# Closed-Line Based Representation of 3D Shape for Point Cloud for Laser-Plasma Scanning 3D Display

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## Abstract

*In this paper, a method of representing 3D object by a closed line using point cloud for Laser-plasma scanning 3D display is proposed. A new device has been developed for 3D spatial displays. This device generates plasma luminous bodies produced by "laser-induced breakdown" in midair. The plasma luminous bodies (the plasma light points) are continually generated one by one using one kilohertz infrared lasesr, and the position of the plasma light points is controlled by the 3D-scanner. In our method, objects are represented by the closed line of the plasma light points. The drawing order of polyhedrons is decided in consideration of human perception. Additionally, a 3D object which consists of a curved face is represented by a spiral and some accessories in consideration of efficient scanning of the 3D-scanner.*


## 1. Introduction

A new device which is able to emit plasma light in midair has been developed for a new 3D display. When a high power laser beam is focused in a gas, ionization of the gas occurs. This phenomenon is called "laser-induced breakdown" and the ionized gas is "plasma". The breakdown of air is accompanied by a bluish white light emission [1][2][3][4]. It was known for a long time. Kimura, Shimada, et al. have developed an innovative 3D display device "Free Space Display of Point Cloud by Laser-Plasma" that generates 3D images in midair [5][6]. The lights produced by this device are observed as points of light such as the examples in Figure 1. These pictures are the simple result of the previous system which could draw 100 points a second. The advantage of this device is that we can draw points of light in midair without any screens. The device continually can generate plasma luminous bodies one by one using infrared pulse laser. The position of plasma luminous bodies can be changed by the 3D-scanner. The plasma life span is very short. However, the plasma emits high intensive light. Therefore a plasma luminous body can be seen about 0.2 seconds as an afterimage. When the distance between the plasma is short, the scanning locus seems to be expressed by a light line.

The recent device is improved to use one kilohertz pulse laser, so about 200 light points can be seen simultaneously, and the device can display objects in a larger space. However, the drawing method for this device is not known, because this device uses a new drawing mechanism. Therefore, it is necessary to consider the representing way for this system. The laser display system to use at laser art or a laser show is similar to our system. It can draw various objects on the screens or the walls of buildings. It can draw 3D objects, however, it can only draw the result which is an projected image to the 2D screen. Therefore, it is difficult to apply it to our system.

In this research, we propose a method of representing objects using a point cloud line in the laser-plasma 3D display. Here, targets are polyhedrons and curved surface objects. In this system, objects have to be created with a single stroke. We need a way to draw 3D objects in a 3D space in one stroke. That is, we have to create a object with a closed line. In the case of polyhedrons, it is easy to perceive them by drawing one face after the other, compared with the way of drawing lines based on edges, because it is more effective to include the face individual information. Therefore, we propose a method of creating a stroke in the requested order of the faces. The drawing order of the faces is manually decided. Additionally, in the case of a curved surface object, we use a spiral to express it to reduce the burden of the 3D scanner. Furthermore, we can express objects effectively by adding some accessories.

## 2. Drawing system

### 2.1. Laser plasma emission

The plasma emission is explained simply in figure 2. Laser beam is condensed to one point in midair and energy

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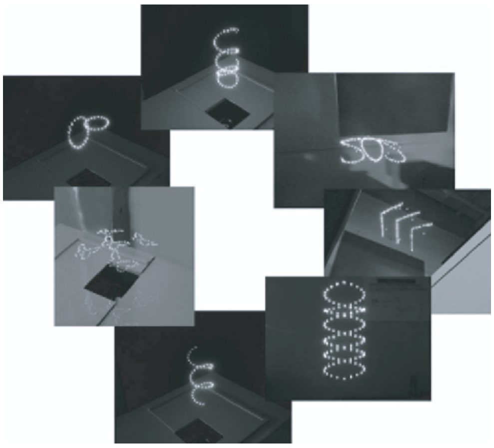


Figure 1. Experiment scenes of the laser-plasma scanning 3D display device. These pictures are the result of the previous model of the 3D display.

of atmospheric molecules increases by making oscillation around here. Then molecules are ionized it is called plasma. When the plasma is generated, strong light is emitted. The generated plasma returns to original state immediately.

