Laser-plasma scanning 3D display for putting digital contents in free space

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ABSTRACT

We present a novel 3D display that can show any 3D contents in free space using laser-plasma scanning in the air. The laser-plasma technology can generate a point illumination at an arbitrary position in the free space. By scanning the position of the illumination, we can display a set of point illuminations in the space, which realizes 3D display in the space. This 3D display has been already presented in Emerging Technology of SIGGRAPH2006, which is the basic platform of our 3D display project. In this presentation, we would like to introduce history of the development of the laser-plasma scanning 3D display, and then describe recent development of the 3D contents analysis and processing technology for realizing an innovative media presentation in a free 3D space. The one of recent development is performed to give preferred 3D contents data to the 3D display in a very flexible manner. This means that we have a platform to develop an interactive 3D contents presentation system using the 3D display, such as an interactive art presentation using the 3D display. We would also like to present the future plan of this 3D display research project.

Keywords: Laser-plasma scanning 3D display, Display in free space, 3D contents analysis, True 3D display

1. INTRODUCTION

We are living in 3D space, so every one has been aiming to watch entertainment contents such as sports and live music performances as 3D visual contents. Unfortunately, such dreams have never been realized. In this paper, we introduce a research project for developing both software and hardware of a display device/system that can display 3D contents in free space, as illustrated in Fig. 1 where people standing in a large-size stadium can watch a 3D live replica of a soccer sports game sent from another game field.

Kimura, Shimada, et. al have already developed an innovative 3D display device "Free Space Display of Point Cloud by Laser-Plasma", that generates 3D image on the surrounding air. This system takes advantage of the technology for generating luminescence at arbitrary point in air based on light emission of laser-plasma phenomenon. The 3D display device uses an infra-red pulse laser reflected with a xyz scanner to make bright plasmas in the air. By controlling the xyz scanner, plasmas are made at the desired position. When many plasma dots are drawn fast enough, the whole image is seen by the viewer. Fig. 2 depicts the 3D display mechanism. This system was presented in Emerging Technologies of ACM SIGGRAPH2006 [11], in which a lot of people were surprised and impressed by the system performances. Kimura et al. also proved that the number of displayed points can be increased by using recent high-spec laser system [12-13]. The uniqueness of this 3D device is the first and only display technology that can produce a light dot in an

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arbitrary point in the space without any screen object that is indispensable for any other display system, including other emerging 3D display techniques.

Fig. 1. Concept of public viewing of a broadcasted soccer game in a stadium.

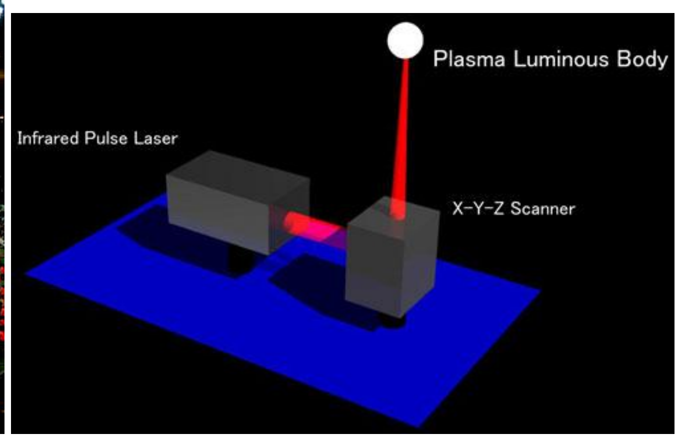

Fig. 2. Free Space Display of Point Cloud by Laser-Plasma.

We have started the project with the volition to develop numerous practical and innovative applications of the display device, which we call “Free Space Display of Point Cloud by Laser-Plasma”. In this project, we do not only focus on the display system development, but also on the 3D contents handling technology and marketing analysis of the demand of such 3D display in our society. We believe that the coordination of those different perspective researches is significant to make the display used in practical applications.

2. DEVELOPMENT HISTORY OF DISPLAY DEVICE

In 2001, Kimura et al. of Burton inc. began to explore how objects can be projected directly in the air. After repeated trial and failure, they found that the plasma phenomenon induced by a laser beam in the air was a convincing way to realize it [1].

