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Projection-Based Olfactory Display with Nose Tracking

Yasuyuki Yanagida[1], Shinjiro Kawato[1], Haruo Noma[1], Akira Tomono[2,1], and Nobuji Tetsutani[1]

[1] *ATR Media Information Science Laboratories*
{yanagida | skawato | noma | tetsutani}@atr.jp

[2] *Dept. of Information Media Technology*
Tokai University
tomono@keyaki.cc.u-tokai.ac.jp

Abstract

Most attempts to realize an olfactory display have involved capturing and synthesizing the odor, processes that still pose many challenging problems. These difficulties are mainly due to the mechanism of human olfaction, in which a set of so-called "primary odors" has not been found. Instead, we focus on spatio-temporal control of odor rather than synthesizing odor itself. Many existing interactive olfactory displays simply diffuse the scent into the air, which does not provide the ability of spatio-temporal control of olfaction. Recently, however, several researchers have developed olfactory displays that inject scented air under the nose through tubes. On the analogy of visual displays, these systems correspond to head-mounted displays (HMD). These yield a solid way to achieve spatio-temporal control of olfactory space, but they require the user to wear something on his or her face. Here, we propose an unencumbering olfactory display that does not require the user to attach anything on the face. It works by projecting a clump of scented air from a location near the user's nose through free space. We also aim to display a scent to the restricted space around a specific user's nose, rather than scattering scented air by simply diffusing it into the atmosphere. To implement this concept, we used an "air cannon" that generates toroidal vortices of the scented air. We conducted a preliminary experiment to examine this method's ability to display scent to a restricted space. The results show that we could successfully display incense to the target user. Next, we constructed prototype systems. We could successfully bring the scented air to a specific user by tracking the nose position of the user and controlling the orientation of the air cannon to the user's nose.

1. Introduction

We perceive the surrounding environment by using our five senses. VR systems so far have been developed to cover visual, auditory, and haptic sensations, so it is a natural progression to incorporate olfaction into VR systems. However, there are various reasons that olfaction has been left in the backcountry of the VR research field. For example:

(1) Olfaction is activated by chemical stimuli. This is very different from visual, auditory, and haptic sensations, which are activated by physical stimuli.
(2) A set of "primary odors," *i.e.*, a small number of bases to represent arbitrary smells, has not been found.

Nevertheless, incorporating olfactory interfaces in VR systems could be effective for achieving a high level of presence [1]. Dinh *et al*. [2] found that an olfactory cue, along with auditory and tactile cues, could increase the sense of presence in virtual environments.

Olfactory sensation itself has a long history of research [3], including attempts to find a set of "primary odors." Amoore [4] categorized 7 primary odors, but later he extended this number to 20–30. Buck and Axel [5] reported at least 100 kinds of receptive proteins, based on the theory of odorant receptor proteins [6]. The number of receptor proteins is theoretically estimated to exceed 1000. Therefore, we can hardly use the same strategy adopted for visual display, by which we synthesize any color by mixing the 3 primary colors (red, green and blue). For tactile displays, recent progress has been based on the idea of selectively stimulating several kinds of mechanoreceptors [7–9]. In these visual or tactile displays, virtuality is achieved by the characteristics of receptors that can detect only a part of the target physical phenomena. If we wanted to make an olfactory display that could provide arbitrary scent based on a similar strategy, we would have to somehow control thousands of odorants.

We are not attempting to solve such an immense problem; our current focus is not on smell recording or synthesis. Instead, we focus on the spatio-temporal control of odor, assuming that the odorant itself is ready to use. There are several subtasks of recording and displaying environments by a certain sensory modality: sensing, coding, storage or transfer, decoding or rendering, and display (Figure 1). Our interest is on the final stage of display: the olfactory counterpart of HMD, CAVE [10], autostereoscopic displays [11], and so on. In contrast to visual displays, not so many olfactory "displays" have been developed so far. Many scent blenders simply diffuse the rendered scent into the air, and these are regarded as counterparts to (controllable) illumination. Some researchers have developed olfactory displays that transfer the scented air through tubes to the nose, to

