

# Air Cannon Design for Projection-Based Olfactory Display

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## Abstract

The olfactory sense is considered to be an important modality in next-generation virtual reality (VR) and teleoperation systems, just as haptics has recently extended the world of VR. However, there are many difficulties in realizing general-purpose olfactory displays. Smell is generally classified as one of the chemical senses (along with taste), and a small number of bases to represent arbitrary smells (primary odors) have not been found. We are not attempting to develop sensing or synthesizing technologies. Our current focus is on display technology, in other words, the spatiotemporal control of odor. We have proposed an unencumbering olfactory display that do not require the user to attach anything to the face. With the unencumbering olfactory display, we can provide a scent to the restricted space around a specific user's nose, rather than scattering scented air by simply diffusing it into the atmosphere. A so-called "air cannon" was adopted and implemented for this purpose. In our prototype systems we could successfully transfer the scented air to the tester's nose, using a desktop system.

However, for some real applications, a greater transfer distance is required. So an empirical study of a toroidal vortex has been carried out to optimize the performance of air cannons, and to find how to increase the effective distance. The results show that we can successfully bring a scent to a specific user who is 2-3 meters away from the projection-based olfactory display, by changing some parameters.

**Keywords:** virtual reality, olfactory display, air cannon, projection-based, nose tracking

## 1. Introduction

To experience a high level of presence in a virtual environment, it is important not only to see, hear, and touch the object but in some cases to smell it and when appropriate, to taste it [1]. VR systems have been developed to cover the "big three" (vision, audition, haptic) so far, recently olfaction and gestation are beginning to be incorporated into VR systems [2]. However, there are so many difficulties that the two later modalities have been left in the backcountry of the VR research field. First of all, olfaction is activated by chemical stimuli, rather than by physical stimuli. This is very different from the "big three". For a long time, many researchers were trying to find a set of "primary odors" [3]. Amoore [4] categorized seven primary odors and later extended this number to 20-30. Later, Buck and Axel [5] reported at least 100 kinds of receptive proteins, based on the theory of the odorant receptor protein [6]. The number of receptor proteins is theoretically estimated to exceed 1,000. This means that it would be difficult to use the strategy of visual display, by which we can synthesize any color by mixing the three primary colors (red, green and blue)

We are not attempting to develop sensing or synthesizing technology. Our current focus is on the spatio temporal control of odors, assuming that the odorant itself is ready to use. We have proposed a novel configuration of an olfactory display that can be considered a counterpart of a projection-based display or an autostereoscopic display. The key concept is to transfer the scented air to the restricted space around a specific user's nose, through free space. A so-called "air cannon" was adopted and implemented for this purpose. Along

these lines, the purpose of this paper is to optimize the performance of the air cannons.

In this paper, we aim to increase the effective transfer distance, and have conducted a set of experiments to examine what factors would affect the performance of the air cannon. The following parameters were analyzed: the volume of chamber, the diameter of the circular aperture, the push speed (time) and the compressed volume.

First, the system concept, principle and prior research will be briefly introduced in section 2, then we will describe our experiment environment and method in the section 3, following by a discussion of the experiment results, and what factors would affect the performance of air cannons in section 4, and present our conclusion in section 5.

## 2. Projection-Based Olfactory Display & Air Cannon

### 2.1 Projection-Based Olfactory Display

The ultimate goal of our research is to develop an olfactory display (Figure 1) that is unencumbering and localized. The reason for the first characteristic is similar to why many people are trying to make an auto-stereoscopic visual display: will be a significant advantage if users do not need to block their face with a device, or to trail cumbersome tubes that transfer scented air between the nose and generator [7, 8].

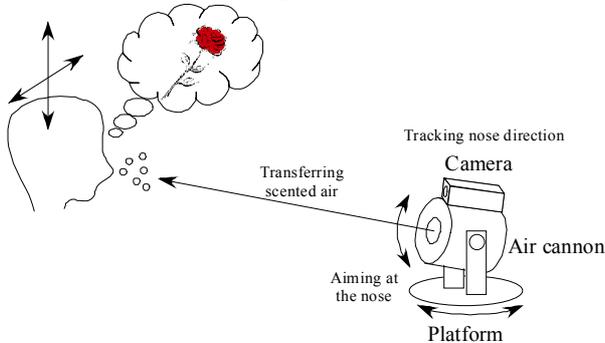


Fig 1: Concept of the projection-based olfactory display.