When a high power laser beam is focused in a gas, the ionization of the gas occurs. This phenomenon is called laser-induced “breakdown” and the ionized gas is called “plasma”. The breakdown of air is accompanied by a bluish white light emission. Though this fact has been well known among laser scientists and engineers (See reviews [2-3]) since the early reports [4-5], there is a little research applying it for projecting objects in the air.

In 2005, Kimura et al. and Uchiyama of Keio University first succeeded in projecting 2D objects with dot arrays of laser-induced plasma in the air. This first laser-plasma scanning display (Mark I), which is shown in Fig. 3, consisted of four components: (1) a light source; (2) a laser focusing system; (3) a laser scanning system; (4) a controller. Nd:YAG laser (the wavelength is 1064nm, the repetition rate is 100Hz) was chosen as a light source [6-7]. Therefore 100 dots of plasma per second could be generated. A laser focusing system was necessary to maintain the quality of the laser beam. The laser scanning system of Mark I could scan the laser beam only on a x-y plane. That is, horizontal 2D objects could be projected in the air.

Based on this technology, Kimura et al., Uchiyama, and AIST researchers invented/set up the first 3D display (Mark II) of laser-induced plasma in February 2006 [8-10], which is shown in Fig. 4. Mark II has a three dimensional scanning system. The repetition rate was still 100Hz.

In August 2006, they built the 2nd generation of 3D display (Mark III) in San Diego. The light source of Mark III had 300Hz repetition rate. Thus it could generate 300 dots of plasma per second in the air. Mark III was presented in Emerging Technologies of ACM SIGGRAPH2006 in BOSTON [11], as shown in Fig. 5.

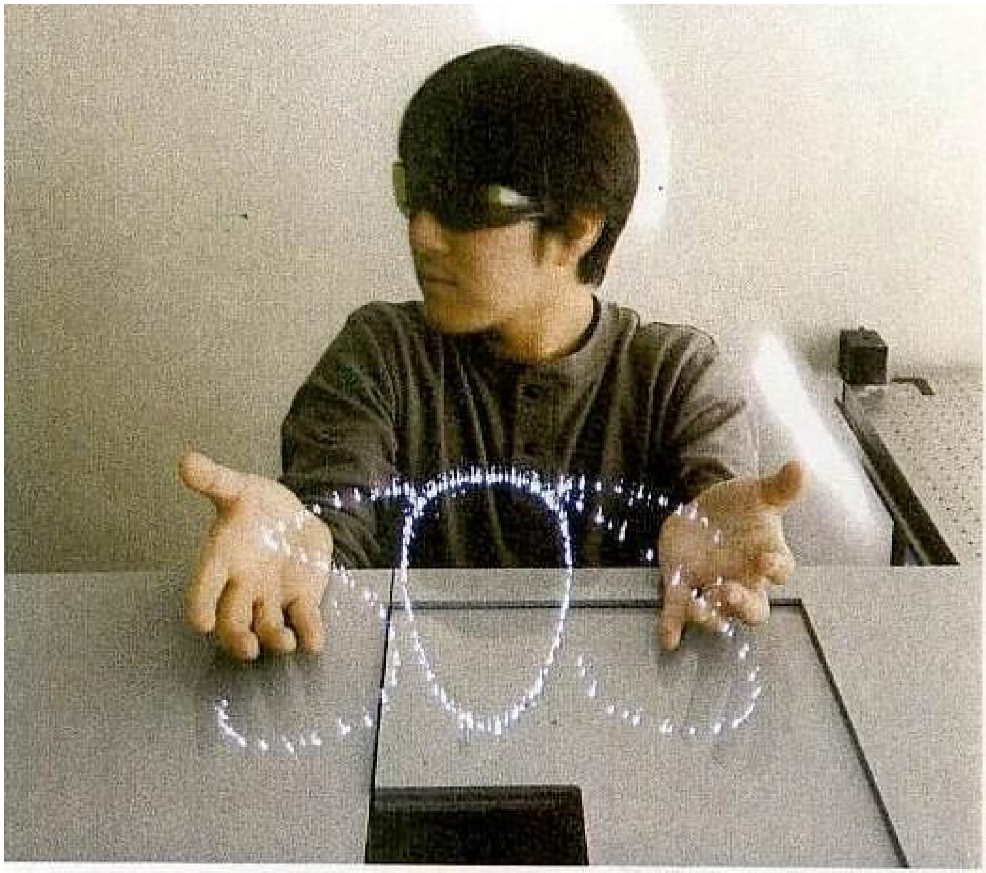

Fig. 3. 2D object “SOS” in the air projected by the first laser-plasma scanning display (Mark I, 2005).

