Integrating a projection-based olfactory display with interactive audio-visual contents

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Abstract

Recently, olfactory interfaces, in addition to visual, auditory, and haptic interfaces, have been examined to enhance the sensation of presence for virtual reality. We have proposed the concept of "projection-based olfactory display" and have developed several prototype systems to realize this concept. A projection-based olfactory display applies the principle of vortex rings launched from an air cannon to deliver a small amount of scented air through free space from a nearby location to the user's nose. The characteristics of projection-based olfactory displays offer strong potential in combination with traditional TV sets and desktop PC environments at home. In our latest prototype system, we implemented cartridge-type units to store the scent source and generate scented air of specific content. This approach allows users to freely choose among scent contents by simply replacing the cartridge. We also developed an interactive application that integrates our olfactory display with game-like, interactive audio-visual content.

1 Introduction

Smells can often be a key to remembering one's experience. VR systems have so far been developed to elicit visual, auditory, and haptic sensations, so it is a natural progression to incorporate olfaction into VR systems. Incorporating olfactory interfaces in VR systems could be an effective way to achieve a high level of presence (Barfield & Danas, 1996; Dinh, Walker, Hodges, Song, & Kobayashi, 1999).

Most attempts to realize an olfactory display have involved capturing and synthesizing the odor, but these processes still pose many challenging problems. These difficulties are mainly due to the mechanism of human olfaction, for which no set of "primary odors" has yet 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 allow the 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 a device on his or her face.

We have proposed a novel configuration of an olfactory display that can be considered a counterpart to projection-based visual displays. The key concept is to deliver 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. To implement this concept, we used an "air cannon" to generate a vortex ring of scented air (Yanagida, Noma, Tetsutani & Tomono, 2003). We constructed and tested prototype systems, and eventually one of them could successfully propel 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. We named the implemented system "Scent Projector."

In order to use Scent Projector for enhancing audio-visual contents with an olfactory experience, a few modifications were required. First, we had to make the set of smell sources interchangeable, so that users could set the appropriate smell source corresponding to the audio-visual program. Second, we had to devise a method for aligning the timing of the smell exposure with the scene in the content that requires that smell. This paper describes attempts to solve the former problem.

2 Related Work

An early approach to incorporating smell with other kinds of displays can be found in Heilig's Sensorama, developed around 1960 (Heilig 1962; Heilig, 1992). 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" (McCarthy, 1974), which could emit the selected scent and produce a sequence of various kinds of smells. Jaidka patented a movie system that produced special effects including olfactory experience (Jaidka, 2000).

Some researchers have already started to explore the possibility of olfactory displays in the context of "record and playback." Davide *et al*. discussed electronic noses and virtual olfactory displays (Davide, Holmberg & Lundström, 2001). NASA JPL has been conducting research and development on electronic noses (Ryan 2001). Nakamoto *et al*. developed odor sensors and blending systems, called the "odor recorder" (Nakamoto & Hiramatsu, 2002). These research works mainly focus on how to sense, code, and reproduce 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 produced odorants. In contrast to visual displays, this style could be regarded as a counterpart to illumination, in that the provided background smell is analogous to colored light. Among the other interactive scent emitters so far developed, Kaye produced several computer-controlled olfactory interfaces in the context of Ambient Media (Kaye, 2001; Kaye, 2004). A company called DigiScents announced computer-controlled scent diffusers, called "iSmell," and Göbel introduced an olfactory interface in a cylindrical immersive visual display (Göbel, 2002). However, these works do not attempt spatio-temporal control in olfactory display. One of the demerits of simple diffusers is that it is difficult to dissipate a scent once it is diffused in the air. This makes it difficult to switch or change the scent within a short period in correspondence with the progress of a scenario or the context of interactive applications.

