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SpotScents: A Novel Method of Natural Scent Delivery Using Multiple Scent Projectors

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ABSTRACT

We propose a projection-based olfactory display method as an unencumbering way to deliver smells using a scent projector. This device allows us to deliver smells both spatially and temporally by carrying scented air within a vortex ring launched from an air cannon. However, our original scent projector had a problem: users often felt a significant, unnatural airflow when the vortex ring hit their faces. In this paper, we propose a novel configuration of a projection-based olfactory display that reduces this breeze effect. We use two air cannons that launch vortex rings that collide at a target point and break by themselves, distributing their smell at the point where they were broken to make a small "spot" of scent. With this configuration, users feel as if the smell came with a soft breeze, so that they can enjoy a more natural olfactory experience.

CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

Keywords: olfactory display, air cannon, vortex ring, olfactory field

1 INTRODUCTION

Display devices for virtual reality (VR) were first developed to cover auditory and visual sensations. Such great innovations immersed people in three-dimensional virtual worlds, but they soon wanted to touch the objects in front of them. When VR interfaces were limited to audio and visual channels, a user's VR experience resembled "being a ghost" because one could not feel physical (mechanical) feedback from objects in virtual worlds. After the development of haptic devices and systems to achieve realistic mechanical interaction with virtual worlds, VR experiences markedly improved. However, they still feel like "being in a spacesuit" because users cannot feel the "air" surrounding them. Therefore, a natural progression has incorporated olfactory interfaces into VR systems, which is an effective way to achieve a high level of presence [1] [2].

There are two major technical fields to realize olfactory VR.

Smell generation: the creation of desired smells by vaporizing or diffusing odor sources in liquid or solid form. This is a counterpart to rendering technology in visual displays.

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Smell delivery: spatially and temporally controlling the smell, according to user behavior and the status of the virtual olfactory space. One key feature is how to bring the scented air to users' noses. This is a counterpart to such 3D visual display technologies as head-mounted displays (HMD) [3] and immersive projection technologies (IPT) [4].

In the field of smell generation, every researcher who wants to generate arbitrary smells faces a serious problem: the inability to synthesize arbitrary smells from a small set of "primary odors." Amoore attempted to propose seven primary odors [5], but this proved very complicated because the number of receptors is estimated to be in the several of hundreds [6], and each receptor detects multiple molecules.

Our current interest is smell delivery. Even without synthesizing arbitrary smells, we believe that it is still useful to present smells in VR applications by appending spatio-temporally controlled olfactory experiences in a virtual space. In this case, the presented smells themselves might just be switched among pre-blended aromas or blended in real-time from a small set of "key" aromas (perhaps also pre-blended). However, we think that completely arbitrary smell generation is less important in the initial stage of appending smells in VR applications because the number of smells presented in a specific application is not expected to be large (around 10 or 20).

Many existing interactive olfactory displays simply diffuse the scent into the air, which does not allow spatio-temporal control of olfaction. Recently, however, several researchers have developed olfactory displays that inject scented air under the nose through tubes. These systems, which correspond to head-mounted displays (HMD), yield a sound way to achieve spatio-temporal control of olfactory space, but they require that users wear a device on their faces.

We proposed a novel configuration of an olfactory display that is considered a counterpart to projection-based visual displays. Its key concept is the delivery of scented air from a location near the user's nose through space. Even though users are not required to wear special devices, it is still possible to switch among different scents within a short period and limit the region in which the scent can be detected. To implement this concept, we used an "air cannon" to carry the scented air by vortex rings.

Starting with a simple air cannon unit, we constructed and tested prototype systems. By implementing nose-tracking and scent-switching functions [7], our recent prototype system has sufficient performance (although there is still room for improvement) to achieve our proposed concept. We named the implemented system "Scent Projector."[8]

However, we encountered a problem with our scent-projection technique. Users felt an unexpectedly strong breeze, caused by airflow accompanying the vortex ring. This "breezy effect" could be prevented by waiting for the vortex ring to collapse by itself, but the behavior of a self-collapsing vortex ring is too unstable to reliably deliver scents. To solve this problem, we propose a novel approach in which vortex rings are intentionally broken by making them collide with each other while in the air. In this configuration, the scented air is carried from a nearby place to stay briefly at a certain location. After the vortex ring breaks, the breeze effect is much smaller than when a vortex ring directly hits a user's face, thus providing a more natural olfactory experience.