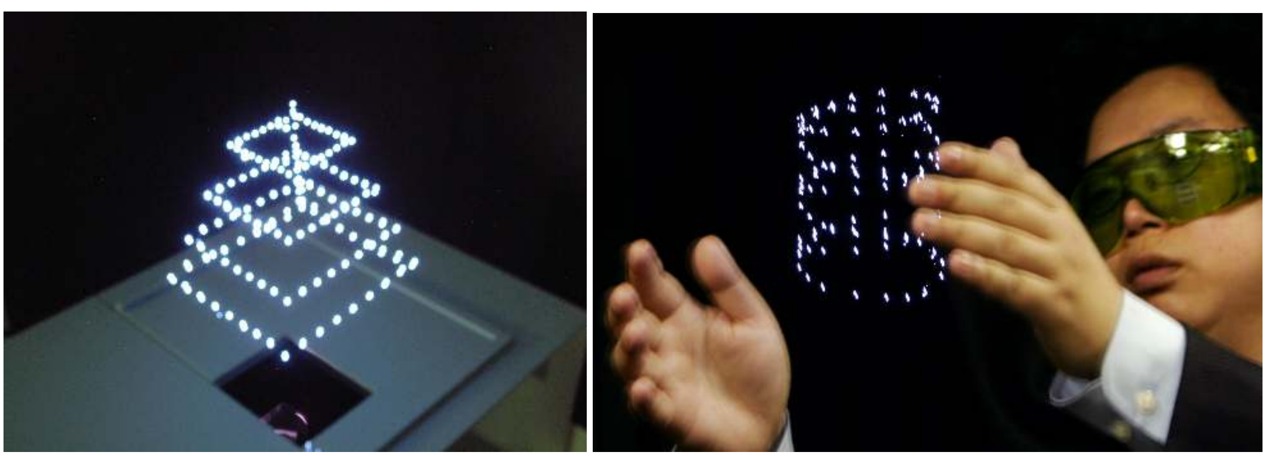

Fig. 4. (Left) 3D object “pyramid” in the air projected by the first 3D laser-plasma scanning display; (Right)3D object “spiral” with a real person (Mark II, 2006) [8-10].

Fig. 5. The scene of the demonstration of the 2nd generation of 3D display (Mark III) in Emerging Technologies of ACM SIGGRAPH2006 in BOSTON [11]

