticed that the strength of the odor gradually got weaker
⑥ Noticed the odor in fragments
⑦ Did not continually notice the odor

The questionnaire results are shown in Figure 8. Despite the presentation of odor by pulse ejection, many participants noticed the odor continuously (①) or on every breath (②), indicating that the system works effectively. In addition, many participants noticed the odor in fragments (⑥). We think one

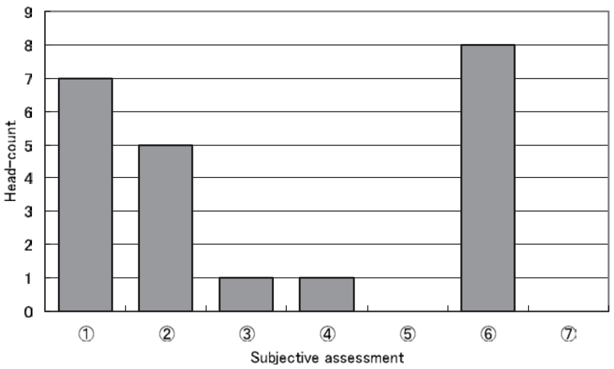

Figure 8: Questionnaire results

reason for this is that participants are not able to detect odor during expiration. Another reason is that there were cases when odor was not present because the pulse ejection presentation system likely did not accurately detect inspiration.

It should be noted that there were no participants who noticed the strength of the odor gradually got weaker (⑤) or could not continue perceiving the odor (⑦). This indicates that the presentation of pulse ejection synchronized with breathing could provide the participants with a continuous sense of smell, avoiding the effects of adaptation and lingering odor in the air at least for about one minute.

6 CONCLUSION

In the field of multimedia, trials using odor to supplement audio/visual media are being conducted and it is necessary to control the presentation of odor in order to synchronize it with changes in audio/visual information over time. However, problems of olfactory adaptation and odor remaining in air remain to be solved. To approach these problems, we developed a pulse ejection to present odor synchronized with the inspiration of the receivers of olfactory information.

Pulse ejection of odor for a very short period of 100 msec was stably presented during inspiration by combining the use of a breath sensor which could acquire breath data in real time with an olfactory display that has high emission control.

System verification experiments showed that the system could detect the beginning of inspiration with a probability of more than 90% and present odor synchronized with breathing. In addition, a questionnaire survey of users' opinion of the odor presented by the system revealed that most users could notice odor continuously or on every breath during the trials and none were considered to have been affected by adaptation and lingering odor in air.

The developed system will make the fine control of odor presentation possible, enabling further advances to be made in the transmission of olfactory information together with audio/visual information. As a result, the synchronization between media is expected to become easier.

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(Received October 3, 2008)
(Revised June 30, 2009)

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