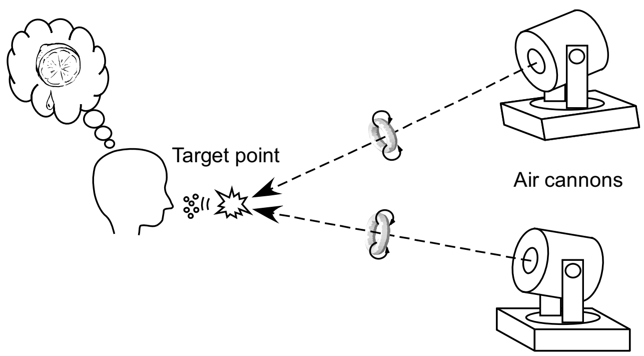

Figure 1. Generating a "spot" of scent by collision of two vortex rings

2 RELATED WORKS

An early approach that incorporated smell with other kinds of displays can be found in Heilig's Sensorama [9] [10]. People enjoyed multimodal movies with breezes and smells as well as through pictures and sounds, although not interactive. Entertainment attractions have also used scent; for example, McCarthy developed a scent-emitting system called "Smellitzer" [11] that emits a selected scent to produce a sequence of smells. Jaidka patented a movie system that produced special effects including olfactory experience [12].

Some researchers have explored the possibility of olfactory displays in the context of "record and playback." Davide et al. discussed electronic noses and virtual olfactory displays [13]. NASA JPL has also been conducting research and development on electronic noses [14]. Nakamoto et al. developed odor sensors and a blending system called "odor recorder" [15]. This research mainly focuses on how to sense, code, and reproduce scent, very challenging projects that need continuous development. As mentioned above, these approaches are beyond the scope of our research.

In terms of the 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 can be regarded a counterpart to illumination because the provided background smell is analogous to colored light. Among the other interactive scent emitters developed so far, Kaye produced several computer-controlled olfactory interfaces in the context of Ambient Media [16][17]. DigiScents announced computer-controlled scent diffusers called "iSmell," and Göbel introduced an olfactory interface in a cylindrical immersive visual display [18]. However, these works do not attempt spatio-temporal control in olfactory displays. One demerit of simple diffusers is the difficulty of dissipating a scent after it has been diffused in the air. This makes it difficult to switch or change the scent quickly in correspondence with the progress of a scenario or interactive application contexts.

Recently, more VR-oriented olfactory interfaces have been developed to control scent according to user location and posture. Cater developed a wearable olfactory display system for firefighter training simulations [19][20]. Hirose et al. developed several head-mounted olfactory displays, including a scent generation and blending mechanism controlled by computer [21][22]. They recently developed a wearable olfactory display system [23] that allows users to move freely. In these display systems, scented air was sent to the nose through a tube. The visual display counterpart to such olfactory interfaces is, of course, HMD. Mochizuki et al. developed an arm-worn olfactory display that focuses on the human habit of grasping a target object, bringing it up to the nose, and sniffing it [24]. Several other olfactory displays are also introduced by Washburn et al. [25], including a shoulder-mounted scent generator named Scent Collar, developed by The Institute for Creative Technologies (ICT) and AnthroTronix. These olfactory displays realized interactive use of smell, but many were "tethered" interfaces that required the users to attach a special device on the face, arm, or other parts of the body. Many people would probably reject the idea of wearing such equipment to incorporate an olfactory effect in existing systems, especially when primarily enjoying ordinary audio-visual contents.

Haque constructed "Scents of Space," an interactive smell system [26], which delivers smell by the slow movements of layered wind. This huge system was larger than a room and included a wall-sized, scent-generating matrix and an exhaust fan.

MicroScents (www.microscent.net) also introduced using air cannons to launch scented air [27]. However, they simply filled the chamber of an air cannon with scented air, and thus they couldn't launch different smells within a short time. One of our innovations is a short-term, scent-switching mechanism that injects scented air into a small cylinder in front of the air cannon's aperture [28]. With this mechanism one can deliver different scents with each shot of a vortex ring.

3 SYSTEM CONCEPT

3.1 Vortex ring

The vortex ring, launched by the air cannon, is not just wind. This vortex ring occurs because of the difference in velocity at the edge (slow) and the center (fast) of the aperture, when launching an air cannon. The pressure at the center of the vortex (ring shape) is kept low so that the vortex retains its shape for a while. The size of the vortex depends on the aperture size, and the speed and reaching distance of the vortex path depend on the velocity profile of the pushing motion and the size parameters of the chamber and aperture.

