Creation of Fluid Art Under Microgravity Using Free-Fall

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Abstract. The time is approaching when space travel will become a reality. What new art will emerge in the space age is an important issue. We have been creating art called "fluid art" using fluid dynamics. Since what kind of new fluid art could emerge under zero-gravity is one example of how art should be in the space era, we plan to create fluid art under zero-gravity or microgravity. To create microgravity on the ground, we designed and constructed a system that creates microgravity using free-fall. This system can create microgravity for about 0.5 s by free-falling a device that generates fluid art from a height of 1.5 m. "Sound of Ikebana," one of the fluid art we have been creating using the vibration of sound, uses a phenomenon that occurs in about 0.5 s and matches well with the constructed microgravity generation system. We confirmed that a new type of fluid art emerged using this system, where the height the fluid jumped up was significantly larger than under normal gravity.

Keywords: Microgravity · Fluid art · Free-fall · High-speed camera · Sound of Ikebana

1 Introduction

Recently, there have been many topics related to space. NASA succeeded in launching the spacecraft on Mars [1]. The SpaceX Crew Dragon plans to carry civilians into orbit around the earth and even around the moon [2], making us realize that space travel will become a reality.

Although the day when ordinary people can go out into space is still a long way off, we need to think seriously about our space travel in the future. Given that space travel will become familiar to the public, it is necessary to think about how the culture that we have built up in our society will change in the space age.

Art has been deeply linked to human spirituality since ancient times, and what art will become in the space age is an essential and exciting issue [3].

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We are interested in what art will look like in zero-gravity or microgravity, which is an environment peculiar to space travel. We have been producing "fluid art" [4, 5], which is an art utilizing fluid dynamics. However, since the fluid behavior would be significantly different under zero-gravity, it is necessary to research fluid art under a zero-gravity environment. However, it is quite challenging to achieve zero-gravity on the earth.

In this paper, firstly, we describe the concept of fluid art production under zero-gravity. Then, we propose a method to realize microgravity with a relatively simple system and describe its development process. Finally, we will describe the system's fluid art production experiment results.

2 Related Research

2.1 Scientific Experiments Under Zero-Gravity

Our bodies have adapted to the environment of gravity, which significantly influences human mental aspects such as thinking. It is an exciting topic how these change in the new environment of zero-gravity.

(1) Physical Science

Many physics experiments have been conducted in the particular environment of zero-gravity. For example, experiments have been conducted on how a specific object behaves in a microgravity space. For example, in zero-gravity, convection does not occur. So high-quality crystals can be obtained [6]. This makes it possible to create new substances that cannot occur on the ground.

(2) Biology and Biotechnology

Various experiments have been conducted on how organisms and plants are born and grow in the unique environment of zero-gravity. Previous studies have revealed that roots and stems change the direction in which it grows in response to a slight difference in humidity [7].

(3) Human Research

Many experiments have been conducted on how weightlessness affects the human body in outer space. Studies have been conducted on the relationship between weightlessness and bone. It was found that when exposed to weightlessness for an extended period, the bone under load under gravity becomes brittle because the load is removed in zero-gravity [8].

2.2 Creation of Art Under Zero-Gravity

JAXA (Japan Aerospace Exploration Agency) has a Japanese laboratory called "Kibo" on the ISS and uses it to carry out various experiments in the scientific field and art areas. From 2008 to 2011, the first theme was solicited and implemented, and nine experiments related to art were conducted in "Kibo" [9]. From 2011 to 2013, eight themes were implemented in the second phase [10].

For example, the "Hiten Project" is an experiment to verify what kind of dance a person can perform under zero-gravity [11].

3 Fluid Art

3.1 Fluid Art "Sound of Ikebana"

Fluid behavior is a large part of natural phenomena. Water flow, wave behavior, ocean currents, etc., are typical examples, and the weather is also a fluid phenomenon due to the atmosphere. Many natural phenomena occur as the behavior of fluids.

We have developed a method to visualize fluid phenomenon and make it into artwork. Specifically, as one of the basic techniques for creating fluid art, we have developed a method for photographing the formation of a liquid made from sound vibration with a high-speed camera. We found that creating a flower-like shape with fluid is possible by giving sound vibration to a fluid such as paint. Figure 1 shows the experimental environment. When a speaker is placed face up, a thin rubber film is put on it, a fluid such as paint is placed on the rubber film, and the speaker is vibrated by sound, then the paint jumps up and makes various shapes. Furthermore, the created form is captured by a high-speed camera of 2000 frames/second [4].