Recently, more VR-oriented olfactory interfaces have been developed to control scent according to the user's location and posture. Cater developed a wearable olfactory display system for firefighter training simulation (Cater, 1992; Cater, 1994). In Japan, Hirose *et al*. developed several head-mounted olfactory displays, including a scent generation and blending mechanism controlled by computer (Hirose, Tanikawa & Ishida, 1997, Hirose, Tanikawa, Tanaka & Sakikawa, 2000). They recently developed a wearable olfactory display system (Yokoyama, Tanikawa, Hirota & Hirose, 2003) to allow users to move freely in a 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. Mochizuki *et al*. developed an arm-worn olfactory display, focusing on the human behavior of grasping a target object, bringing it to the nose, and sniffing (Mochizuki *et al*., 2004). Several other olfactory displays are also introduced in the article by Washburn *et al*. (Washburn & Jones, 2004). These olfactory displays realized interactive use of smell, but many of them were "tethered" interfaces that required the users to attach a special device on the face, arm, or some other parts of the body. Many people would reject the idea of wearing such equipment in order to incorporate an olfactory effect in existing systems, especially when they are primarily enjoying ordinary audio-visual contents.

Haque constructed "Scents of Space," an interactive smell system (Haque, 2004). This system delivers smell by a slow movement of layered wind. This was a huge system larger than a room that included a wall-sized scent-generating matrix and an exhaust fan.

3 System Concept

The goal of our research is to provide an unencumbering (untethered), but still spatio-temporally controllable olfactory display. The key concept is that the system should emit only a small amount of odor so that no special exhaust facility is required. We examined ways to deliver scented air to one's nose through free space and found that "air cannons" could be used for this purpose by delivering scented air through vortex rings.

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 cut out a hole in a cardboard box and seal 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, hitting it hard produces a clump of air reaching 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. 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. This vortex ring occurs due to 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 maintains its shape for a while. The size of the vortex depends on the aperture size, while the speed and reached distance of the vortex path depend on the volume of the air pushed out of the aperture, the velocity profile of the pushing motion, and the size parameters of the aperture.

By using an air cannon, we can construct a scent-emitting system that delivers scents to the user locally, both temporally and spatially. The system is composed of a nose tracker, an air cannon, a pan-tilt platform that carries the air cannon, and a scent generator (Figure 1).

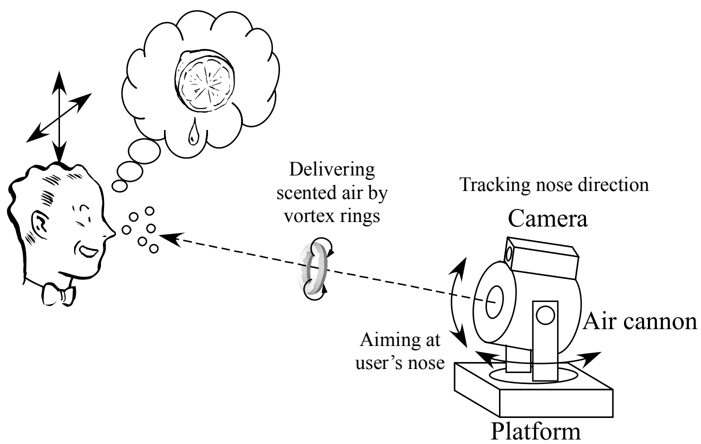


Figure 1: Concept of projection-based olfactory display.

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. However, we again prefer methods that do not 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. Movement in two degrees of freedom (pan and tilt) is controlled to determine the direction of the air cannon (Yanagida, Kawato, Noma, Tomono & Tetsutani, 2003). In order to deliver different kinds of smell in each shot of the air cannon, we should not fill the body of the air cannon with scented air—we need to load the scented air just before the air cannon launches a clump of air. For this purpose, we designed a novel scent-switching mechanism for our Scent Projector (Yanagida, Kawato, Noma, Tomono & Tetsutani, 2004).

Although we independently came upon the idea of using air cannons for local scent delivery, we found that we were not the first to work with this basic idea. Previously, MicroScents patented the basic configuration of using air cannons to launch scented air (Watkins, 2002). However, they simply filled the chamber of an air cannon with scented air, and thus they cannot launch different kinds of smells within a short time.

4 System Hardware

The system hardware consists of an air cannon unit carried on a two-degree-of-freedom (2-DOF) platform, a video camera, a scent generator subsystem, and a personal computer for controlling the system. We recently implemented an aroma cartridge as a component of the scent generator subsystem. A block diagram of the entire system is shown in Figure 2.