### 2.2. The drawing system mechanism

The drawing system mechanism of the device is shown in figure 3. It consists of an infrared laser generator and a 3D-scanner(xyz-scanner). The laser generator continues to create one kilohertz pulse laser, and the 3D-scanner controls the direction of the laser beam and the distance of the focus point. The sequential plasma luminous bodies are continually generated at the arbitrary positions in midair. When the laser is scanning, plasma luminous bodies are drawn on the locus of laser focus point.

The input data to this system is the digital data (the discrete time series data) which show the positions of the plasma luminous bodies as 3D-coordinates, for example, (0.0, 0.0, 0.0), (1.0, 0.0, 0.0), from a control computer. The 3D-scanner is controlled through a D/A converter. The D/A converter converts from the input digital data to analog data for the scanner. The analog data is voltage. However, there is the limit that laser cannot scan next position far from previous position as the characteristics of the scanner. Therefore, we have to consider about the drawing orders to represent objects.

## 3. Method

### 3.1. Representation of polyhedrons

There is a lot of drawing way for polyhedrons. The most efficiently way to describe is the optimal path that is the shortest path through all the edges of the polyhedron. However, it is difficult to calculate the optimal path with the complicated polyhedron. In addition, we cannot see simultaneously the whole parts of the polyhedron not to be able to describe it in 200 points. Because, in the case of the optimal path, the shape which can be seen simultaneously tend not to represent the face of the polyhedron, the perception of the polyhedron becomes unstable. Therefore, we select one way that the contours of polyhedron faces are drawn one by one. The drawing order of the face is manually decided. There are some restrictions for deciding the drawing order of faces.

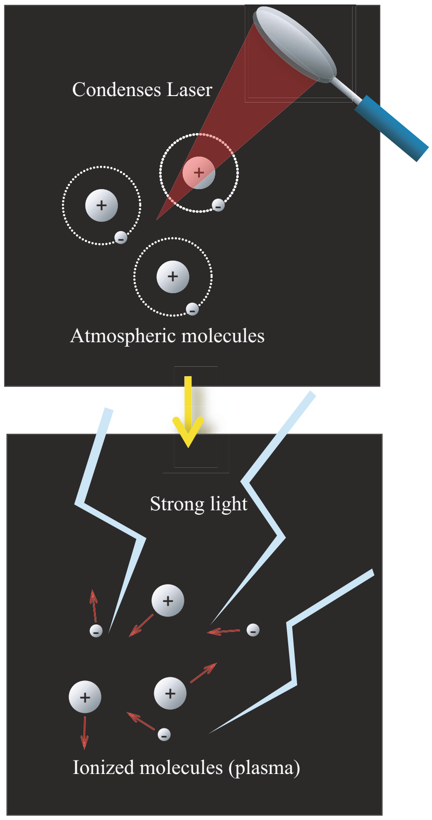



Figure 2. The plasma emission phenomenon. When strong laser beam is focused in midair, molecules are ionized (it is plasma) and strong light is emitted.

•The only faces that can be selected in deciding the order must be connected to the previous face.

•The first face and the end face of the drawing order have a shared side to make the continuity of faces.

•To draw the same face more than twice is allowed.

•To draw the same edge more than twice is allowed.

The way of deciding the path for drawing the edge of a polyhedron is explained in the following. To draw a contour of a face, three parameters are needed.

•the direction of revolution (clockwise or counterclock-

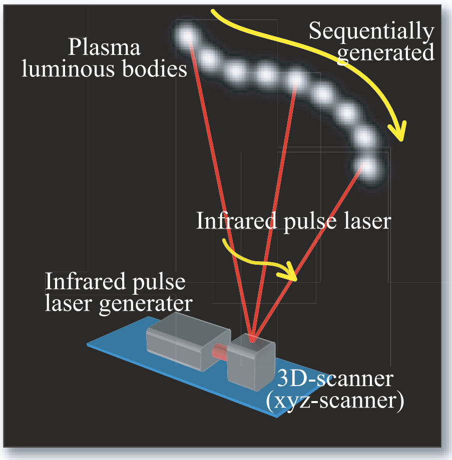



Figure 3. The drawing system mechanism. The 3D display device consists of an infrared one kilohertz pulse laser generator and a 3D-scanner(xyz-scanner). By controlling the laser, plasmas are created at the required position. When many plasma luminous bodies are drawn fast enough (1000 point/sec).

wise)

- the start point
- the end point

The way of detecting these parameters is the following.