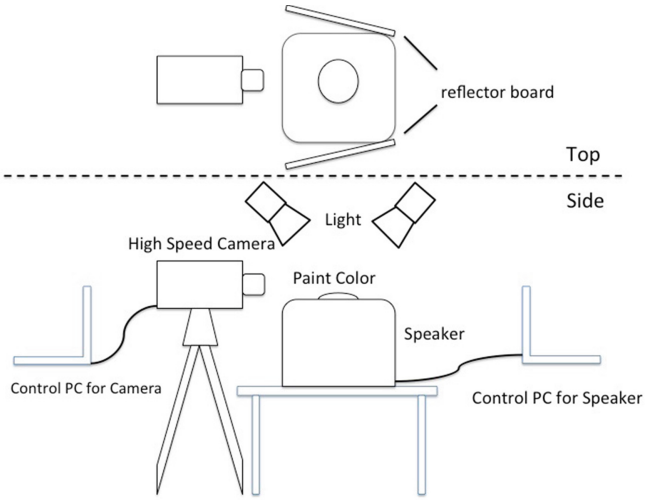

Fig. 1. Fluid art generation system.

3.2 Fluid Art "Sound of Ikebana"

Using this environment, we systematically changed the shape of sound (sine wave, sawtooth wave, etc.), frequency of sound, type of fluid, fluid viscosity, etc., and shot various fluids with a high-speed camera. One of the authors, Naoko Tosa, confirmed that Ikebana (Japanese flower arrangement) like shape emerges. Moreover, she created a video art called "Sound of Ikebana [5]" by editing the obtained video images. Figure 2 shows scenes of the work. In April 2017, as part of Tosa's Japan Cultural Envoy activities, an exhibition was held at Times Square in New York using more than 60 digital billboards. Figure 3 shows a scene of the exhibition.

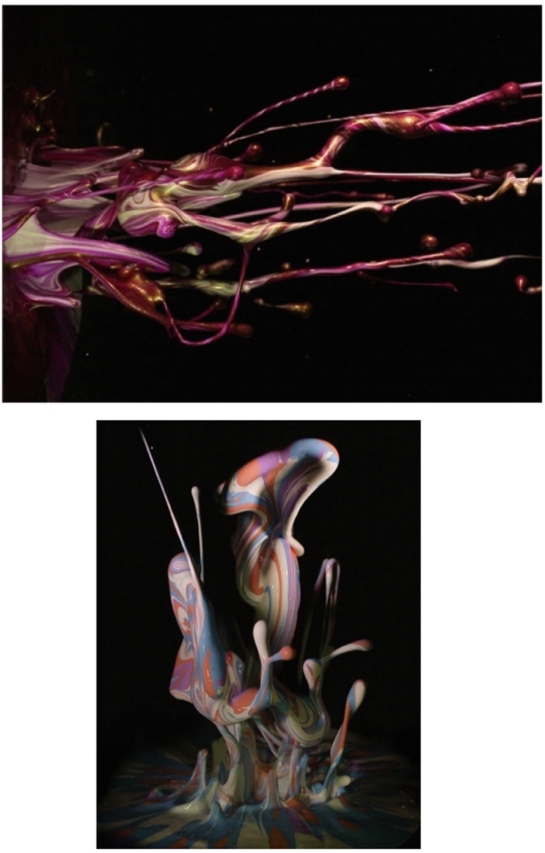

Fig. 2. Scenes of “Sound of Ikebana.”

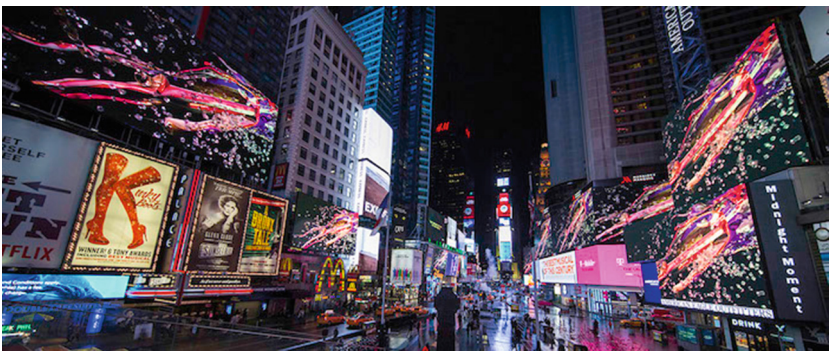

Fig. 3. Exhibition of “Sound of Ikebana” at Times Square, New York.