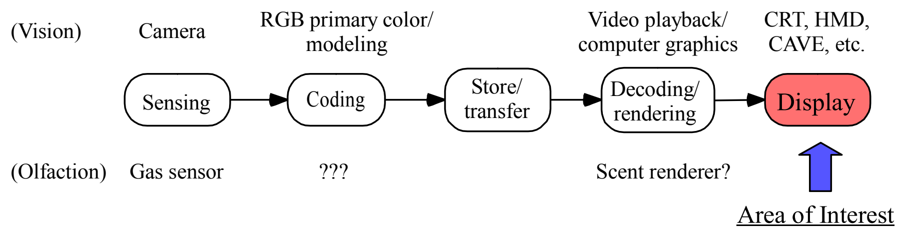

Figure 1. Subtasks in sensory recording and display.

enable interactive control of odor in accordance with the position and orientation of the user's head. These are considered to be counterparts to head-mounted displays (HMD). However, there have been no olfactory counterparts to projection-based displays and autostereoscopic displays.

In this paper, we propose a novel configuration of an olfactory display that can be considered a counterpart to projection-based displays or autostereoscopic displays. The key concept is to deliver the scented air from a location near the user's nose through free space. Users are not required to wear anything on the face, but it is still possible to switch among different scents within a short period and to limit the region in which the user can detect the scent. Among several technical challenges, we focus on how to deliver scented air to the user's nose. Here, we use an "air cannon," which is often introduced in science demonstrations.

2. Related Work

An early approach to incorporating smell with other kinds of displays can be found in Heilig's Sensorama developed in 1962 [12, 13]. People could enjoy multimodal movies through breezes and smells as well as through pictures and sounds, although it was not interactive. There have also been some entertainment attractions using scent; for example, McCarthy developed a scent-emitting system called "Smellitzer" [14], which is used in Disney World. Smellitzer could emit the selected scent and produce a sequence of various kinds of smells.

Some researchers have already started to explore the possibility of olfactory displays in the context of "record and playback." Davide *et al*. [15] discussed electronic noses and virtual olfactory displays. NASA JPL has been conducting active research and development on electronic noses [16]. Nakamoto *et al*. [17] has been developing odor sensors and blending systems, called the "odor recorder." These research works mainly focus on how to sense, code and reproduce the scent, and they are very challenging projects that need continuous development. As mentioned above, these approaches are beyond the scope of our research.

In terms of spatio-temporal control of olfactory space, most display devices that focus on scent synthesis or blending simply diffuse or spray the resultant odorants. In contrast to visual displays, this style could be regarded as a counterpart to illumination that provides background smell (analogous to colored light). There are also other interactive scent emitters; for example, Kaye [18] produced several computer-controlled olfactory interfaces in the context of Ambient Media. A company called DigiScents announced computer-controlled scent diffusers, called "iSmell" (unfortunately, their business has not been successful). Göbel [19] introduced an olfactory interface to a CAVE-like visual display. However, these works do not attempt spatio-temporal control in olfactory displays. One of the demerits of simple diffusers is that it is difficult to dissipate the previous scent once it is diffused into the air. This makes it difficult to switch or change the scent within a short period in accordance with the progress of a scenario or the context of interactive applications.

Recently, more VR-oriented olfactory interfaces have been developed to control the scent according to the user's location and posture. Cater [20, 21] developed a wearable olfactory display system for firefighter training simulation. In Japan, Hirose *et al.* [22, 23] developed several head-mounted olfactory displays, including a scent generation and blending mechanism controlled by computer. They recently developed a wearable olfactory display system [24] to allow users to move freely in the space. In these display systems, scented air was sent to the nose through a tube. The counterpart to these olfactory interfaces in visual display is, of course, HMD.