1. ) The direction of revolution is decided by the sides which is shared with the next face, as shown in figure 4. Here, $L_r$ is the path length between the $i-1^{th}$ face and the $i+1^{th}$ clockwise, and $L_l$ is counterclockwise. When $L_r$ is more than $L_l$, the $i^{th}$ face is drawn counterclockwise. When $L_r$ is less than $L_l$, the $i-1^{th}$ face is drawn clockwise. The direction of the revolution of the $i-1^{th}$ face does not depend on the direction of the revolution of the $i-1^{th}$ face. When the direction of revolution cannot be decided (for example, when $L_r$ is equal to $L_l$, and when the first face), counterclockwise is selected.
2. ) The start point of the $i^{th}$ face is decided by the direction of the revolution of the $i+1^{th}$ face. The start point is the earlier order vertex which is on the shared side between the $i-1^{th}$ face and the $i^{th}$ face in each direction of revolution.
3. ) The end point of the $i^{th}$ face is the first point of the $i+1^{th}$ face. By deciding the three parameters in this way, the repeated edges will be less and the path is drawn efficiently.

An example of a cube is shown in figure 5. The drawing path which is painted in green is a closed line. It starts from the red dot, and it describes each face one by one. The number in each face is drawing order.

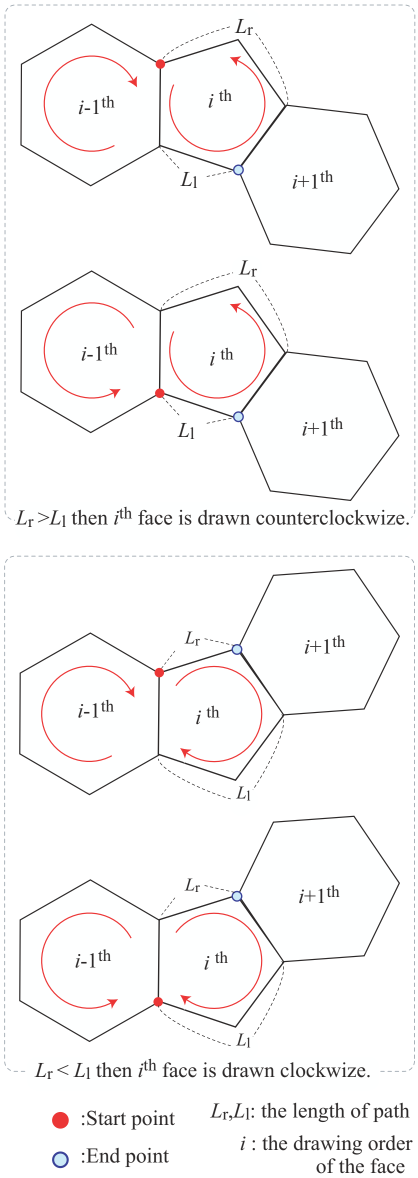



Figure 4. The way of deciding the direction of the revolution of a face contour.

### 3.2. Representation of curved surface objects

We try to represent a curved surface object by describing points on the surface of it, because it has few edges. It is difficult to decide the position of points on the surface, and the drawing order of them. To represent a sphere as the simplest curved object example by points, we tried to two ways. One is the way of describing it by multi circles, and

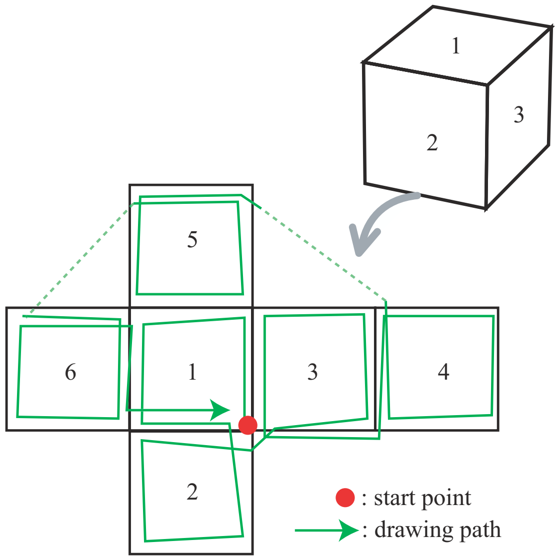



Figure 5. The example of drawing path (a cube). The number in the faces is the drawing order.