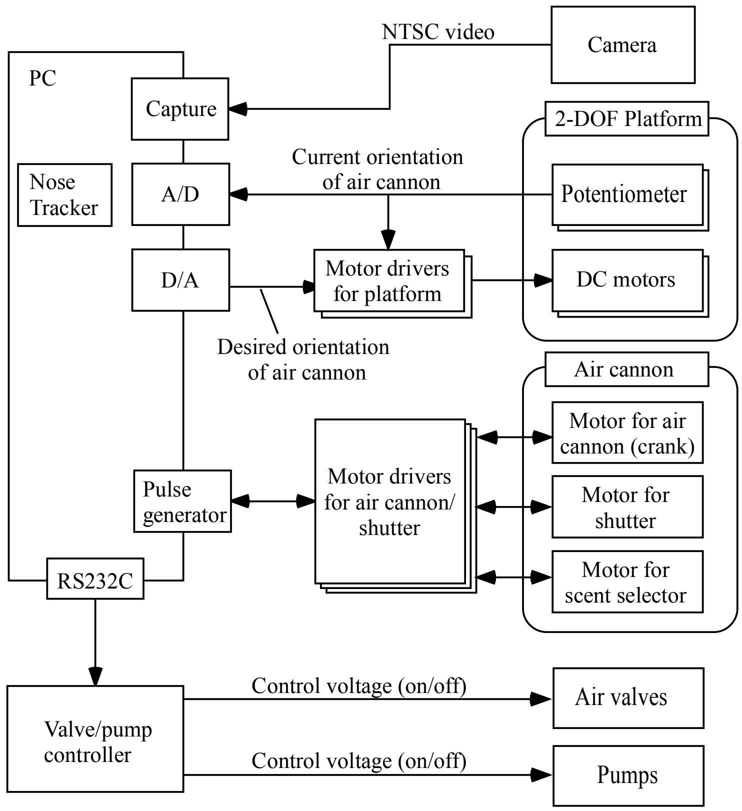


Figure 2: Block diagram of Scent Projector hardware.

4.1 Air cannon unit with platform

The air cannon unit, the main body of the system, is shown in Figure 3. The body of the air cannon is a bellows, made of rubber, so that it can generate a larger volume change for its entire size. This design is based on our experimental study of air cannons (Yu, Yanagida, Kawato & Tetsutani, 2003), showing that the maximum transfer distance of vortex rings is mainly affected by the size of aperture and the profile of the volume change but less affected by the total volume of the air cannon itself. A stepping motor (Oriental Motor ASC-34AK) 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 (Sony CCD-PC1). The pumps and valves are controlled through controller units that communicate with the PC (DELL Workstation, Intel Xeon 2 GHz dual, RedHat Linux 8.0) through an RS-232C communication line.

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.* (Kawato & Tetsutani, 2002). There is usually a highlight pattern at the tip of the nose, and this characteristic can be used to track the 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 4). 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 data representing the desired orientation of the air cannon, which were fed to the motor driver (TITECH Driver JW-143-2). The platform that carries the air cannon has two degrees of freedom (pan and tilt) and is equipped with a DC motor and a potentiometer for each axis. With this configuration, the air cannon could continuously trace the nose of the seated user, even if he/she moved the upper body.