3. System Concept

The HMD-type olfactory display is a reliable way to realize spatio-temporal control of olfaction, but the user generally experiences an encumbrance in wearing a mask or moving while attached to a tube. In addition, blocking one's face with some device may not be suitable for bidirectional telecommunications. There is demand for a system to provide users with the ability to enjoy scent without wearing encumbering and obtrusive devices on the face, just as some researchers are trying to develop the

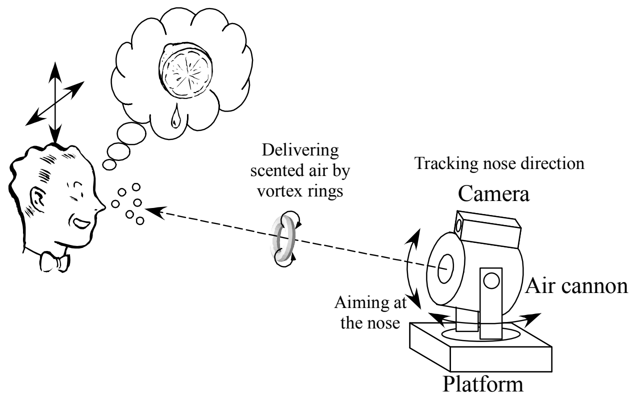

Figure 2. Concept of projection-based olfactory display.

ultimate autostereoscopic visual display. Our approach is to develop a new kind of spatio-temporally controllable olfactory display with fewer encumbrances.

Hence, our goal is to develop an olfactory display with the following characteristics:

- *Unencumbering*. Users do not need to wear any devices or glasses. This is not only for users' convenience but also for application to bidirectional telecommunications.
- *Localized*. Scent should be perceived only within a limited range of space and at a certain time. By localizing the scent, we can display different smells to multiple users. Also, we can significantly reduce the amount of (often expensive) odorant compared with simply diffusing the scent into an entire room, as the volume of the air sustaining the odorant is so small. The system can thus be relatively cost-effective. In addition, this small clump of scented air can easily dissipate in a short time, which enables us to wield short-term control of the olfactory effect.

To achieve an olfactory display with these features, we need to deliver a clump of scented air from a position near the nose through free space. We have explored the possibility of using an "air cannon" for this purpose. Here, we overview the entire system design. How we use the air cannon is described later.

The entire system (Figure 2) is composed of the following components:

- Nose tracker
- Air cannon platform
- Air cannon
- Scent generator

First, we have to detect the position of the user's nose. For this purpose, popular head tracking technologies such as magnetic trackers or mechanical trackers can be used. Here, however, we again prefer methods that do not

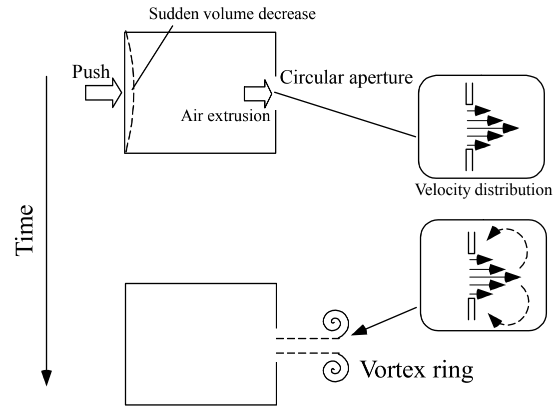

Figure 3. An air cannon generating a vortex ring.

require the user to wear anything; therefore, computer-vision-based face tracking would be the most suitable approach. Once the location of a part of the head/face is measured, it is easy to calculate the position of the nose.

Next, the platform on which the air cannon is mounted is controlled so that we can aim at the user's nose. Two degrees-of-freedom angles (azimuth and elevation) are controlled to determine the direction of the air cannon. It is not necessary for the scent generator to fill the chamber with scented air—it only has to spray the scent just before the air cannon launches a clump of air. Thus we can send a different scent with each launch and cover multiple users with a single air cannon.

An air cannon (also known as a vortex cannon) is a chamber with a circular aperture, and it is very popular in science demonstrations for children. The simplest way to make an air cannon is to use a cardboard box, cutting out a hole and sealing the seams with packing tape. If we use a box whose dimensions are 30 cm by 20 cm by 20 cm with a hole of approximately 5 cm in diameter and hit it hard, a clump of air reaches 5-10 m as if it were an invisible bullet. If we fill the box with smoke and push it more gently, we observe a smoke ring moving smoothly forward. The speed of the smoke ring is approximately 50 cm to several meters per second. This ring demonstrates a toroidal vortex (vortex ring) generated by the air cannon, and it shows that the vortex can carry particles that exist around the aperture when the air cannon launches the air. The schematic of an air cannon and a toroidal vortex is shown in Figure 3.