On the other hand, if our aim was simply to develop an unencumbering display, we could just diffuse the scented air into the room or use wind to carry the scent. However, with these methods, it is difficult to control the olfactory effect in a short time span and to provide different scents to individual users. We wish to control the scent in both space and time without making the user wear anything on the face.

To realize an olfactory display with these features, we need to transfer an amount of scented air from a nearby position to the nose through free space. We have explored the possibility of using an “air cannon” for this purpose.

### 2.2 Air Cannon

The air cannon (also known as a vortex cannon) is a chamber with a round 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 fill the box with smoke and push it gently, a smoke ring will be observed moving smoothly forward (Figure 3). The speed of the smoke ring is approximately 50 cm to several meters per second. This ring demonstrates the toroidal vortex 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 is shown in Figure 2.

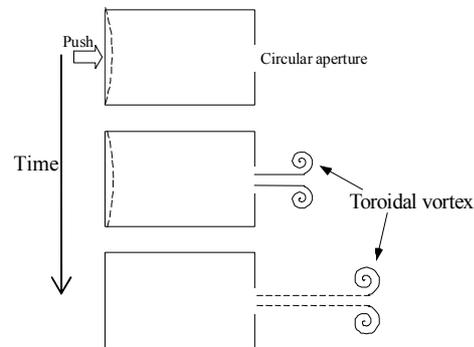


Fig 2: An air cannon generating a vortex ring.



Fig 3: A smoke ring launched from an air cannon.

It is said that this vortex occurs because the difference in velocity at the edge (slow) and the center (fast) of the aperture of the center of the vortex (ring shape) is kept low so that the vortex keeps its shape for a while.

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 an amount of air. Thus we can send a different scent with each launch and reach multiple users with one air cannon.

### 2.3 System Example

Our prototype system is composed of the following components:

- Nose Tracker
- Air Cannon Platform
- Air Cannon
- Scent Generator

A vision-based nose tracker (Figure 4) was used to detect and track the target user's nose position. The reason why we selected a vision-based tracker is that this method could maximize the proposed concept's non-encumbering characteristic. We applied a nose tracker based on an eye tracker developed by Kawato et al. After detecting the position of both eyes, the nose position was detected by searching for the brightest spot within the estimated region in which the nose exists.

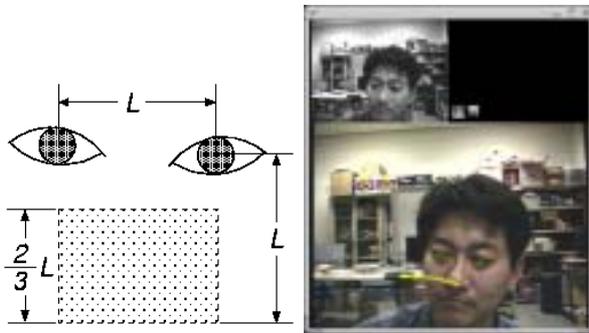


Fig 4: Vision-based nose tracker used in the system.

Once the nose position is detected, the system traces the nose position by template matching and finding the brightest spot [9].

The detected nose position is then converted to the desired orientation of the air cannon, which is fed to the motor driver. The platform 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 (Figure 5).

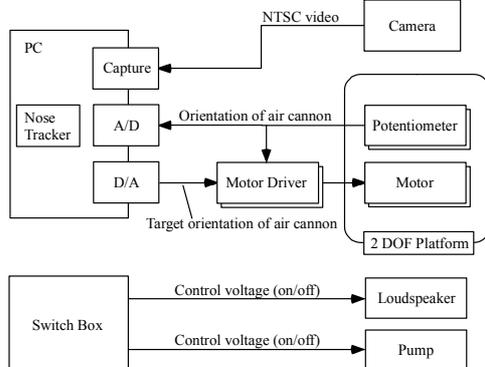


Fig 5: Block diagram of prototype system.

The outputs of the potentiometer are used for position control at the motor driver. With this configuration, the

air cannon could continuously trace the nose of a seated user, even if he/she moves the upper body.

Next, the platform on which the air cannon is mounted is controlled to aim at the user's nose. Angles (azimuth and elevation) with 2 degrees of freedom are controlled to determine the direction of the air cannon. A part of the prototype system is shown in Figure 6.



Fig 6: Prototype system.