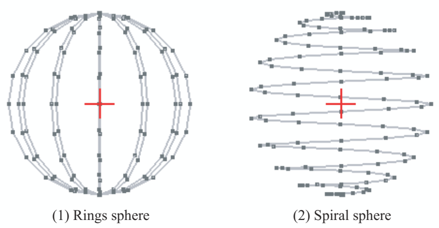



Figure 6. The example routes of describing sphere as the simplest curved surface object. (1) is by multi circles, (2) is by a spiral.

the other is the way of describing it by a spiral. The scanning routes are shown in figure 6. We found that the system hardware prefers a spiral sphere to multi circles sphere for the stability by pre-test. Therefore, we represent a main curved surface with a spiral. It is easy to draw a spiral in one stroke and to represent it by a closed curve.

The way of generating a spiral object shown in figure 7 is simple. This way resembles the sweep function of CAD. At first, we draw a curved line, for example, like an apple. Next, a point is moved on the curve, and this point and the curve are simultaneously rotated. The dotted line in figure 7 is the rotating axis. The resulting locus of the moving point is an apple. It can be drawn in one stroke.

An accessory does not need to be a spiral, but it needs to be a closed curve to be drawn in one stroke. The accessory is put in position near the main spiral object, and they are connected to the nearest point as shown in figure 8. As a result, two objects become one object that can be drawn in one stroke.

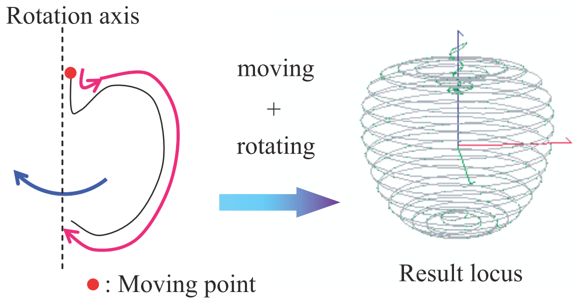



Figure 7. The example of creating a spiral object (an apple).

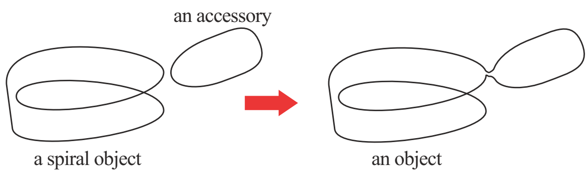



Figure 8. The connection of a spiral object and an accessory.

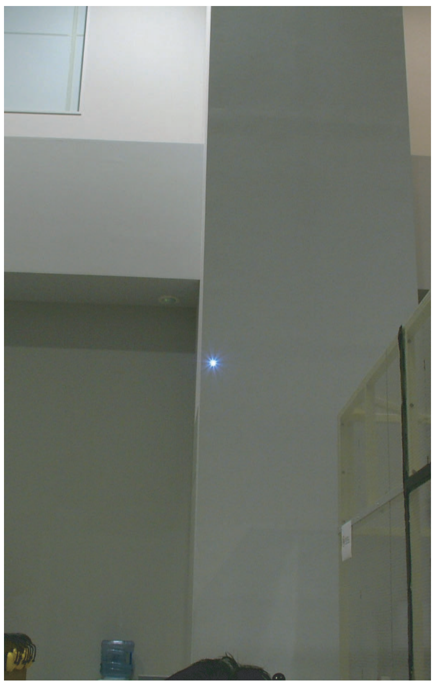


Figure 9. Plasma luminous body. It is basic state of the system. (Shutter speed:0.25[s])

## 4. Experiments

Plasma luminous bodies which are generated at the same place are observed as shown in figure 9. It is basic state of the system. About 250 points of plasma are taken in this picture at the same position.

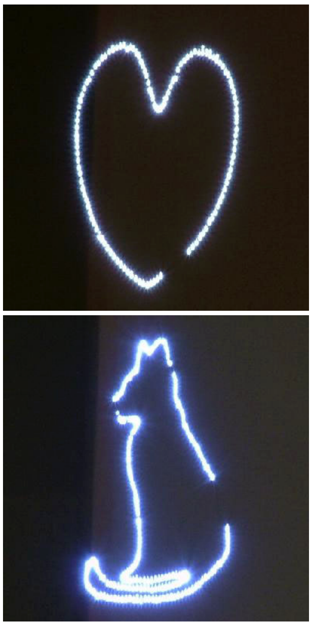


Figure 10. The example of 2D shapes. (Shutter speed:0.25[s])