It is said that this vortex ring occurs because of the difference in velocity at the edge (slow) and the center (fast) of the aperture. The pressure at the center of the vortex (ring shape) is kept low so that the vortex keeps its shape for a while. The size of the vortex depends on the aperture size, while the speed and reaching distance of the vortex path depends on the velocity profile of the pushing

Figure 4. A smoke ring launched from an air cannon.

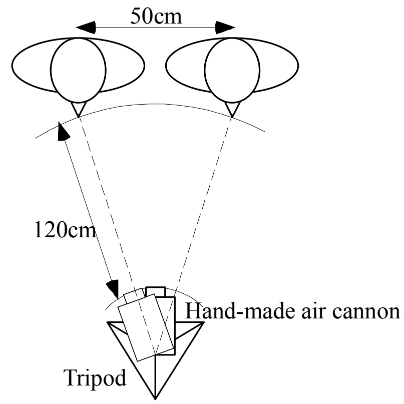

Figure 5. Arrangement of the preliminary experiment.

motion and the size parameters of the chamber and aperture.

4. Preliminary Experiment

We conducted a preliminary experiment [25] to examine whether an unencumbering, localized olfactory display is feasible by the proposed method.

We determined the size parameters of the air cannon experimentally. To make the trial-and-error process easy, we made air cannons from PET bottles and rubber balloons. We cut off the bottom of the bottle and covered it with a part of the rubber balloon. We also cut off the neck of the bottle so that we could attach various aperture sizes. We tested the combination of several sizes of PET bottles and several aperture diameters and found that the vortex ring travels most stably when we used a bottle with a 2-liter volume and a 2.5-cm aperture diameter. Using this configuration, the vortex ring traveled up to 4 meters without breaking its shape and approximately 2 meters on average.

We filled the bottle with the smoke of a *senko* (Japanese incense stick) to observe the aspect of launched toroidal vortices, as well as to use it as a kind of odorant. Though it was not necessary to fill the bottle with smoke in advance, it was useful to do so in order to observe the smoke ring clearly (Figure 4).

The purpose of this preliminary experiment was to test the following questions:

- How stably can an air cannon provide scent to the user from a remote place?
- Is it possible to display scents separately to users arranged in a side-by-side configuration?

Figure 5 shows the arrangement of the experiment. Two subjects were asked to sit on chairs side-by-side, and the air cannon was placed on a tripod 120 cm from the subjects. The distance between the noses of the two subjects was 50 cm. Subjects were asked to close their eyes during the experiment and to raise their hands if they detected a smell. The air cannon was set to aim at the two subjects and at other places in random order each time it launched a smoke ring.

There were 59 trials in total, including several miss hits. The number of successful hits, *i.e.*, trials where the smoke ring reached the correct target area (face of either subject, right and left sides, and between the two subjects) was 48. Accordingly, the successful hit ratio was 81%. A failed trial means that the smoke ring disappeared before reaching the subjects' face or it trailed off to pass outside the face region. Among the successful hits, in 9 trials the air cannon was aimed at non-subject targets; therefore, the number of hits to either of the subjects was 39: 17 for subject A and 22 for subject B. Subject A detected the smell 13 times out of the 17 successful hits, and this rate was 15 out of 22 for subject B. Therefore, the successful detection rate was 76% for subject A, 68% for subject B, and 71% in total. There was no trial in which either subject reported the smell when the smoke hit a different target, including the point between the two subjects. Among the successful hits to the face, the smoke reached the forehead in 8 trials, and of these the subject reported the smell only 1 time. Therefore, 27 detections of smell were reported out of 31 hits, if we exclude the case of the smoke reaching the forehead, which results in an 87% (92% for A and 82% for B) success rate of smell detection. This can be regarded as a very high rate, which shows that the proposed method has the potential to stably display scent to a particular user.

5. Prototype Systems

After confirming the possibility of realizing a spatio-temporally localized olfactory display, we constructed prototype systems. First, we made an air cannon unit and then, based on this prototype, constructed a comprehensive system as a second prototype.