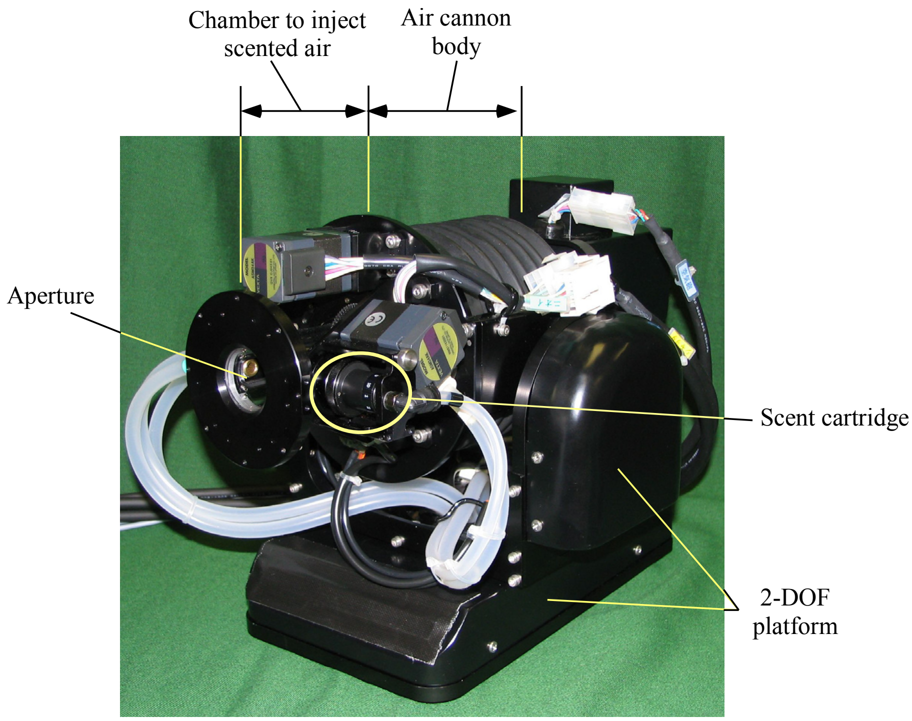


Figure 3: Air cannon unit with a pan-tilt platform.

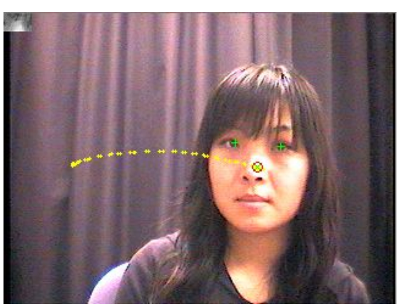


Figure 4: Vision-based nose tracking.

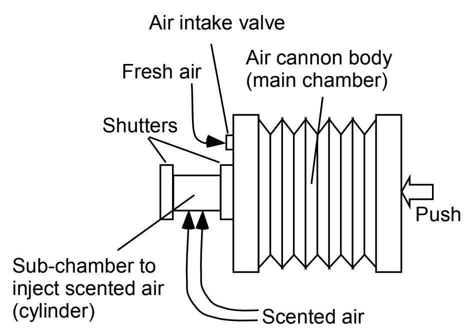


Figure 5: Mechanism for scent-switching.

The scent-switching mechanism (Yanagida, Kawato, Noma, Tomono & Tetsutani, 2004) is a unique feature of our Scent Projector. In our previous prototypes, scented air was injected into the body of the air cannon (main chamber) so that the vortex ring is steadily composed of scented air. With this configuration, however, we could present only a single kind of scent to the user because significant amount of the scented air diffused into the air cannon's body, and it was difficult to eliminate this remaining portion of the previously injected scent. To solve this problem, we attached a short cylinder with the same diameter as the aperture of the air cannon (sub-chamber) and equipped it with mechanical shutters at both ends (Figure 5). Scented air is injected into the sub-chamber, and there is a valve to intake fresh air into the main chamber.

The procedure of launching the vortex ring is as follows:

1. Close the shutters at both ends of the sub-chamber.
2. Open one of the injection valves and an evacuation valve, drive the pumps, and intake scented air into the sub-chamber.
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 fresh-air intake valve on the cannon’s body.
6. Recover the condition of the bellows.
7. Close the fresh-air intake valve on the body.

By following this procedure, we can push the scented air injected in the sub-chamber almost completely out of the air cannon in order to inject a different smell into the sub-chamber for the next shot.

4.2 Scent generator

In our previous prototype system, scented air was generated by commercial aroma diffusers (Hippocampe by Jaques G. Paltz) and simple containers with a piece of cotton moistened by aroma oil or other smell sources in liquid form. There were five holes on the surface of the sub-chamber of the air cannon for air intake and evacuation. A tube was connected to each hole, through an air valve, to a pump. We used four holes for scent injection and one for evacuation.