3.3 Meaning of Fluid Art Generation Under Zero-Gravity

We are currently researching to generate various fluid art represented by the Sound of Ikebana under zero-gravity. Now that space travel is not just a dream story, we believe producing the Sound of Ikebana under zero-gravity has the following meanings.

Art is an essential element of society for us. In the future, where people's lives in space will become commonplace, it is necessary to think about what art will become in the space age. New art suitable for the space age may arise in the space age. Therefore, it is necessary to search for a new form of such art. Also, as mentioned earlier, the behavior of fluids under zero-gravity is an important research topic. Similarly, an important issue is what kind of fluid art shape would emerge under zero-gravity.

4 Microgravity Generation Method

Zero-gravity is a normal state in outer space. However, gravity is always working on the ground. There are two typical methods to realize zero-gravity or microgravity.

4.1 Free-Fall Generator

Gravity G is always working downwards and pulling things downwards on the ground. However, when an object falls downward, it is in a weightless state (actually, it is not complete weightlessness due to the air resistance). In other words, zero-gravity is possible by creating a free-fall state by dropping things from a high place.

Fig. 4. The ZARM drop tower

The Micro-Gravity Laboratory of Japan (MGLAB) in Toki City, Gifu Prefecture, has a free-fall distance of 100 m and a free-fall time of 4.5 s. This drop tower evacuated

the inside of the tower to eliminate air resistance and allow the fall capsule to fall freely [13]. Unfortunately, this facility has already stopped working.

Overseas, the ZARM microgravity experimental facility at the University of Bremen in Bremen, Germany, is famous. The height is 147 m (actual fall distance is 110 m), and if the falling capsule drops in a tower that has been evacuated, weightlessness for almost 4.7 s can be achieved [14]. Figure 4 shows the ZARM drop tower.

4.2 Parabolic Flight

Parabolic flight means flying along a parabolic flight path [15]. After gaining sufficient speed by a rapid descent, the aircraft is raised, and parabolic motion is performed by narrowing the thrust to the extent that it compensates for air resistance. A microgravity environment of about 10^{-2}G to 10^{-3}G can occur in the aircraft for 10 to 20 s during the parabolic flight. So it is used for microgravity experiments and training of astronauts. Figure 5 shows the flight curve in parabolic flight and the gravity in each phase.

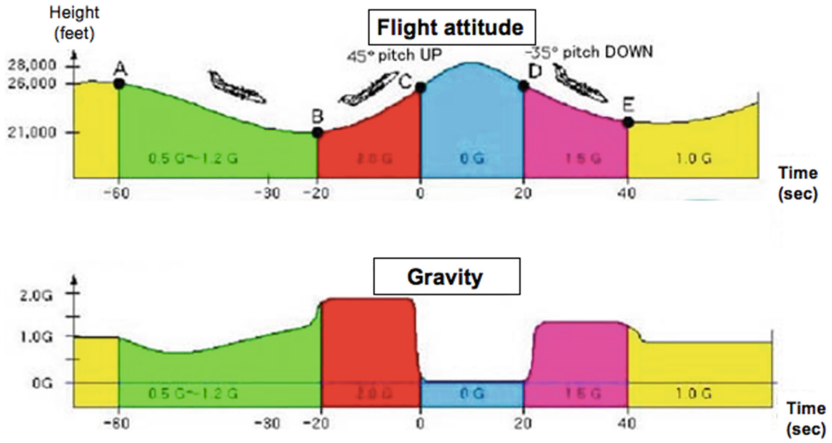

Fig. 5. Parabolic flight

5 Creation of Fluid Art Under Microgravity

5.1 Prototype of Free-Fall System

As mentioned earlier, we are at the beginning of the space age, and we think it is time to consider how art should be in the space age. Art has been produced under normal gravity, such as the Sound of Ikebana as we are doing. Therefore, the behavior of fluid in zero-gravity greatly influences art production. Moreover, attempts to create art using fluid dynamics in zero-gravity are of great significance.