### 2.4 Preliminary Experiment

A preliminary experiment has already been conducted to examine whether an unencumbering localized olfactory display is feasible by using an air cannon [10]. 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. It has a 2-liter volume and a 2-cm aperture diameter. We filled the bottle with the smoke of a SENKO (Japanese incense stick) to observe the aspect of the launched toroidal vortices, as well as to use it as a kind of odorant.

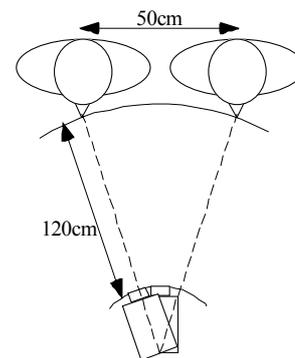


Fig 7: Arrangement of the preliminary experiment.

Figure 7 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. The subjects were asked to close

their eyes during the experiment and to raise their hands if they could detect the smell. The air cannon was set to aim at the two subjects and at other places in random each time it launched a smoke ring.

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. This shows that the air cannon can provide a scent separately to users arranged in a side by side position, and 27 detections of smell out of 31 hits were reported. The success rate of smell detection is thus 87%. This can be regarded as a very high percentage, which shows that the proposed method has the potential to stably provide a scent to a particular user.

## 2. Air Cannon Design

In our prototype systems, we successfully transferred the scented air to the tester's nose one meter away, which is far enough for most desktop applications. But for some real applications, such as a living room, classroom and other VR, more powerful air cannons are needed to send scented air to restricted spaces located in a reasonable range.

In this paper, we aim to increase the effective transfer distance, the distance over which scented air can be clearly transferred and detected by human noses. Although fluid dynamics analysis will give some deep views of the problem, we consider that experimental analysis will be more helpful because there are too many factors and the interrelation among them is too complex. We want to control the transfer distance by changing some simple parameters, the experimental results of effective distance is more useful than analysis how the vortex be generated or simulate the air fluid base on fluid dynamics.

### 3.1 Modeling

The main part of an air cannon is a cubic or cylindrical chamber. There is a hole at the center of one end of the chamber. On the other end, the air cannon is tapped for impact. In certain circumstances, a vortex is generated at the hole.

Figure 8 shows a model of our air cannon. The volume of the chamber is  $V$ . The diameter of the hole is  $D$ . The push velocity is  $v$  and the air cannon is distorted with compressed volume  $\Delta V$ .

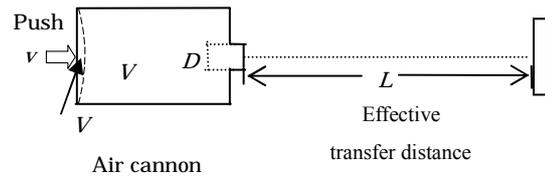


Fig 8: Experiment design.

The effective distance  $L$  is defined as the distance over which the vortex can maintain its shape and be detected by a human nose within the effective transfer distance  $L$ . Our objective is to maximize the  $L$ : Effective transfer distance by carefully analyzing and adjusting the following parameters.

#### Size Factors:

- $V$ : Volume of the chamber
- $D$ : Diameter of the circular aperture

#### Impact Factors:

- $v$ : Push speed (t : time)
- $\Delta V$ : Compressed volume

### 3.2 Cubic Air Cannon

Two kinds of air cannons were built in order to carry out the experimental analysis. Figure 9 shows the first one, a cubic air cannon. The main part is a plastic cuboid with a tube on one end, which enables us to attach different panels to change the diameter of the hole (3 cm, 4 cm and 5 cm). On the other end, the material is rubber membrane. A single pendulum is set to simulate different impacts by varying the initial positions (angle  $\alpha$ ).

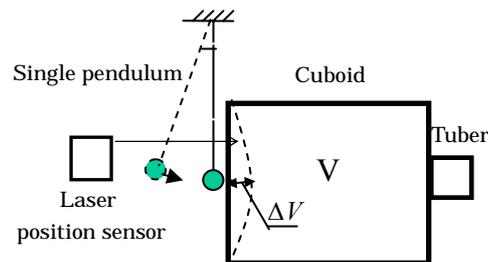


Fig 9: Cubic air cannon experiment model.



Fig 10: Experiment view.

The length, width and height of the plastic cuboid are 20 cm, 20 cm and 15 cm, and the tuber: 10 cm, 10 cm and 5 cm, respectively.