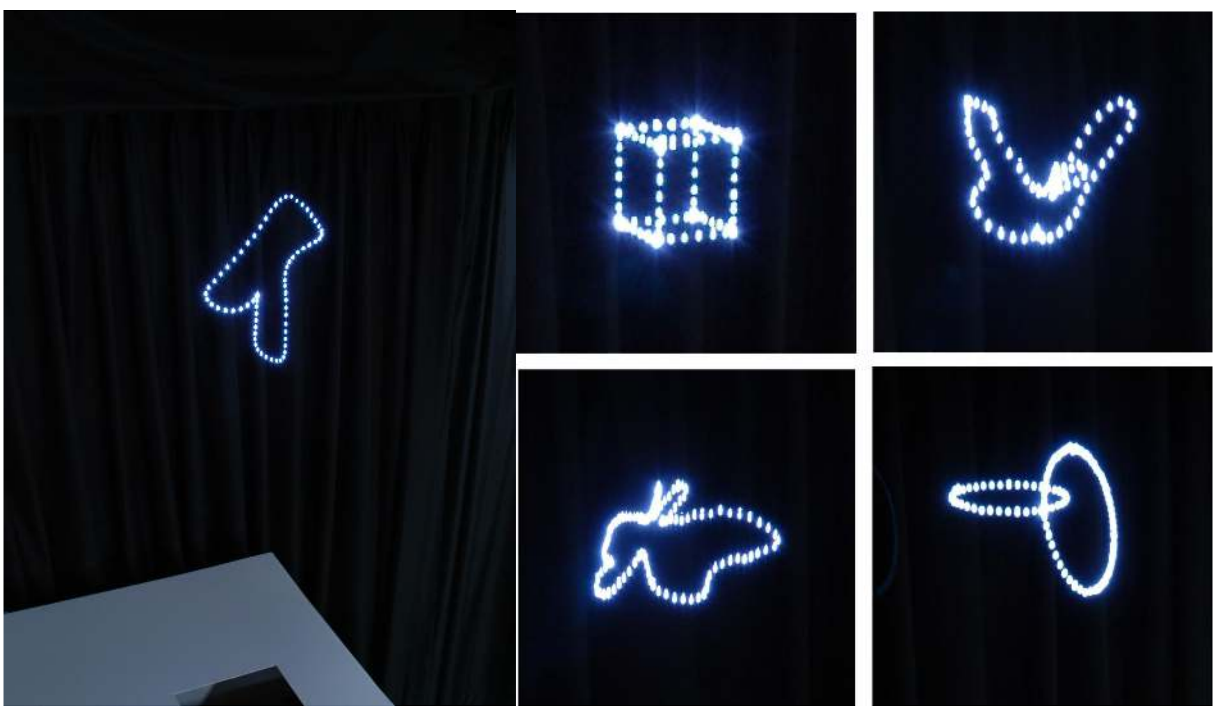

Fig. 6. (Left) Symbol in the Japanese syllabary, “ [i]” projected in the air by the 3rd generation of 3D display (Mark IV) (size: approximately 40cm); (Right) Images projected by Mark IV [12-13].

In 2007, Kimura et al., AIST researchers, and HAMAMATSU Photonics revealed the 3rd generation of laser-plasma 3D display (Mark IV) in the city of Hamamatsu (Japan) [12-13], as shown in Fig. 6. Mark IV is capable of generating 1000 dots of plasma in every second in 50x50x50cm free space. To achieve this new level of projection, they used the newly developed laser source (repetition rate: 1kHz, average power: 200W) and improved the 3D scanning system as well as the laser focusing system. This dot rendering speed enhancement made possible to draw animations more smoothly than Mark III.

Now we are developing the 4th generation of 3D display (Mark V). The size of the light source of Mark V will be reduced for transport. The laser focusing system, the laser scanning system, and the controller will be improved for projecting much complex objections.

3. RESEARCH/DEVELOPMENT SUBJECTS

In order to achieve a practical use of a 3D space display system based on the laser-plasma phenomenon, we define three subjects to be researched and developed.

1. Higher-spec display device (Hardware)

2. Tools and algorithms for 3D contents creation, analysis, and design (Software)

3. Survey of demands of 3D contents in human society (Marketing)

The following parts describe the purpose and current status of each research subject.

3.1 Higher spec display device

The previously developed display device presented in SIGGRAPH2006 can generate luminescence at tens or hundreds points per second. This is not sufficient to practically display a high number of dots with the feeling that those dots are drawn simultaneously. Therefore we need to increase the frequency of the display device. Using high frequency pulse laser will basically makes possible to increase the number of points drawn every second, but the total/global design of the 3D device for such higher frequency laser is an important research issue. One example of such trial has been done by Hamamatsu et al. [12-13], in which they demonstrated that it is possible to display thousands points per second for more continuous display.

Color is another limitation of this display device. Currently, the color of the dots is determined by the laser frequency and can not be controlled. Of course, color management is a relevant issue for 3D display applications. The size of the display space is also a central issue in our system. In our current experiments, this size is up to a 0.5m diameter spherical area, but this should become larger in order to increase the number of viewers that can see the displayed content.

3.2 2.2 Tools and algorithms for 3D contents creation, analysis, and design

Even though researches on technologies for processing, analysis, creation, and display of 3D contents have extensively been performed in the area of visual media processing, virtual reality, etc., most of conventional technologies implicitly assume that the 3D contents will be displayed onto the conventional 2D screen. Indeed, our 3D display involves 3D information can be seen from all around the display. Point rendering vs. primitive rendering. Transparency.

Therefore, we focus on developing tools and algorithms for processing, analysis, creation, and design of 3D contents suited for the 3D display developed in this research project.