Under such circumstances, we are very interested in how the art Sound of Ikebana created using fluid dynamics will be shaped under zero-gravity. We are planning to try

this art creation in a zero-gravity environment using parabolic flight among the methods for realizing zero-gravity mentioned above.

However, at the same time, the parabolic flight is a large-scale experiment, as it is necessary to work in collaboration with a company that can achieve parabolic flight using their airplane, which is costly. Based on an estimate by a company providing parabolic flight service, one experiment costs US$50K or more. Therefore, it is risky to carry out the parabolic flight experiment without knowing what shape will emerge. Also, even in experiments using free-fall devices described in Sect. 4.1, only a limited number of free-fall devices can carry out experiments that include equipment such as speakers and high-speed cameras, which also require lots of preparation and budget.

When we wondered what to do, a researcher who worked at JAXA advised us to develop a small-scale free-fall experimental system indoors. After studying according to this advice, we found that a small-scale free-fall in our laboratory environment very well matches the fluid art creation we have been doing.

Experiments under regular zero-gravity experiments require at least tens of seconds, or even minutes or more. On the other hand, the fluid art that we have been doing is to create art by shooting a fluid dynamics-based phenomenon that occurs in a short time of 1 s or less, with a high-speed camera. This means that free-fall for a short time within 1 s can occur without the need for such a large-scale device.

As is well known, the relationship between the fall distance h and the time t when a free-fall starts from a stationary state is expressed by the following equation, where g is the gravitational acceleration.

$$t = \sqrt{\frac{2h}{g}} \tag{1}$$

If there is air resistance, it becomes a little complicated and is expressed by the following formula. Here, m is the mass of the falling object, and k is the air resistance coefficient.

$$t = \sqrt{\frac{m}{gk}} \operatorname{acosh}\left(e^{\frac{hk}{m}}\right) \tag{2}$$

Table 1 shows the time when free-fall occurs from the height of 1 m, 1.5 m, and 2 m, where $g = 9.80665$, $m = 20$ kg, and $k = 0.24$.

Table 1. Free-fall distance and time

Free-fall distance	Time without air resistance (sec)	Time with air resistance (sec)
1 m	0.452	0.453
1.5 m	0.553	0.555
2 m	0.639	0.641

From Table 1, a microgravity time of 0.553 s can occur when falling from a height of 1.5 m, and 0.452 s can occur from a height of 1 m. It is clear that even when the air

resistance is taken into consideration, the fall time is only increased by about 0.001 to 0.002 s compared with the case where the air resistance is not taken into consideration. This is because the velocity is low at the beginning of the transition from the stationary state to the free-fall, so it is not easily affected by air resistance. This is also a condition suitable for creating a microgravity environment by utilizing a free-fall state for a short time.

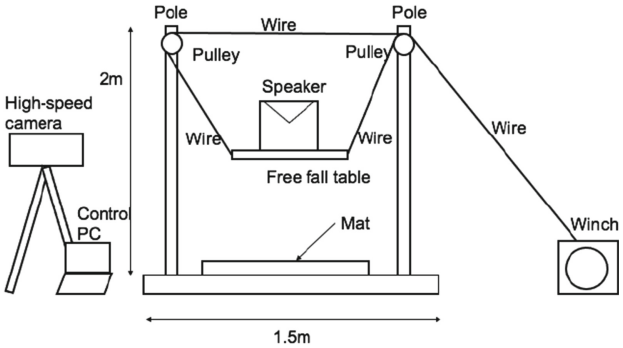

Fig. 6. Conceptual diagram of free-fall system (High-speed camera is installed outside)

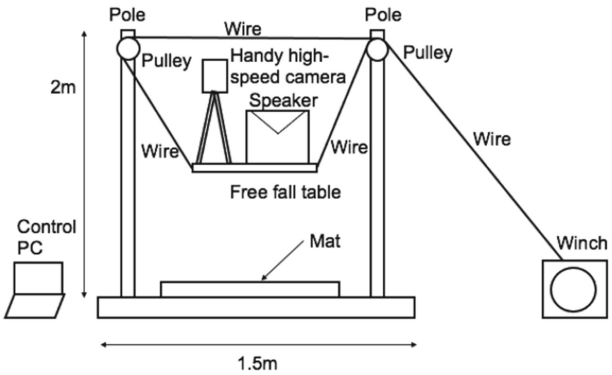

Fig. 7. Conceptual diagram of free-fall system (High-speed camera is installed on the table)