With this configuration, it was difficult to exchange particular smells in correspondence with the contents. To solve this problem, we implemented cartridges to produce scented air. Scent cartridges are in the form of a lotus root (or revolver), which has through-holes parallel to the axis of the cylinder. This form was proposed by Aoki *et al*. for the compact aroma diffuser prototype at EPSON (Aoki & Sakagami, 2004). The cartridge is attached to the side surface of the air cannon’s sub-chamber. To select the target smell, these scent cartridges are rotated so that the through-hole of the cartridge containing the smell source is aligned with the hole on the surface of the sub-chamber. At the same time, the other end of the through-hole of the cartridge is aligned with a tube that provides fresh air from a pump. The fresh air becomes scented air while going through the through-hole of the cartridge before being injected into the sub-chamber. The target smell can be set within approximately 0.2 seconds, which is much shorter than the time required to fill the sub-chamber with the selected smell. The current configuration of the scent generator subsystem is shown in Figure 6.

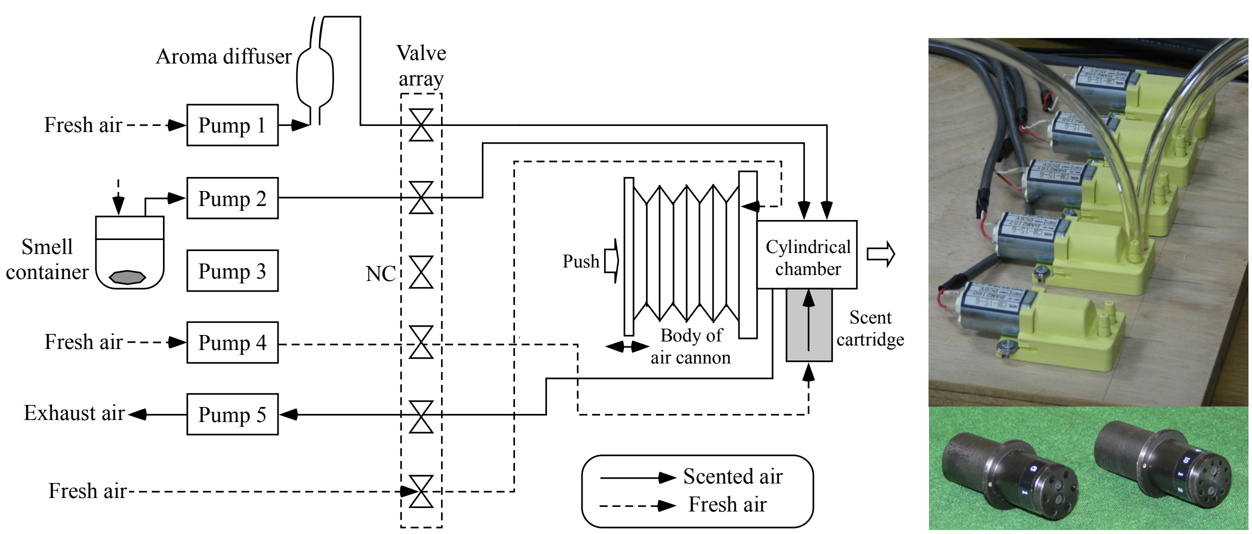


Figure 6: Scent generator subsystem for Scent Projector. Left: current configuration of the air system; upper-right: pump array; lower-right: scent cartridges (left: 6 scents, right: 10 scents).

5 Software

5.1 Software configuration

The software configuration is shown in Figure 7. The scent projector hardware is connected to a PC (PC1 in Figure 7) running RedHat Linux 8.0 (kernel version 2.4.18-14smp). The hardware of the Scent Projector is controlled by a controller process through I/O interfaces. The controller process refers to shared memory, where the nose tracking process and other processes write commands to drive the Scent Projector system. When the controller process is invoked, the "nose tracker/control GUI" process is executed as well so that the user can directly control the system (Figure 8). Other processes are optional, and these add game-like interaction between the user and the system.

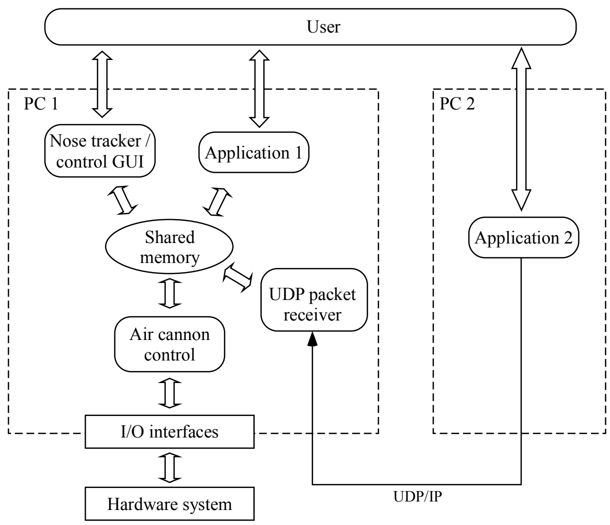


Figure 7: Configuration of software modules.