Vortex rings feature two kinds of airflows: the flow of the movement itself and the construction of a vortex ring, that is, local and high-speed airflows (Figure 2). When the speed of the launched vortex ring decreases, the local airflow still briefly maintains a high velocity. Therefore, the vortex ring completely disappears in time.

3.2 Breaking vortex rings and generating olfactory fields

We propose to generate an olfactory field using vortex rings by breaking the vortex ring, which includes a scent source. After breaking the vortex ring, the scent source can finally spread. Methods of breaking the vortex ring include collisions with objects or waiting for it to disappear by itself. Collisions between vortex rings and objects show no relation to vortex ring speed and reaching time. While flying stably, the vortex ring will collide with the target object. Waiting for the vortex ring to disappear by itself takes time, and it is unstable to the destination. Therefore,

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we use a breaking vortex ring method that involves collisions with objects.

During vortex ring delivery near a human, the vortex ring's target object is a human nose. But the vortex ring is bigger than a human nose, about 10-15 cm. In this case, the target object is the human face. Users could feel a significant wind force and some smell when the vortex ring hits their face. This wind force, which is a big problem for naturally feeling scent, is caused by the speed of the vortex ring. The most important cause is the airflow from which the vortex ring is constructed. The speed of the airflow is faster than the vortex ring's speed. Therefore, if the self speed is slow, users could briefly feel a high air pressure.

Here, we propose a novel method to allow scented air carried from a nearby place to stay a while at a certain location without the unnatural feeling of a sudden air current.

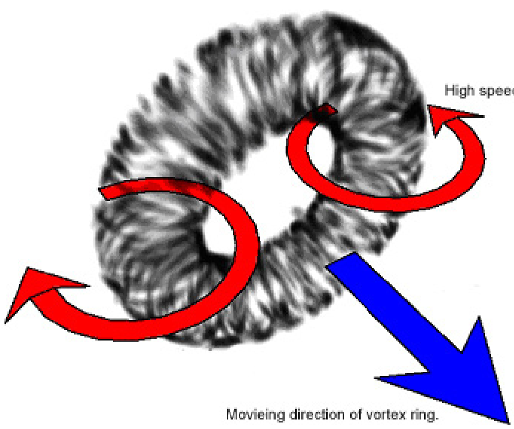

Figure 2: Airflow of vortex ring.

3.3 Generating olfactory fields using multiple air cannons

We propose a new method of generating olfactory fields without causing users to feel a breeze. This method intentionally breaks the vortex rings by launching multiple vortex rings so that they collide at the target point. We use two air cannons. Each cannon launches vortex rings at the target. When two vortex rings collide in front of a face, ring speed decreases. At the same time, the local high-speed airflow that constructed its own vortex ring was disrupted, generating an olfactory field. Since users could feel slight airflow and some smell, the generated olfactory field was not completely stopped. To stop it, two vortex rings must collide head-on. By not stopping the olfactory field, it is possible to feel smells as if carried on a light breeze by controlling the launching angle of the vortex ring and using the residual speed of the olfactory field. This situation is natural because that scene feels the smell. Figure 3 shows the differences in feeling the vortex ring airflow directly hitting the human face and the new method where two rings collide in front of the face.

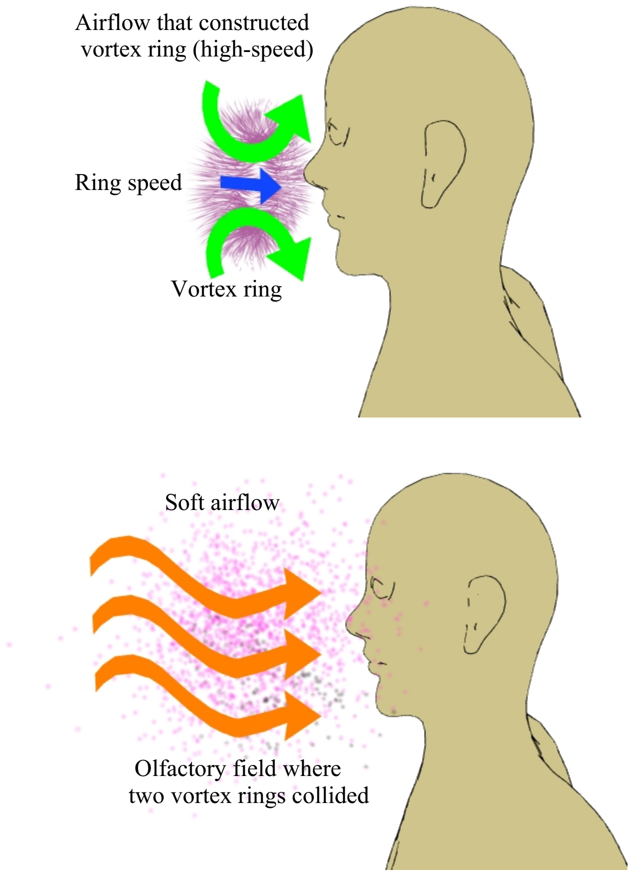

Figure 3: Difference in feeling airflow of vortex ring hit directory (up) and collided two rings (down)