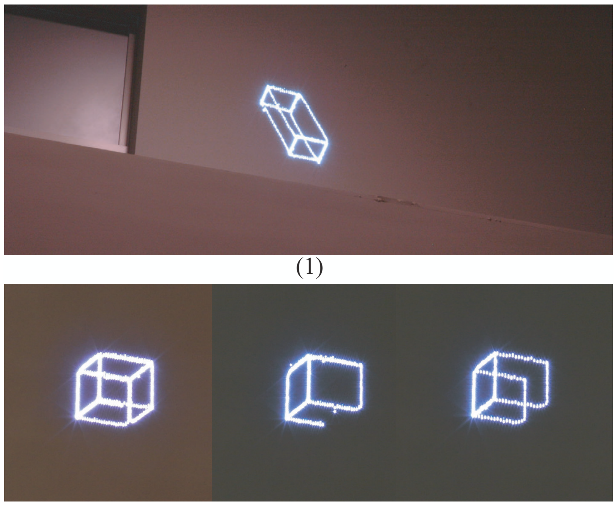



Figure 11. The examples of simple polyhedrons. The upper image (1) is a rectangular solid, The lower left image (2) and the lower right images (3) are the same cube. The pictures of (3) are progress of (2). (Shutter speed:(1) 0.33[s], (2) 0.5[s], (3) 0.25[s], Aperture Value:F8.9)

### 4.1. 2D shapes

To know the drawing ability of the system, some 2D shapes are shown in figure 10. The complex shapes can be drawn by the system.

### 4.2. Polyheadrons

The result of simple polyhedrons, a rectangular solid and a cube, are shown in figure 11. The pictures of the cube were taken by different shutter speed. The pictures which are taken by the shutter speed 0.25[s] show the progress of the drawing cube.

A semi-regular dotriacontahedron is shown in figure 12 as an example of the more complex polyhedrons. In figure 12, a part of a whole object is photographed by changing the shutter speed of camera is shown.

### 4.3. Curved surface objects

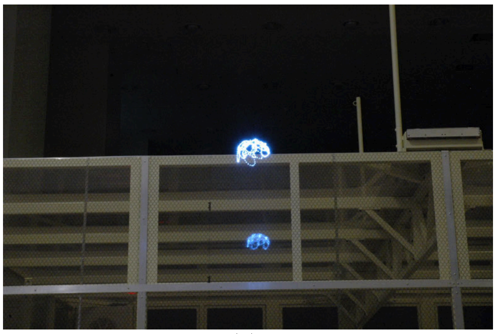
The result of a sphere, which is a simple curved surface object, a sphere is shown in figure 13. A sphere which has a disc added as an accessory, like Saturn, is shown in figure 14. The disc is a spiral object. In figure 14, a part of a whole object is photographed by changing the shutter speed of camera is shown.

Furthermore, a spiral object such as an apple shape and the apple with a leaf as an accessory are shown in figure 15. The leaf is not a spiral object.

### 4.4. Discussions

In the case of the simple polyhedron, it could be drawn intelligibly. In the case of the complex polyhedron, it was difficult to perceive it, because we could not see simultaneously all the faces of the polyhedron. In this paper, the drawing order of faces was decided manually. Further examination is necessary, because our easiness of perceiving a polyhedron changes with the drawing order of its faces. For example, when we saw the face of the opposite side together, our perception of it became difficult, so we have to consider the drawing order of the faces. Furthermore, when the length of the drawing path is larger, the distance between plasma luminous bodies is longer, too. Therefore, the scan speed of laser becomes high, and the drawing result is unstable, for example, corners curl up as shown in figure 16 (2). We have to use appropriate number of points to represent objects.

