LuminantCube: Omnidirectional and Auto-stereoscopic 3D Display using Diffusion of Laser-light within a Micro Region

FUJII Takuya[1], ENDO Ryuta[2], OHASHI Yoshiki[3], ISHII Hirotake[4] and SHIMODA Hiroshi[5]

1. *Graduate School of Energy Science, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan (fujii@ei.energy.kyoto-u.ac.jp)*
2. *Graduate School of Energy Science, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan (ryuta@ei.energy.kyoto-u.ac.jp)*
3. *Faculty of Engineering, Electrical and Electronic Engineering, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan (ohashi@ei.energy.kyoto-u.ac.jp)*
4. *Graduate School of Energy Science, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan (hirotake@ei.energy.kyoto-u.ac.jp)*
5. *Graduate School of Energy Science, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan (shimoda@ei.energy.kyoto-u.ac.jp)*

Abstract: Standard flat screen 3D displays such as 3D-televisions use parallax to replicate spatial effect within the plane. However, such types require wearing special glass-like equipment and both viewing angle and total number of viewers are very limited. Thus, the present paper proposes a new 3 dimensional display named "*LuminantCube*", which is able to provide omnidirectional and auto-stereoscopic views. *LuminantCube*, consisted of a glass cuboid and laser pico-projectors, uses diffusion of lights projected from the projectors, caused within a volumetrically arranged micro voids processed numerously and randomly inside the glass. LuminantCube will be able to achieve high resolution and contrast ratio by optimizing the algorithm of converting projector pixel to display pixel for multiple projectors for the former and overlapping multiple light rays from multiple projectors for each individual micro voids for the latter.

Keyword: multi-viewer, tracking less, transportable, correspondence of convergence and focusing, full colour

1 Introduction

Researches on stereoscopic displays have been a trend for a few decades, nevertheless it is not yet fully popularized for common use. This result attributes to many challenges still left to be solved for existing stereoscopic 3D displays. For example, commonly used 3D-televisions use binocular parallax in order to replicate images and videos with spatial effect within the plane. However, most of them require viewing from the front of the screen using special equipment such as polarizer glasses or high-speed shutter glasses[1]. Consequently, the viewing angles and number of simultaneous viewers are limited[2].

Hence, the present paper proposes a new 3 dimensional display named "*LuminantCube*", which is able to solve the above challenges by providing omnidirectional and auto-stereoscopic views. *LuminantCube* is consisted of a glass cuboid and a laser pico-projectors. It uses luminous phenomenon by diffusion of light projected from the projectors caused within a volumetrically arranged micro voids processed numerously and randomly inside the glass cuboid. By using the projector to emit multiple voids to form a group of luminous points, the display can show 3D images and animations in full colour.

The contrast ratio and maximum brightness depend on those of projectors and at the present stage it is difficult to use under sunlight in outdoor environment. This specification can be solved by overlaying multiple projections for each micro void instead of one to one correspondence. Moreover, the resolution can be also improved by increasing the number of projectors to be used in order to increase the projectable micro voids without conflicting with others, resulting over 10000 pixels inside the cuboid for the future. As for the first prototype apparatus, there are approximately 3600 voids processed inside

the cuboid and is able to show an animation of simplified molecule structure of H_2O in full colour.
Three respective examples for the future applications can be introduced. First is an interface for educational or design aiding purpose assumed for multi-user operation or simultaneous observing. The former can be as simple as showing time variation of molecule structure 3D model within a chemical reaction, and the latter can be used for designing large-scale facilities with simultaneous handling. Second example is a 3D digital signage with enlarged version of the present display. Last is a real time 3D tele-communication or tele-presence much like the ones we see in Sci-Fi films. This can be achieved by installing a depth camera as well as improvements for a faster processing algorithm to reconstruct the user's face and surrounding environments.