3.3 Survey of demands of 3D contents

We consider that a 3D device can be used in various applications, such as outdoor display for advertisement, desktop size display for medial or game application, etc. We will make a survey of 3D contents demands, and then the results will be feedback into the device developments and contents creations.

4. 3D CONTENTS CAPTURING FOR LASER-PLASMA SCANNING 3D DISPLAY

While developing the display system of luminous point cloud in free space, we are continuously performing researches on 3D contents creation, analysis, and design based on computer vision technologies. We believe that computer vision is one of significant research for intelligent handling of 3D media contents, because some sort of recognition, estimation, and retrieve of visual media should be used in media contents creation, analysis, and design, as long as human always do those kinds of intelligent tasks implicitly.

As an example of researches on 3D contents creation, analysis, and design based on computer vision, we would like to introduce a recent research on real time depth image estimation from multiple cameras, which can be used with the 3D display device for realizing the next generation 3D media.

We are intending to display real 3D structure of a scene or objects by the 3D display device. For doing this, it is significant to capture the 3D structure of the scene or objects. In most of cases, the scene is not static, but moving and changing. So it is very important to obtain a 3D structure of the scene or object in real-time for using the 3D display device in effective manner.

Using multiple cameras, we can obtain the 3D structure of the scene in real-time based on the plane sweeping method. Given a small set of calibrated images from video cameras, we wish to generate a depth map of the scene from an arbitrary viewpoint. Considering a scene where objects are exclusively diffuse, we first place the virtual camera cam_x and define a *near* plane and a *far* plane such that every object of the scene lies between these two planes. Then, we divide space between near and far planes in parallel planes *Di* in front of cam_x as shown in Fig. 7.

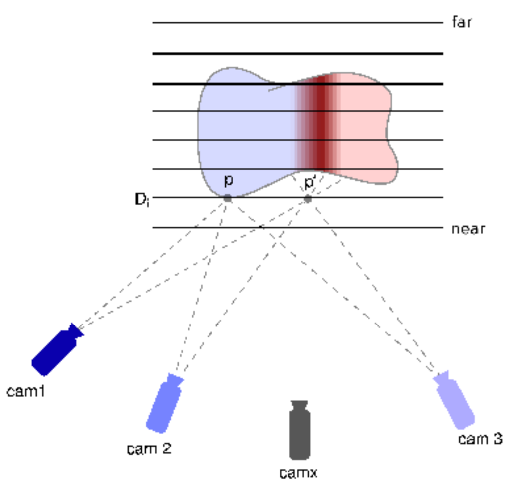

Fig. 7 Plane-sweep : geometric configuration.

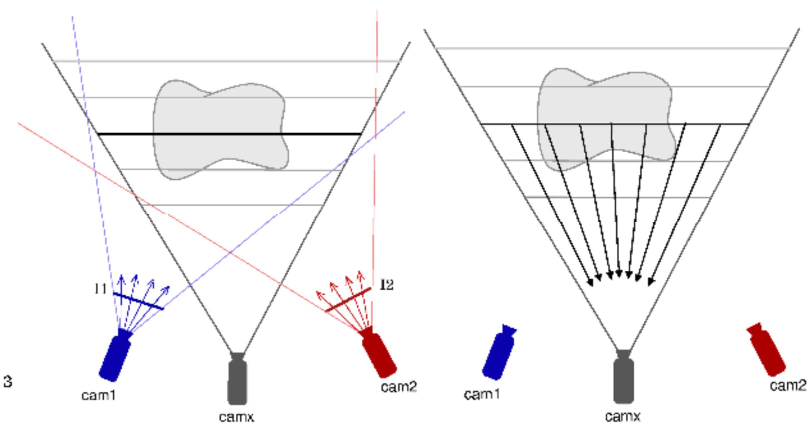

Fig. 8 All input images are projected on the current plane. A score is computed for every point of this plane. These computed scores and depth of the plane are projected on the virtual camera.

Let's consider a visible object of the scene lying on one of these planes *Di* at a point *p*. Then this point will be seen by every input camera with the same color (i.e. the object color). Consider now a point *p'* that lies on a plane but not on the surface of a visible object. As illustrated on Fig. 7, this point will probably not be seen by the input cameras with the same color. Therefore, points on planes *Di* whose projection on every input camera provides a similar color potentially correspond to the surface of an object of the scene.