The representing of the curved surface was enabled by using a spiral. The surface can be perceived, even if it is drawn by an only curved line using point cloud. This spiral way is good for the system hardware. Additionally, various objects can be expressed efficiently by connecting some object as accessories. However, when the object to draw is large, the plasma light points to use increase. Therefore, we cannot see a part of the whole object simultaneously, and then it is difficult to recognize it. About that, it is necessary that we experiment with the relation of the revolution number of the spiral, the density of the plasma light points and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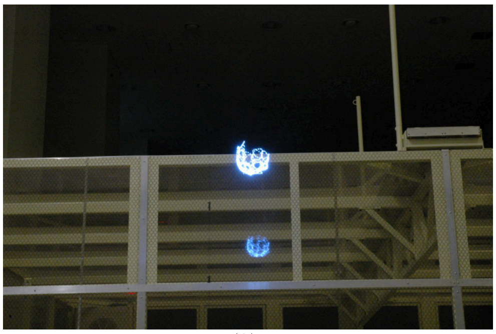
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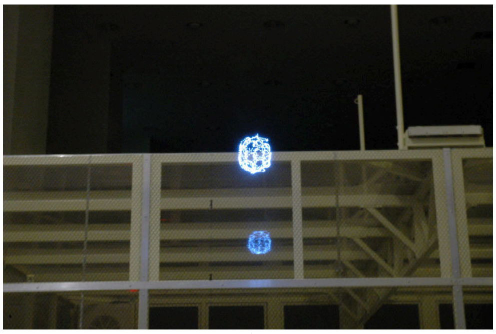
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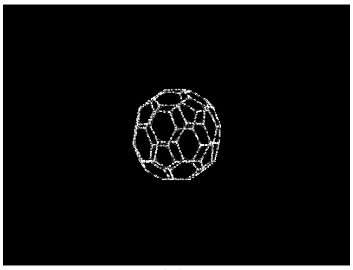
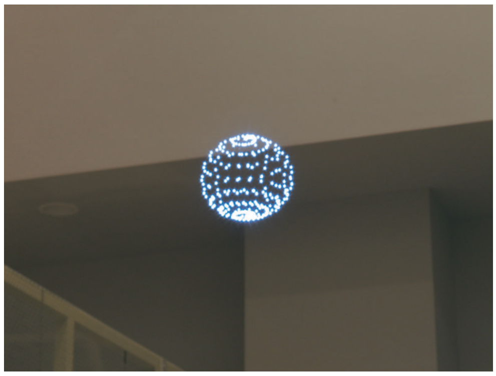

(4)

Figure 12. A semi-regular dotriacontahedron. The top image (1) is the result that the upper half of the object is photographed. The second image (2) is the lower half. The third image (3) is the whole object. (4) is the computer graphics model of it. The size of the object is about 25[cm]. (Shutter speed:(1) and (2) 0.25[s],(3) 0.33[s], Aperture Value:F25)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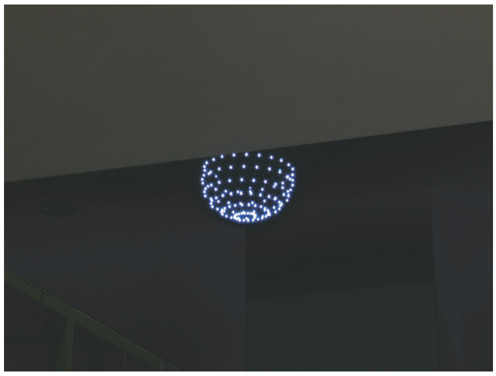

(2)

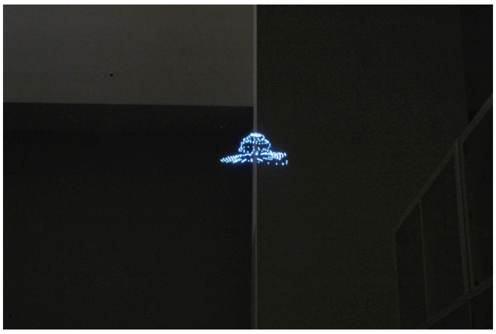
Figure 13. A simple object (a sphere). The size of the sphere is about 25[cm]. (Shutter speed:(1) 0.25[s], (2) 0.125[s] Aperture Value:F8.6)

the easiness of perceiving the object. Furthermore, there is the difference between the real object and its photograph. We cannot feel depth from it very much. Then, we tend to feel the vertical length of object shorter than the same object of photograph. It is necessary for us to investigate this phenomenon.

## 5. Conclusion

In this paper, we proposed a method of representing a 3D object by a closed line using point cloud line for the laser plasma scanning 3D display. In the case of a polyhedron, the way of representing the edges that considered the drawing order of faces was proposed. We could see the faces of the polyhedron consciously by this way. In the case of curved objects, the way of representing the whole surface using spirals was proposed. We were able to draw real 3D curved surface objects.