2 Related researches

There have been many researches based on methods and algorithms aiming to achieve stereoscopic displays. For example, Iwasawa et al. [3] and Yamada et al. [4] each proposed a flat-screen type stereoscopic displays which use Fresnel/lenticular lens placed in front of the screen and multiple projectors to show different images for each view. These displays don't require any kind of special glass-like equipment. However, as the screen itself is planar, viewers were required to stand in front of the display within only a few distances to the sides in order to achieve the stereoscopic vision. Also, the method with multi-layered transparent displays showing different images for each layer, which Barnum et al. [5] and Gotoda[6] each proposed had the same disadvantages of limited viewing angle as the flat-screen types, meaning that the display was not capable of multi-angle viewing. In the other hand, the mirror-spinning technique with a fast spinning LED panel or a mirror reflecting the projection to every direction with differing images which Jones et al. [7] proposed overcame the former problems as it had 360 degrees free viewing angles. The main disadvantages of this technique are that the size of the display itself is limited and flickering would occur even at high refresh rate. Lastly, examples for the volumetric display techniques with no limited viewing angles are the water droplets display proposed by Eitoku et al. [8] and laser plasma 3D display

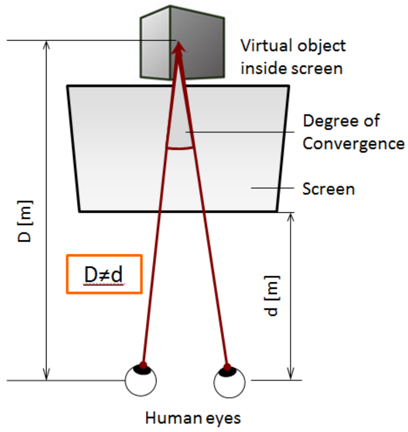


Fig. 1 Conflict between degree of convergence and focusing.

proposed by Nakatani et al. [9]. These displays had a more natural viewing experience with omnidirectional viewing but the resolution was critically low making it difficult for showing complicated 3D content.
Because above mentioned challenges are not solved, natural, omnidirectional and auto-stereoscopic 3D displays has not yet achieved by the existing methods and techniques.

3 Principle of proposed method using diffusion of laser lights

3.1 Challenges of designing omnidirectional and auto-stereoscopic display methods

In order to achieve a natural stereoscopic viewing, meaning a display with omnidirectional viewing with naked eyes, both binocular parallax and kinematic parallax must be replicated[10]. In another words, differing images must be shown for each eye and for each viewing angles as the viewer moves around the display.
Especially for the former, the degree of convergence and focusing are used to recognize the distance to the observing object from the viewer[11]. However, when trying to replicate virtual objects with excessive depth information within a flat-screen 3D display, an inconsistency between focusing distance and convergence degree will occur. When viewing the content in the display, the human eyes would focus to the distance to the screen itself, meaning that the distance perceived from focusing will be equal to d [m] in Fig. 1. However, if the object of the content is placed further away with a larger virtual depth inside

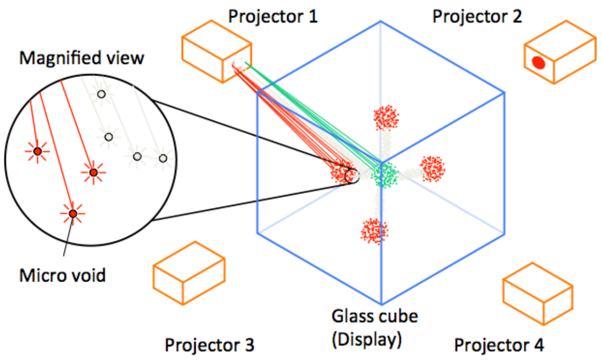


Fig. 2 Principle of LuminantCube.

the display, the convergence degree will become smaller than the actual, meaning that the distance perceived from convergence degree will be equal to *D* [m] in Fig. 1. As these two distances conflict, it will not only induce 3D sickness and visual fatigue but also inhibit perceiving spatial effect for people with stereo-blindness[12-14]. Hence, for general flat screen 3D displays, ±2-3 [deg] is the maximum range of achieving the correct binocular fusion[15].

For the latter, existing methods use projector array and slit layer to show different sets of images for each view point[16]. However, because it requires a large number of output devices according to the number of viewers, the overall apparatus will become complicated and expensive, as well as having a relatively low resolution.

In order to overcome these challenges, the pixels for showing the 3D content should be placed in a three dimensional volumetric arrangement, with light diffused to every direction, just as the light in the real world we see would do.