Therefore  $V$  and  $D$  are

$$V = 20\text{cm} \times 20\text{cm} \times 15\text{cm} + 10\text{cm} \times 10\text{cm} \times 5\text{cm} \\ = 6500\text{cm}^3$$

$$D = 3.0\text{cm}, 4.0\text{cm}, 5.0\text{cm}$$

The cubic air cannon is a prototype system (Figure10) enabling us to do some basic tests, and the  $\Delta V$  and  $v$  always change together, so we put a laser-based position sensor behind the single pendulum to measure the tiny movement (Figure 11) of the surface of the cuboid to calculate them.

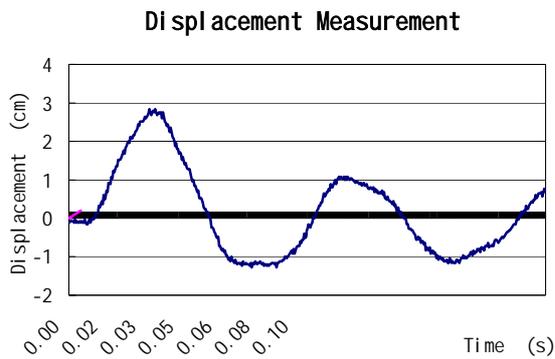


Fig 11: The displacement of the membrane.

We assumed that the displacement is symmetric. So we chose three points on the surface of impacted side, between the center and the edge, then estimated the displacement from measurements data. Figure 11 is one of the data graphs, x axis shows the time during which the displacement takes place, and y axis shows the movement of displacement. The calculations are based on average of three runs.

### 3.3 Accordion Air Cannon

The accordion air cannon shown in Figure 12 is a more advanced air cannon which enables us to control  $\Delta V$  and  $v$ . The main part is a 9.5 cm diameter accordion cylinder. The length of the cylinder is of 10 cm. On one end, there is a 3.0 cm diameter hole. On the other end, a stepping motor is set to generate a rapid compression. With the accordion air cannon, it is easy for us to change  $\Delta V$  and  $v$  by adjusting the speed and moving distance of the stepping motor.

The volume of the chamber  $V$  and  $D$  are:

$$V = \pi \times (4.65\text{cm})^2 \times 10\text{cm} = 678.94\text{cm}^3$$

$$D = 3.0\text{cm}$$

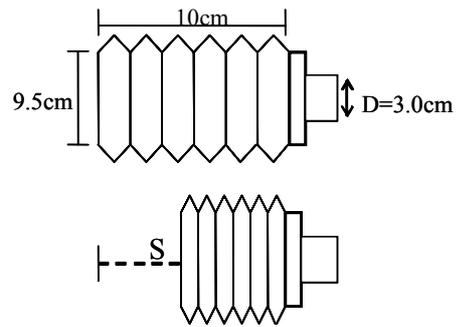


Fig 12: Accordion air cannon experiment model.



Fig 13: Accordion type air cannon.

So the  $\Delta V$  and  $v$  could be calculated, if the stroke movement and time are known. The stepping motor is controlled by a maximum 500 of pulses (2.0 cm), and in our experiment the speed  $v$  was set from 40 to 200 cm/s.

### 3. Experiment Results

Various kinds of experiments were carried out on the cubic air cannon and accordion air cannon in order to clarify the rules between the effective transfer distance and other parameters. Unless otherwise specified, all data shown are based on an average of 100 runs.

#### 4.1 Preliminary result of the relationship between impact and $L$ (cubic air cannon)

The first experiment was carried out on the first air cannon to clarify the relationship between  $L$  and impact. In this experiment, the starting angle of the single pendulum was set to  $\pi/6$ ,  $\pi/4$ ,  $\pi/3$  to simulate different impacts with different striking speeds.

Figure 14 is a bar chart showing the relation between the effective distance  $L$  and the impact where  $D$  is 3.0 cm, 4.0 cm and 5.0 cm, respectively. When  $D$  is 5.0 cm and  $\alpha$  is  $\pi/6$ , the effective transfer distance is 180 cm. When  $\alpha$  increases to  $\pi/3$ ,  $L$  becomes larger. In the same way as other data reveal,  $L$  increases as the impact becomes stronger. The increasing ratio when  $D = 5.0$  cm is greater

than that when  $D = 4.0$  cm. When  $D = 3.0$  cm,  $L$  is slightly changed.