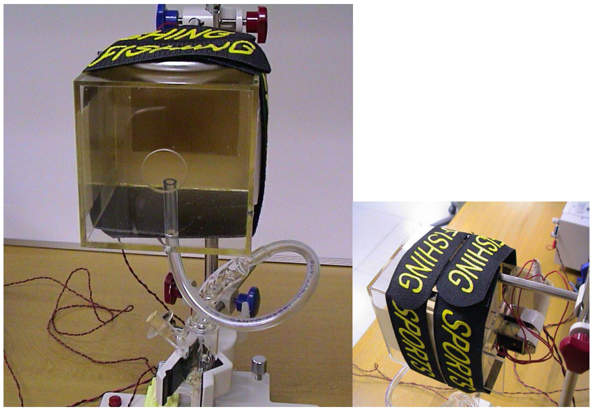

Figure 6. First prototype of air cannon unit.

5.1 First Prototype

The first prototype was simply an elementary electro-mechanically-driven air cannon equipped with a scent generator (Figure 6). We used an acrylic box with a size of 10 cm cubed. An aperture of 2.5 cm in diameter was made on the front pane, and the backside was covered with a rubber membrane. The rubber membrane was impacted by two solenoids in parallel.

We used a commercially available scent diffuser, the "Hippocampe" of Jacques G. Paltz, as the scent generator, with the air pump replaced by the Enomoto Micro Pump CM-15-6. Hippocampe is a scent diffuser that generates a fine mist of essential oils. We injected the scented air near the aperture so that the injected air could be immediately launched from the aperture.

Using this first prototype unit, we could display the scent to a restricted area approximately 1 m away from the air cannon. The scent was recognized only by the target user, who sat in front of the air cannon, and not by other people in the experiment room.

5.2 Second Prototype

We added a nose-tracking feature in the second prototype system [26]. The system consists of a camera, an air cannon, a 2-degrees-of-freedom platform to hold the air cannon, a set of control circuits, and a personal computer for vision-based nose tracking and platform control. The system configuration is shown in Figure 7, and a full view of the system is shown in Figure 8.

A vision-based nose tracker was used to detect and track the target user's nose position. Generally speaking, we can use any kind of existing tracker, but we selected a vision-based method to maximize the proposed concept's encumbrance-free characteristic. We applied a nose tracker based on an eye tracker developed by Kawato *et al.* [27]. There is usually a highlight pattern at the tip of the nose, and this characteristic can be used to track the

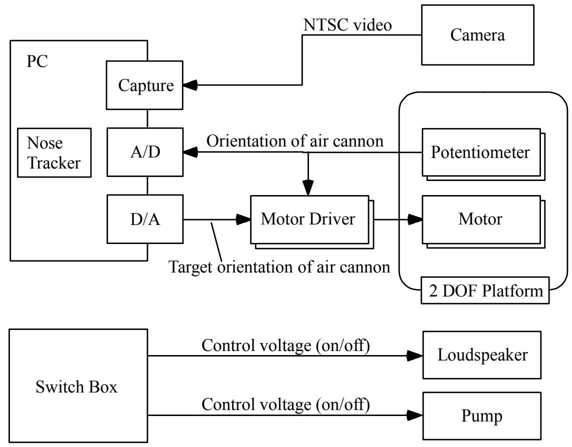

Figure 7. Block diagram of the second prototype System.

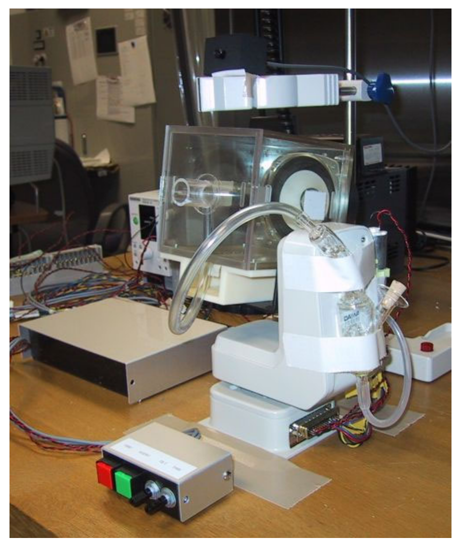

Figure 8. Second prototype system with nose tracking function.

nose. After detecting the positions of both eyes, the nose position was detected by searching for the brightest spot within the estimated region in which the nose exists. Once the nose position was detected, the system traces the nose position by template matching and finding the brightest spot (Figure 9).