Figure 6 shows a conceptual diagram of the free-fall system. The free-fall table, made of lightweight iron frames with the speaker, is prepared and set in a cubic frame made of sturdy iron pipes. The steel wires are attached to the four corners of the free-fall table, and the four steel wires are gathered and connected to the winch through the pulleys attached to the tops of the four steel poles. By winding up the winch, the free-fall table raises to a height of about 1.5 m. Then the free-fall table freely drops in synchronization with the drive of the speaker on which the paint is placed and the start of shooting with the high-speed camera.

Although it is desirable to mount the high-speed camera on a drop table, Fig. 6 shows a diagram in which it is installed outside in consideration that it leads to an increase in

weight. In addition, a high-speed camera is a delicate device and may break by the impact of a drop. If the fall distance is 1 m to 1.5 m, the fall speed is not high. So, if we need a still image, we can shoot with this setting. Of course, if we want to obtain video images, it is better to install the high-speed camera on the drop table. Figure 7 shows the diagram in which the high-speed camera is on the free-fall table.

Fig. 8. Full view of the free-fall system.

Fig. 9. The scene when the free-fall table and speaker are pulled up.

Figure 8 shows a complete view of the free-fall system. In addition, Fig. 9 shows the state in which the free-fall table and the speaker placed on it are pulled up. In this state, the drop table freely drops in synchronization with the start of driving the speaker on which the paint is placed and shooting with the high-speed camera. The free-fall of the drop table can occur by removing the winch stopper. However, to avoid the influence of the winch friction, it was found that it is more suitable to generate microgravity by cutting the wire every time.

5.2 Fluid Art Under Microgravity

We are currently conducting experiments to generate the "Sound of Ikebana" under microgravity using the free-fall system above. Figure 10 shows several shapes of the "Sound of Ikebana" created under microgravity using the system.

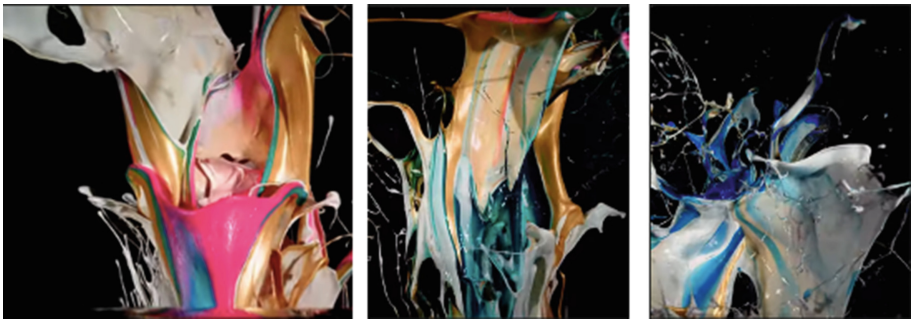

Fig. 10. The shape of "Sound of Ikebana" created under microgravity.

Full-scale experiments are yet to be completed. However, compared to the "Sound of Ikebana" made under normal gravity, the liquid jumps up highly and spreads laterally. More dynamic and beautiful liquid forms can be obtained.

6 Conclusion

As the space age arrives, it is essential to consider the future form of art in the space age. Based on such an awareness, we are interested in new forms of our video artwork, "Sound of Ikebana," produced by giving sound vibration to liquids such as color paints under zero-gravity and microgravity.

In this research, we investigated the method for creating zero-gravity and described the concept, design, and development of a free-fall system for creating microgravity in our laboratory. We also described examples of creating the "Sound of Ikebana" by creating a microgravity environment using the free-fall system.

In parallel with this, we are preparing to produce "Sound of Ikebana" under complete zero-gravity by using parabolic flight. By comparing the production of artworks using the free-fall system in the laboratory described in this paper with the artworks in parabolic flight, we can improve the free-fall system to create fluid art under more complete zero-gravity conditions. As our free-fall system installed in our laboratory is simple to use and capable of adding more functions, the system could be used to create a new type of fluid art.

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