4 Prototype System

4.1 Fourth prototype air cannon

We have created several prototype air cannons. First, we made a simple air cannon with a scent diffuser. The next prototype aimed for the human nose using computer-vision-based face tracing. The third can launch several kinds of scents. Such functions as launching vortex rings, aiming for human noses (air cannon controls the direction), and selecting scents are enough for a scent projector.

In this paper, we built a fourth prototype air cannon to collide two vortex rings. Basically, its functions are identical to the third prototype, but the fourth prototype can change some calibers that select the size of the vortex ring. The moveable range of the pan axis is ±45º, and the tilt axis is ±30º. To construct a generating olfactory field environment, we made two fourth prototype air cannons (Figure 4).

When a vortex ring is launched, we need to know the basic specifications of the air cannon, that is, the relation between reach distance and lapsed time. Unless they are known, we cannot correctly force a collision between the two vortex rings. To measure this relationship, we used a high-speed camera (NAC Image technology, fx-6000) and captured the flight pass of the vortex ring. The measurement method included a scale measurable to 150 cm par 10 cm, which was placed at muzzle of the air cannon. The vortex ring was launched horizontally, and all were recorded using a high-speed camera. Since vortex rings are usually invisible, we used stage smoke (K&L. Inc. Tiny-fogger). Figure 5 shows a vortex ring, including the smoke, launched from an air cannon in the measurement environment. The frame rate of the high-speed camera is 500 fps. We recorded the reaching time of the vortex ring edge every 10 cm. We repeated the experiment eight times, and the results are shown in Figure 6. The vortex ring was stabilized and it flew until about 1100 mm. After checking each recorded movie, the vortex ring started moving up and down when the flying distance became longer than 1100 mm. But the amount of vertical direction movement of the vortex ring is small. Therefore, the vortex ring launched from the fourth prototype air cannon will absolutely collide with the other vortex ring when its flight distance is within 1100 mm. Around 1500 mm, the possibility of collision slightly decreases, without colliding completely, and part of the vortex ring collides with the other vortex ring. Immediately after the launching of the vortex ring, it can fly several meters, but it is spatially unstable timewise.

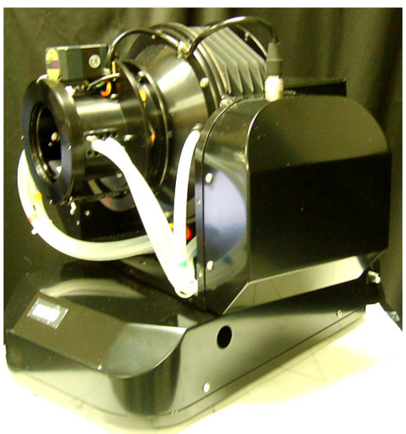

Figure 4: Fourth prototype air cannon

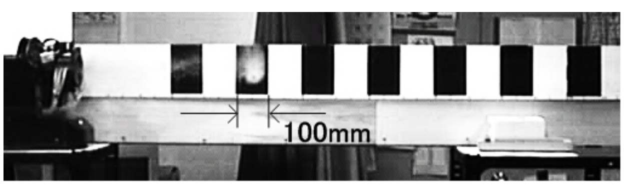

Figure 5: Image of vortex ring including smoke launched by air cannon in measurement environment

4.2 System configuration

To construct environment generating olfactory fields in free space, we need to decide the position of the two air cannons. When their positions are changed, the area in which collisions occur changes, too. The range distance of the vortex ring is 1500 mm, so we decided that would be the position of the air cannons and the area in which the rings would collide (Figure 7). The distance between each air cannon was 1500 mm, and they rotate ±45º, aiming for the center. The maximum range of the area that could generate an olfactory field is about 1300 mm, which is the forward distance from air cannons, and the vertical direction is about ±750 mm.

The best way to make the two vortex rings collide is head-on, but if we always use it, we need to control the position of the air cannons, which is too difficult. The air cannons have a platform control function that we used to decide the most spacious area for collisions.