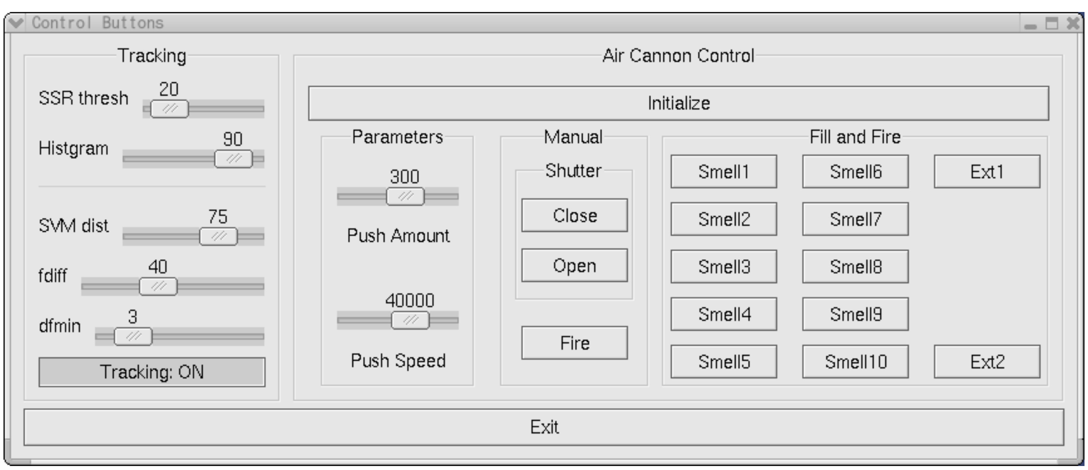


Figure 8: Control panel of Scent Projector.

5.2 Applications

We developed two sample applications for use with the Scent Projector system: "Quiz Samurai" and "Concentration."

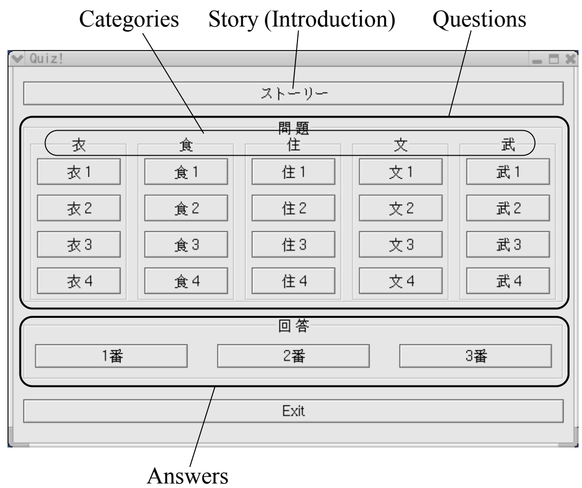
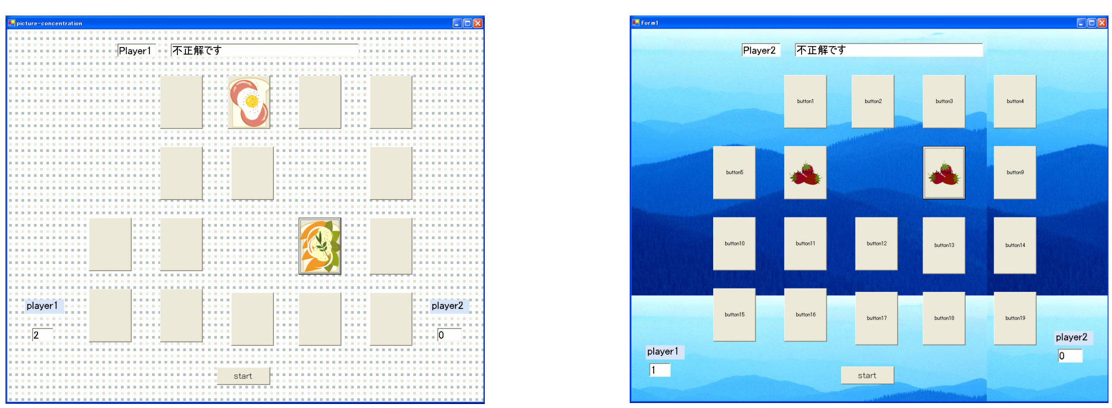