A usual way to create a depth image is to process the planes *Di* in a back to front order. For each pixel *p* of each plane *Di*, a score is computed according to the matching of the projected colors (Fig. 8). When every pixel *p* of a plane is computed, every score and the depth of the plane *Di* are projected on the virtual camera cam_x. The final image is computed in a z-buffer style: consider a point *p* projected on a pixel of the virtual image. This pixel's depth will be updated only if the score of p is better that the current score. We note that, thanks to this plane approach, this method is well suited for use on graphic hardware.

Fig. 9 shows example results obtained by using multiple/four cameras based on the plane sweeping algorithm. The left image represents an example appearance of the captured 3D shape of the face shown in the middle image, which is assumed to be displayed in the 3D display device. As shown in this example, showing real and dynamic scene or object in the 3D display device will provide a novel way to handle interactive entertainment, art, and communications.

Fig.9 Assumed example of the 3D contents displayed in this project.

5. 3D CONTENTS DESIGN FOR LASER-PLASMA SCANNING 3D DISPLAY

According to the contents displayed on the system, it is very important to consider the characteristics of the system. First of all, the system can draw a set of three dimensional physical points in the air. In addition, it can draw a large-sized (one meter by one meter cubic) image, and is available even in outdoor spaces. So this system is well suited for displaying advertisement or warning signals in public spaces. On the other hand, we should consider the restrictions of the hardware scanning mechanism, which prevents from displaying smooth 3D images, leads to that the smoothness of the scanning order is highly required. In addition, the number of three dimensional points which clearly discernible as a point cloud (image) is limited by the frequency of the laser pulse modulation.

Consequently, we should consider the following conditions for the contents on this display.

-Three dimensional movement and spaciousness are attractive.

-The audience would see the contents from surrounding viewpoints.

-Abstraction of the contents is critical because of the limited number of points.

-The smoothness and scanning order of the contents should be considered.

-Dot rendering involves “semi-transparent” object.

Since it is not easy to satisfy all of them, our research is divided into two categories. The rendering of 3D objects and the rendering of 2D objects with 3D motion. Indeed, 3D objects rendering involves to take into account specific aspect such as cognitive perception or point rendering acceleration that does not occur with 2D object rendering. Moreover, public attentions can be collected by displaying a two dimensional image in the air with three dimensional motion and complex three dimension shape is not necessarily important.

The following examples illustrate some contents ideas.

-Fall of dripping: A dripping falls and extends the spray and the ripple. We can express the 3D motion of point cloud and the existence of the water surface while raising the abstraction level.

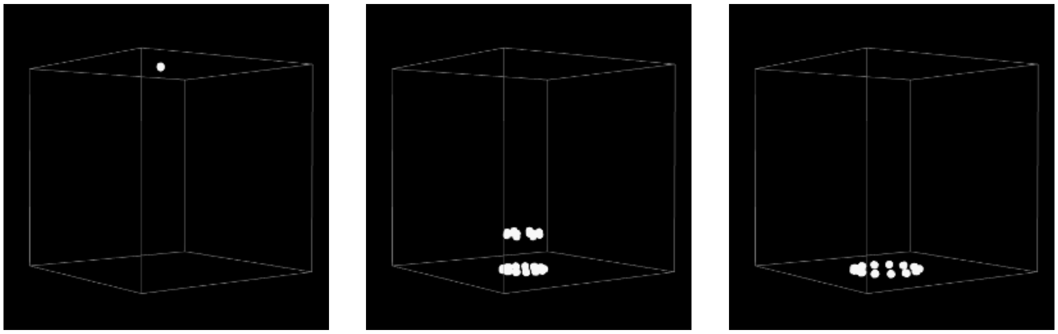

Fig.10 A dripping falls and extends the spray and the ripple.

-Person: A walking person falls down and gets up. We can recognize the point cloud as a human from the motion sequence.