We used an ELMO QN42H micro CCD camera for image capturing. The camera was placed just above the air cannon. The video image was captured with a Bt878-compliant video capture board installed in a PC/AT compatible PC (DELL Workstation, Intel Xeon 2 GHz dual) running RedHat Linux 8.0. The nose tracker could trace the nose position at video rate, *i.e.*, 30 times per second.

The detected nose position was then converted to the desired orientation of the air cannon, which is fed to the

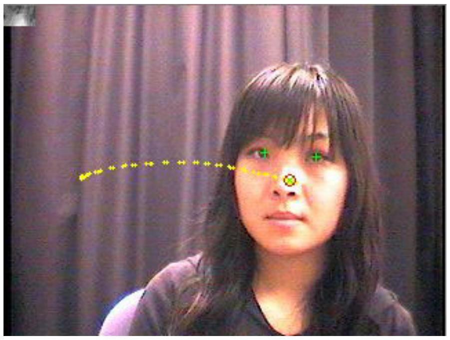

Figure 9. Vision-based nose tracker used in the system.

motor driver (TITECH Driver JW-143-2). The platform (DAIWA ATP-3DCP II) that carries the air cannon has 2 degrees of freedom (pan and tilt) and is equipped with a DC motor and a potentiometer for each axis. The rotation speed was 60 degrees per second for pan and 7.5 degrees per second for tilt when driven at the rated control voltage (12 volts). The outputs of the potentiometers are used for position control at the motor drivers. With this configuration, the air cannon could continuously trace the nose of the seated user, even if he/she moved the upper body.

The design of the air cannon in the second prototype system is nearly equivalent to that of the first prototype, except that the driving unit replaced the loudspeaker used (Fostex FF85K). This change was intended to suppress the sound when the solenoids impacted the plate attached to the rubber membrane. The scent generator was also the same as that used in the first prototype. The operator activates the scent generator before he or she launches the clump of scented air.

5.3 Third Prototype

We incorporated a scent switching mechanism in the third prototype system. In the previous prototypes, scented air was injected into the body of air cannon, in order to steadily compose the vortex ring with scented air. With this configuration, however, we could present only a single kind of scent to the user because some portion of scented air diffused into the air cannon body, where it was difficult to eliminate previously injected scent.

To solve this problem, we attached a short cylinder with the same diameter as the aperture of the air cannon and equipped with mechanical shutters at both ends (Figure 10). There are five holes on the surface of the cylinder for air-intake and evacuation. A tube is connected to each hole, through an air valve, to a pump. We used 4 holes for scent injection and one for evacuation. There is also a valve on the body of the air cannon for intake of fresh (non-scented) air.

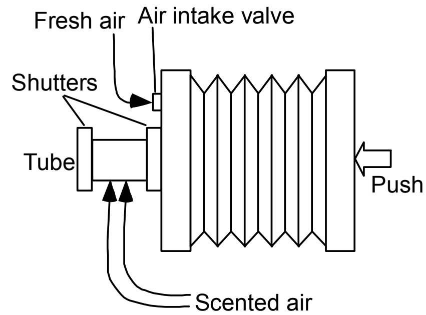

Figure 10. Scent switching mechanism.

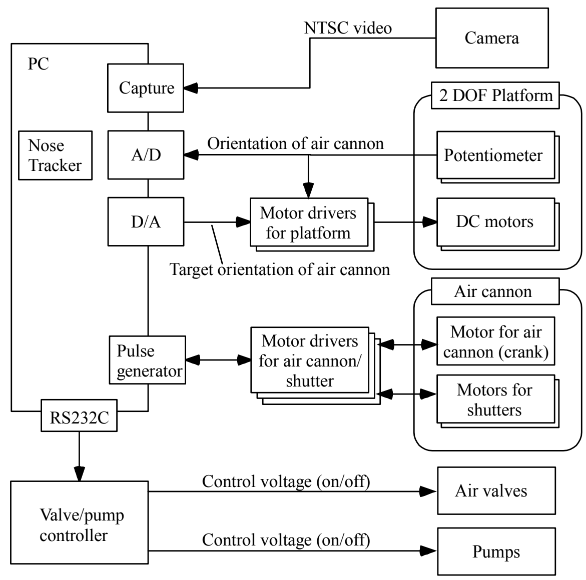

Figure 11. Block diagram of the third prototype system.