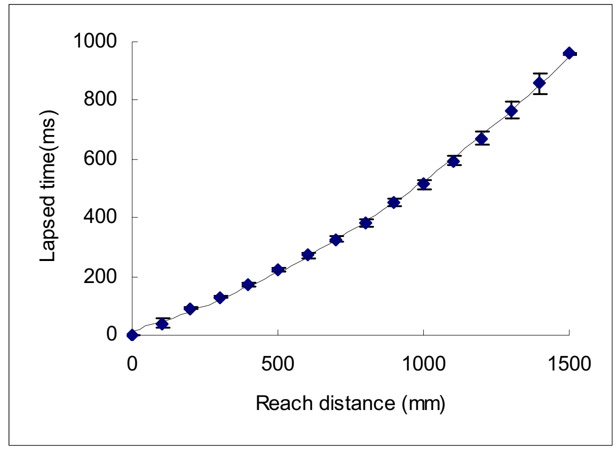

Figure 6: Relation between reach distance and lapsed time

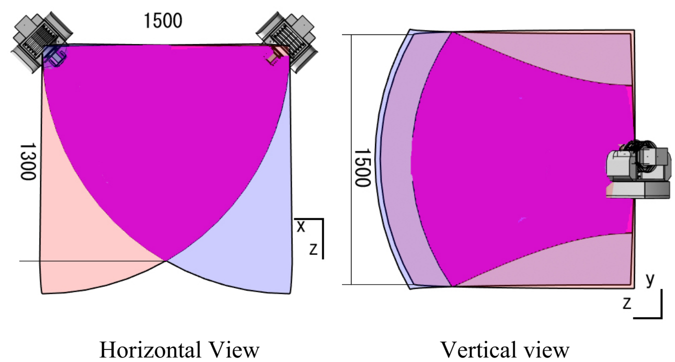

Figure 7: Areas that can collide

5 Evaluation and Discussion

5.1 Collision experiments

We conducted an experiment to examine whether the olfactory field can generate at an inner area in which two vortex rings can collide, as explained in the preceding chapter. As an evaluation method, first, the vortex rings are made visible with a smoke machine, and next, they are launched at the target point. We recorded the colliding appearance with a normal DV camera. After the experiment, we checked these recorded images to confirm collisions. If two smoke rings collided, an olfactory field was generated. Target points are 1000 mm, 1500 mm, and 2000 mm, which are the distances from each air cannon (Figure 8). For 2000 mm, we checked the collision situation outside of the collision area. We tried each target position 20 times and calculated the hit rate.

Based only on this experiment, an olfactory field couldn't be generated in free space, only at the center line between each air cannon. So, we needed another experiment whose target point was a different distance from each air cannon. The target point is the same distance from each air cannon, and the launch timing is identical to the time and speed of the vortex ring. In another case, where the point is different from the distance, we need to control the launch timing or the speed. Since speed control is too difficult, we need to measure the relation between reach distance and lapsed time for each vortex ring speed. Using time control to launch the vortex ring is easier than speed control. The data is shown in Figure 6. The elapsed time is calculated from each distance of the target, and time-lag is decided. In this experiment, the target point is decided from each air cannon at distances from 1000 and 1500 mm (Figure 8). We tried 15 times in this case. Experiment results are shown in Table 1.

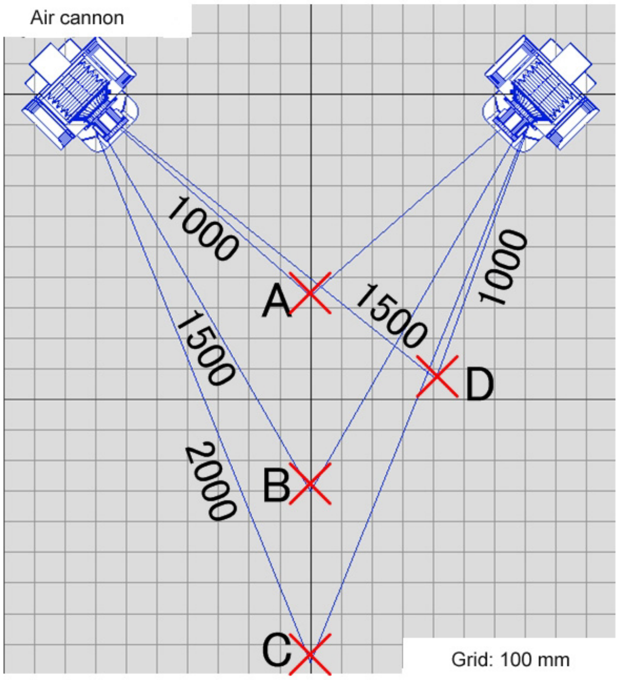

Figure 8: Target points

Table 1: Results of collision experiments

Target point	Collided successfully	Collided without breaking	Didn't collide	Collision ratio
A	20/20	0/20	0/20	100%
B	15/20	4/20	1/20	75%
C	7/20	7/20	6/20	35%
D	15/15	0/15	0/15	100%