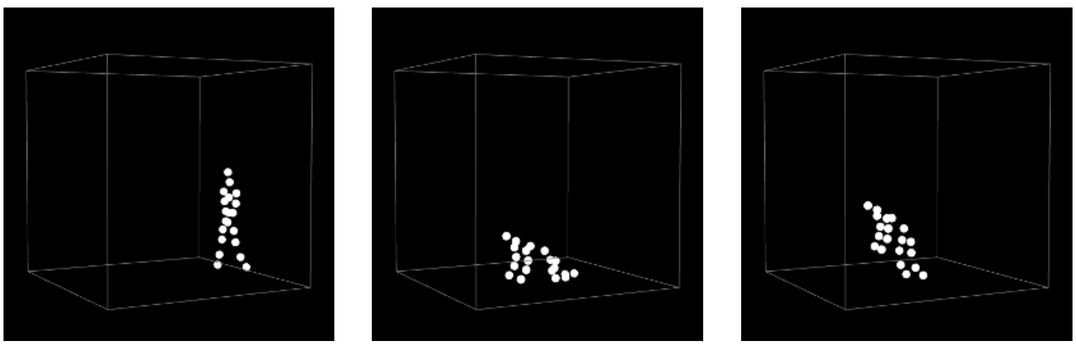

Fig.11 A walking person falls down and gets up.

-Information presentation: 2D letters rotate on a vertical cylinder side. This content can be observed from the surrounding audience.

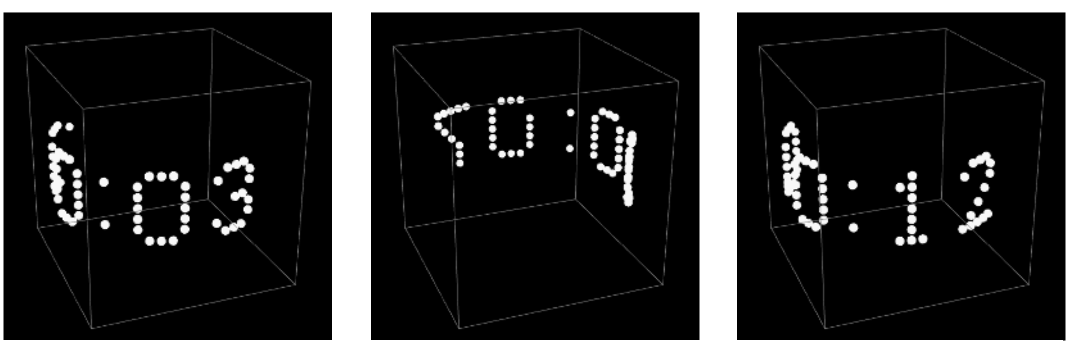

Fig.12 2D letters rotate on a vertical cylinder side.

-Motion graphic of character: Falling points form a message, and break into pieces. The audience would try to figure out what is the message is.

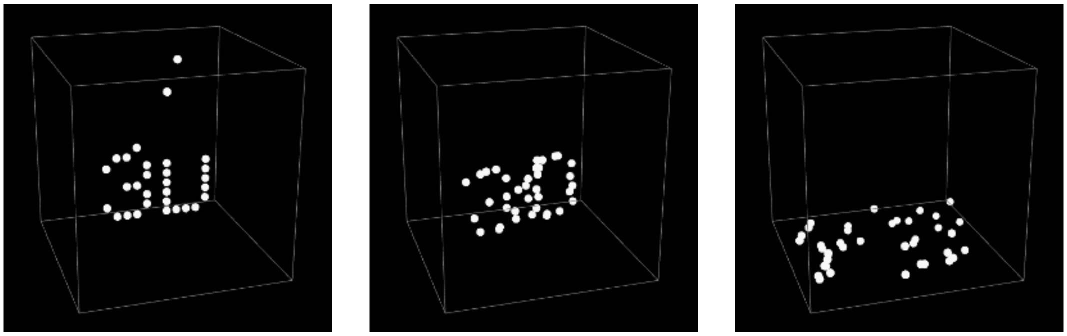

Fig.13 Falling points form a message, and break into pieces.

-UnitedPoints: A set of points which looks like being arranged randomly is recognized as a message only when seen from one unique viewpoint. This work is selected for weekly best selection of a media art TV program.