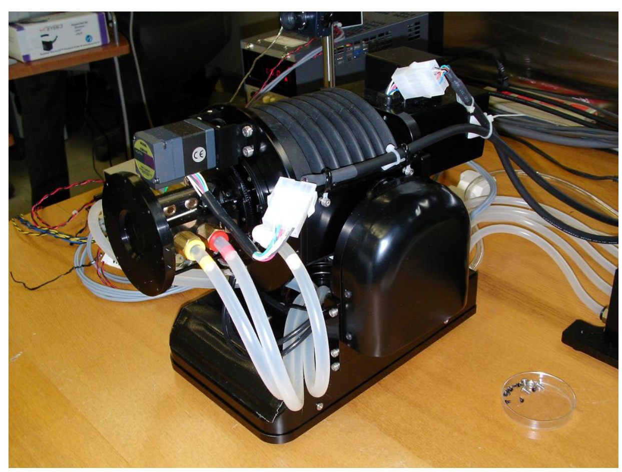

Figure 12. Third prototype system with scent switching function.

The body of the air cannon is composed of a bellows so that it can generate a larger volume change for its entire size. This design is based on our experimental study on the air cannon design [28], showing that the maximum transfer distance of vortex rings are mainly affected by the size of aperture and the profile of volume change but less affected by the total volume of the air cannon itself. A stepping motor was used to drive the crank for pushing the bellows.

This system is also equipped with a 2-DOF platform (custom made) and a CCD camera (Keyence CK-200, 0.25 mega pixels). The pumps and valves are controlled through controller units that communicate with the PC (as described above) through an RS-232C communication line. The system configuration is shown in Figure 11, and a full view of the system is shown in Figure 12.

The procedure of launching the vortex ring is as follows:

1. Close the shutters at both ends of the cylinder.
2. Open one injection valve and an evacuation valve, drive the pumps, and intake scented air into the cylinder.
3. Close the valves and open the shutters.
4. "Fire" the air cannon (push the back of the bellows).
5. Close the shutters and open the valve at the body.
6. Recover the condition of the bellows.
7. Close the valve at the body.

We demonstrated this system at the ATR Research Expo held on November 6 and 7, 2003. We arranged two kinds of fragrance (orange and mint) generated by a scent diffuser (Hippocampe, as mentioned above) as well as an offensive smell (ammonia: just stored in a container). We succeeded in delivering different smells with each shot of the air cannon. Most visitors could tell the differences between these odors, and they showed distinct reactions when we shot ammonia. However, we found several problems through this demonstration.

- The density of the fragrance was not sufficient for perfect distinction.
- The temporal duration in which users could detect the smell was so short that they could not find any smell if they exhaled when a scented vortex ring reached their nose.
- Though the system could switch the scent, a continuous use caused a slight mixture of odors, since the scent adhered to the inner wall of the cylinder.

These problems indicate the future work that we must accomplish to improve the system.

6. Conclusions and Future Work

We proposed a novel configuration of an olfactory display that does not require users to put anything on the face and that localizes the effective space of the displayed scent. The technical key to realizing this concept is to transfer a clump of scented air from a place near the nose, and we confirmed that this is possible by using an air cannon. The constructed prototype system successfully displayed the scent to the target user, even if the user moved his or her head.

We do not claim that the proposed method is superior to HMD-style olfactory displays in terms of the performance of spatio-temporal controllability. Rather, we would like to present another choice in methods to enjoy scent in interactive applications. We believe that the wider the variety of olfactory displays, the wider the variety of applications will emerge to make our VR experience rich and realistic.

So far we have focused on developing a method of delivering scented air, but many problems remain. Improvement of scent generation is necessary to extend the variety of displayed scent, and we can learn a lot from preceding research efforts on scent blending and generation. Also, precise theoretical analysis of a toroidal vortex might be effective for optimal design of the air cannon. We plan to solve these problems step-by-step in order to construct a transparent, easy-to-use olfactory display system.

Acknowledgement

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