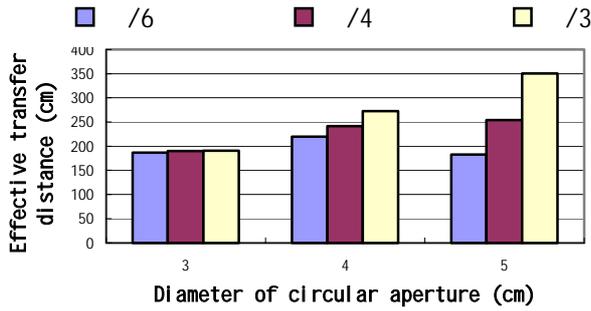


Fig 14: Experiment result for cubic air cannon

#### 4.2 Relationship between $\Delta V$ , $v$ and $L$

The result of the first experiment depicts the trend between impact and  $L$ . The impact is determined by two factors, the push speed and compressed volume  $\Delta V$ . We designed experiments with the accordion air cannon to analyze their contribution. The accordion air cannon provide more flexibility to adjust the  $\Delta V$  and  $v$  separately by controlling the moving distance of the motor and the moving speed of the motor.

In this experiment, we change  $v$  while fixing  $\Delta V$ . Figure 13 depicts the relation between  $L$  and push speed  $v$  when  $\Delta V$  is  $67.89 \text{ cm}^3$  and  $135.79 \text{ cm}^3$ , respectively. For the blue line ( $\Delta V = 67.89 \text{ cm}^3$ ),  $L$  increases with large  $v$ . On the other hand, we also changed  $\Delta V$  while fixing  $v$ . The graph shows that  $L$  also increases with a large  $\Delta V$ .

For comparing, we also calculated the displacement of cubic air cannon, The measurement result of  $\Delta V$  for  $/6$ ,  $/4$  and  $/3$  are  $440.64 \text{ cm}^3$ ,  $535.06 \text{ cm}^3$  and  $627.92 \text{ cm}^3$ , the result of time are  $0.028 \text{ s}$ ,  $0.024 \text{ s}$  and  $0.02 \text{ s}$ . The results of first experiment also show that the transfer distance  $L$  increases with large  $\Delta V/t$ .

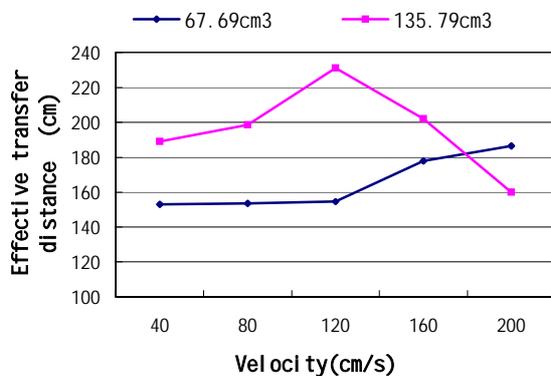


Fig15: Experiment result for accordion type

We also found that the above results only apply to a limited range. For the upper line ( $\Delta V=135.79 \text{ cm}^3$ ) where  $v > 120 \text{ cm/s}$ ,  $L$  decreases as  $v$  is becomes large. In some extreme situation, no vortex will be generated.

#### 4.3 Discussion

By comparing data on the cubic air cannon and accordion air cannon, we found that when the diameter was  $3.0 \text{ cm}$ , the effective transfer distance of each type was almost the same, although the two types of air cannon have totally different shapes. So the diameter of the circular aperture  $D$ , push speed  $v$  and compressed volume  $\Delta V$  might affect the effective transfer distance more great, under certain conditions.

#### 5. Conclusion

In order to achieve an air cannon, which is the key part of a projection-based olfactory display, experimental analysis has been made to clarify the factors and analyze their relation with the effective transfer distance.

The experimental result generally tells us that when the bottom is gently tapped spinning smoke rings will be launched. When it is tapped hard, the smoke rings will zoom so fast that you only see a grey blur. When it is tapped too hard, it generates air turbulence but no smoke rings. In our prototype system, the last two phenomena are inappropriate, because an unencumbering way to provide scent is our research goal. For the first step, we successfully transfer the scent by using air cannon, and obtain some knowledge about how to control the transfer distance through our experimental analysis. Of course, there are still many problems remain. These include the referring environments, implementation of a scent switching or blending mechanism. We are going to solve these problems step-by-step to construct a transparent, easy to use olfactory display system.

#### Acknowledgements

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