In this system, the object is drawn by the plasma luminous bodies which are generated sequentially, so that time lag occurs. Therefore, the number of the points that we can perceive simultaneously is limited when we try to draw a large object, and we cannot recognize the object. It can be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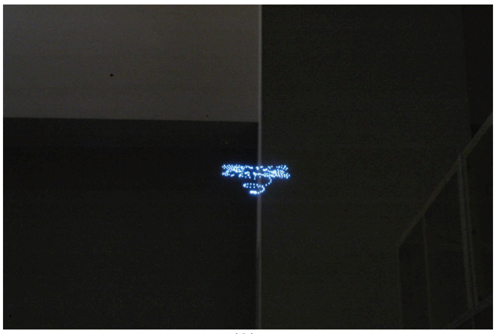
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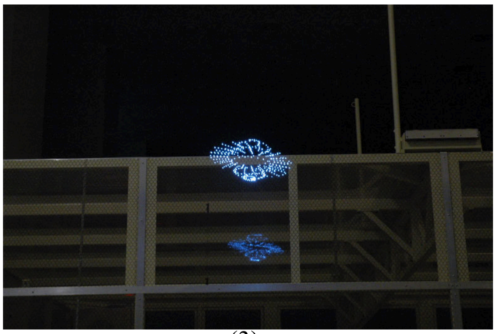
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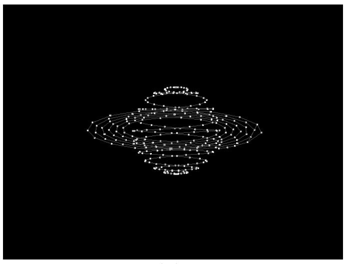
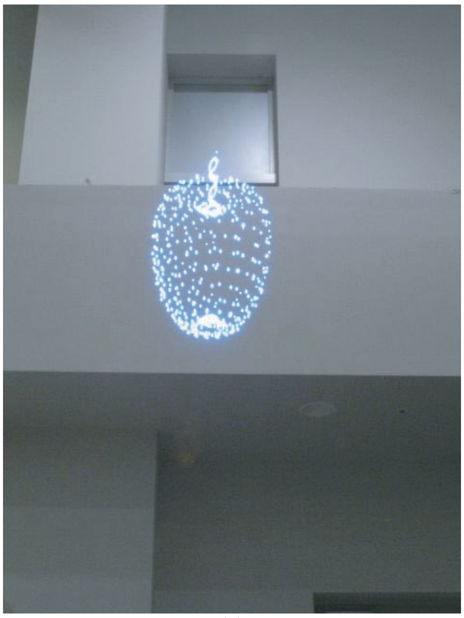

(4)

Figure 14. A compound object which consists of two spiral objects. The top image (1) is the result that the upper half of the object is photographed. (2) is the lower half. (3) is the whole object. (4) is the computer graphics model of it. The size of the object is about 25[cm]. (Shutter speed:(1) and (2) 0.25[s],(3) 0.33[s], Aperture Value:F25)

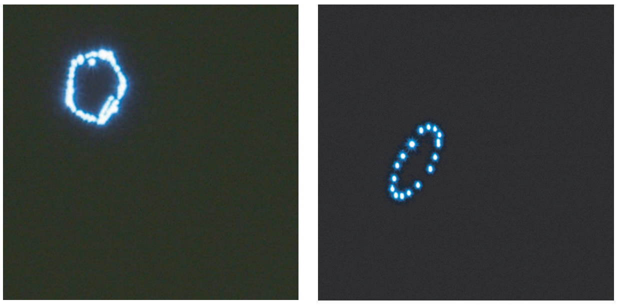

(1)

(2)

Figure 15. Apples. The upper image (1) is only a spiral object. The lower image (2) is an apple with a leaf as an accessory. The size of the apple is about 20[cm]. (Shutter speed:(1)0.67[s], (2)0.62[s], Aperture Value:(1)F22, (2)F18)

coped by improvement of the hardware (for example, the plasma generator is increased) to solve this problem. By the improvement, it will be able to draw multi objects simultaneously, too.

In future works, we have to consider the drawing-order



(1) (2)

Figure 16. A face of the semi-regular dotriacontahedron. In these pictures, the number of plasma luminous bodies to use for a face is different. Many more points are used on the left (1) than on the right(2). When many points aren't used, the scanning speed becomes fast and corners curl up.

that we can perceive objects by using short memory, even if all of the plasma light points aren't displayed simultaneously. In addition, we try to create moving image by generating animation effect.

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