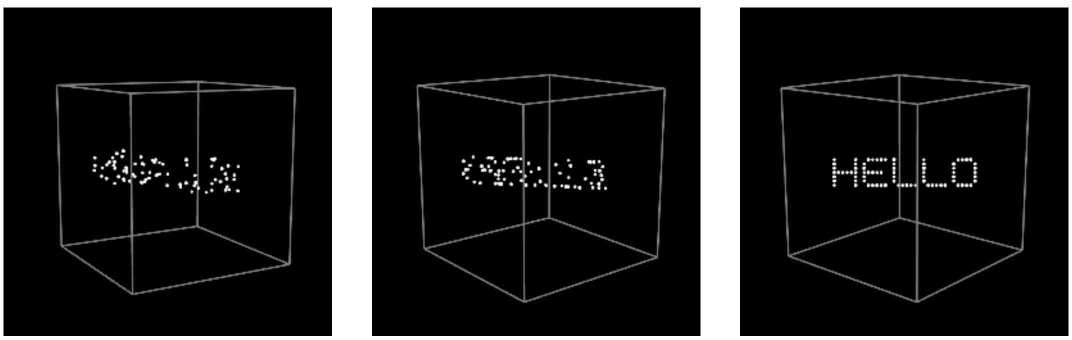

Fig.14 A set of points which looks like being arranged randomly is recognized as a message only when seen from one unique viewpoint.

In this section, we introduce some of ideas for 3D point cloud contents. In the future, we will concentrate on making a GUI tool for producing such contents according to the characteristic of the display system.

6. FUTURE PERSPECTIVE AND CONCLUDING REMARKS

In five years, we would like to demonstrate that the 3D space display can be used for some practical applications. One of our target is outdoor advertisement, like an application where people in wide area could see the same contents from everywhere at the same time. Fig. 15 shows an example of that kind of application using the 3D display device. Even now such free space advertisements are sometimes displayed by using airplanes, balloons, or other kinds of floating system, but such advertisements need huge cost for display, and it is not easy to be frequently repeated. The 3D display device developed in our project will enable to show such free space advertisements at anytime and anywhere.

Other interesting application will be illumination entertainment in the space, such as fireworks. Especially in Japan, fireworks show is one of the most popular entertainment events in summer season. In the same frame of mind, we already found numerous entertainment applications based on the 3D display device.

Fig.15 Examples of the advertisement use of the 3D display device.

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REFERENCES

[1] M. Momiuchi, H. Kimura, Japan Kokai Tokkyo Koho, 2005, 2005-171221
[2] C. De Michelis, IEEE J. Quant. Electron, QE5, pp. 188-202 (1969).
[3] J. F. Ready, “Effects of High-power Laser Radiation” (New York: Academic Press, 1971).
[4] A. F. Haught, R. G. Meyerand, and D. C. Smith, in “Physics of Quantum Electronics”, edited by P. L. Kelley, B. Lax, and P. E. Tannenwald (McGraw-Hill, New York, 1966).
[5] R. G. Tomlinson, E. K. Damon, and H. T. Buscher, in “Physics of Quantum Electronics”, edited by P. L. Kelley, B. Lax, and P. E. Tannenwald (McGraw-Hill, New York, 1966).
[6] N. Kroll and K. M. Watson, Phys. Rev. A, Vol. 5, No. 4, pp. 1883-1905 (1972).
[7] D. E. Lencioni, Appl. Phys. Lett., Vol. 25, No. 1, pp. 15-17 (1974).
[8] http://www.aist.go.jp/aist_e/latest_research/2006/20060210/20060210.html
[9] AIST TODAY International Edition, 2006 No. 21 Summer
[10] http://www.aist.go.jp/aist_e/aist_today/2006_21/hot_line/hot_line_13_2.html
[11] T. Uchiyama, H. Kimura, S. Shimada, T. Kimura, F. Sasaki, M. Kakehata, H. Matsuda, Japan Kokai Tokkyo Koho, 2007, 2007-206588
[12] SIGGRAPH2006 http://www.siggraph.org/s2006/main.php?f=conference&p=etech&s=true
[13] http://www.aist.go.jp/aist_j/press_release/pr2007/pr20070710/pr20070710.html
[14] http://jp.hamamatsu.com/hamamatsu/press/2007/2007_07_10.html