Figure 9: GUI panel of Quiz Samurai.

5.2.1 *Quiz Samurai*

“Quiz Samurai” is an interactive application that provides a good smell if the user responds with the correct answer but emits a bad smell if the user gives a wrong answer. This application and the controller process run on the same PC (PC1). Figure 9 shows the GUI panel of the Quiz Samurai application. The top button is for showing the background story of the quiz, and the 5 x 4 button array is used to select the question. Each column indicates the category of the quiz, with 4 questions provided in each category. When the user clicks one of these buttons, a movie in Macromedia Flash format is played back. After watching the movie, the user is asked to select one answer from three options by clicking the corresponding button below the question button array. If the user gives the correct answer, a movie for the correct answer is played back, and at the end of the move a fragrance is shot from the Scent Projector. Otherwise, a movie for the wrong answer is played back and a bad smell (ammonia) is shot from the Scent Projector.

The GUI panel of “Quiz Samurai” is written in C/C++ language using GTK Toolkit, and runs on Linux. Movies are in Macromedia Flash format, and they are played back by using swfplayer on Linux.



(a) Visual feedback (b) Olfactory feedback

Figure 10: Card game “Concentration.”

5.2.2 *ScentConcentration (card game)*

ScentConcentration applies the Sent Projector in an even more interactive application. Concentration is a well-known card game in which the players try to find pairs of cards with the same number among scattered cards. For this application, we simplified the game to make it suitable for our Scent Projector by reducing the number of possible card types. There are several versions of the programs, and the user is fed back the result with different kinds of sensory modalities. In the ordinary version of the Concentration game, visual feedback is provided to the user by showing the pattern of the reverse side of the clicked card on the computer display. In the olfactory version, the clicked card is shown by the scent assigned to that card instead of the image.

The characteristics of our Scent Projector enabled this kind of interactive application with olfactory feedback. If the scent is diffused by an ordinary olfactory display, it is difficult to present different kinds of smell in a short period, such as within 2 or 3 seconds. With our Scent Projector, however, different kinds of smell can be delivered in each shot of the air cannon so that the user can appreciate the delivered smell.

The Concentration program was written in C# language, and it runs on a PC running Microsoft Windows XP. Whenever the user clicks a card, the smell ID is sent to the PC, which controls the Scent Projector via a UDP packet. On the PC running the controller process, a UDP packet receiver process is running to receive and pass the scent ID to the shared memory.

Screenshots of the Concentration program are shown in Figure 10. Figure 10 (a) shows the visual-feedback version, an ordinary card-game application running on a PC. Figure 10 (b) is the olfactory-feedback version, in which the picture on the clicked cards is the same. The information on the kind of card clicked is given by emitting the scent assigned to the card, rather than showing a picture of the card.

6 Conclusions

We made interactive contents using the proposed Scent Projector system to provide short-term, localized smell exposure in a manner that does not tether the user to a device. Because it is very difficult to generate an arbitrary smell with a single, general-purpose scent generating machine, restricting the number of smells is considered an effective measure toward achieving practical use of olfactory displays. Based on this strategy, we implemented the use of smell cartridges with our Scent Projector, allowing the user to exchange the contents of smell according to the progress of audio-visual programs.

Future works include developing display systems that provides more natural olfactory experience, because with our current system the temporal duration in which users can detect smell is too short. Another problem is that the user feels an unexpected sensation of wind caused by the airflow accompanying the vortex ring. Although this wind effect may be positively evaluated in some cases, in other cases it contradicts our expectations of how we should experience smell in our daily life. We intend to address these problems in our future work.

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