First, the target point experiments had the same distance from each air cannon (points A, B, C). For point A, the collision ratio was 100%, so there were no problems generating the olfactory field. Point B's ratio was down (75%), but it included things of collide rings and not break rings, and the collision ratio was 95%. The vortex rings were flying stably and being accurately aimed. For colliding without breaking at point B situation, we considered that the speed of the vortex ring was slowing down, but the local airflow of the constructed vortex ring still had high speed, so the two rings repelled each other. At point C, the vortex ring was unstable, so collision failure increased; if collisions succeeded, rings did not break. Around point C, when aiming for the front of user faces, users will feel high air pressure at their face or other places.

Next, in the case of point D, which had different distance from each air cannon, the collision ratio was 100%. This method effectively controlled the launch time.

A high-speed camera image of the breaking vortex rings is shown in Figure 9.

5.2 Observations of user behavior at SIGGRAPH'2005

As a usability test of the generated olfactory field with two vortex rings, we examined the behavior of novice users. We are interested in the behavior of novice users. To collect subjects for this purpose, we brought our fourth prototype air cannon to the Emerging Technologies venue at SIGGRAPH'2005 (July 29-August 4, 2005, Los Angeles). Figure 10 shows a scene from our booth. Demonstration participants experienced four olfactory fields (vanilla, orange, mint, and ammonia) generated by two vortex rings. The major motivation of this experiment was for novices to naturally feel and understand the different scents. We added head tracking and selectable scent functions to the prototype system for the SIGGRAPH demonstration.

More than 1300 conference attendees experienced our system for five days. Through observations of the experiments, we confirmed that most users could feel some scents and understand the different scents from each air cannon shot. But, we could not confirm that the scent was successfully felt because of the generation olfactory field or that the vortex rings actually hit users' faces. We recorded user behaviors that reflected such observation, for example, moving hair, and so on. The vortex rings and olfactory field are invisible.

Finally, we noticed some problems while using this prototype system: density and mixture of scent. Some users felt that the scent density was very weak, which was probably caused by aiming mistakes or system design. When we used the generation olfactory field, one vortex ring was scented, but another had only fresh air. We thought that one vortex ring might break another vortex ring. We need to use scented air in two vortex rings. About the scent mixture problem, at the end of the conference, a user said that his feeling increased for only one scent. We selected scents from AROMA BLENDER (Mirapro Inc), and the source scents were normal aroma oils. Only one tube in the air cannon's chamber brought air scented by aroma oil. Therefore, it is thought that it gets mixed by some aroma oils adhering to the inside of the tube. We should use one tube and use one scent.

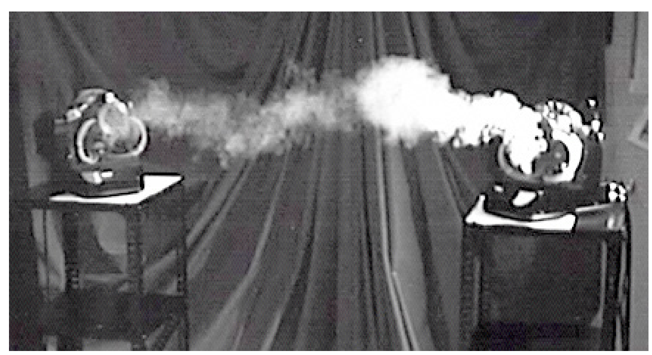

Figure 9: Breaking vortex rings

Figure 10: SIGGRAPH'2005 demo

6 Conclusions and Future Work

We proposed a novel configuration that uses multiple scent displays to generate an olfactory field in a free space where users can naturally feel scent. The technical key to realizing this concept is to collide two scented vortex rings in front of the face. We confirmed this possibility by using two air cannons. The prototype system successfully generated an olfactory field for target users, even if they moved the front of their face. They did not feel a strong superfluous airflow.

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

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

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