3.2 Configuration of the proposed method

To satisfy the above mentioned manner to achieve an omnidirectional and auto-stereoscopic display, the present paper proposes a method using luminous phenomenon by laser light diffusion within a volumetrically arranged micro region. As shown in Fig. 2, by projecting light into a transparent glass cuboid with micro voids processed randomly and numerously inside, each void would emit light towards every direction when a projected light hits. This phenomenon makes possible of showing 3D images and animations regardless of number of viewers and their viewing angles. Therefore, the proposed method can be said as natural stereoscopic

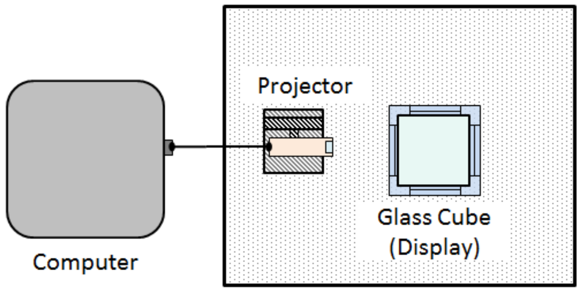


Fig. 3 Schematic view of the apparatus.

viewing with no requirement of special glass-like equipment or head tracking. Therefore, with stereoscopic vision with their naked eyes viewers are not only freed from visual fatigue and 3D-sickness but are also able to walk around the display freely and observe the content's each dimension.

Note that the pixels can only emit where the micro voids are preliminarily processed. In another words, it cannot be changed freely for each projection. As a matter of fact that the pixels at the further side from the viewer is visible from between the margins of the closer pixels, the viewer will be easier to recognize each part of the content correctly by adding colour contrast between them.

3.4 Controlling method for laser light projection

In order to show any 3D content perspective correctly, the directions of each projection must be controlled to hit the intended micro voids without hitting the others in its path. Also, despite the fact that the projected light would diffuse into every direction when hitting the micro voids, the light penetrating from the incident direction would remain strongly. Thus, every path of each pixel set to be projected will be calculated carefully not to conflict with each other from entering and exiting the cuboid. To help this procedure, each micro voids are placed randomly and spacing between are secured above a certain amount. Accordingly, the pixel density will be comparatively lower to existing flat screen type 3D displays. However, Gu Ye et al. reported that in spite of the imperfectness of visual information, if the image shows more than a certain quantity, the viewer can perceive the content by complementing the missing information[17]. Thus, the proposed method can satisfy the viewing experience.

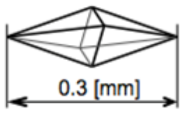


Fig. 4 Shape of micro void

Table 1. Specifications of laser pico-projector (Celluon inc., picopro)

Display Performances	
Display Method	Laser
Brightness	32 [ANSI Lumens]
Aspect Ratio	16:9
Throw Ratio	1.3
Contrast Ratio	80000:1
Resolution	1920 x 720 [pixel]
Colour Depth	RGB 24 [bit]
Focus	Focus free

4 Specifications of first prototype apparatus

4.1 Design of the hardware

The schematic view of the apparatus is shown in Fig. 3. The apparatus is consisted of a glass cuboid with a height of 80 [mm], width and depth of 50 [mm] respectively and a laser pico-projector which is placed 50 [mm] to the side of the glass cuboid and connected to a computer for controlling. Inside the glass cuboid, which is the display itself, there are approximately 3600 micro voids processed in a random arrangement using *High-power Laser Engraving Method*[18]. Also, 4 markers are processed on the surface of the cuboid to use for calibration which will be explained later. Here, to aid the diffusion to spread in all direction equally, the shape of the micro voids are designed approximately as shown in Fig. 4, and each are small enough that it is not visible without any projection. Additionally, as the distance between the projectors and the voids differ according to the latter's coordinate inside the display, focus-free projectors with laser light source are used for projection. The specifications of the projector are shown in Table 1. The reasons for choosing glass for the display material are because it was clearer and the colour reproducibility when projected was relatively higher than those of 3D printed transparent cuboid as shown in Fig. 5. Here, the latter is printed by Stratasys Objet500 Connex 3D using VeroClear-RGD810.

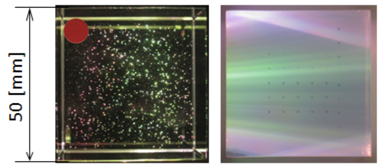


Fig. 5 Comparison of appearance between glass (left) and 3D printed material (right).

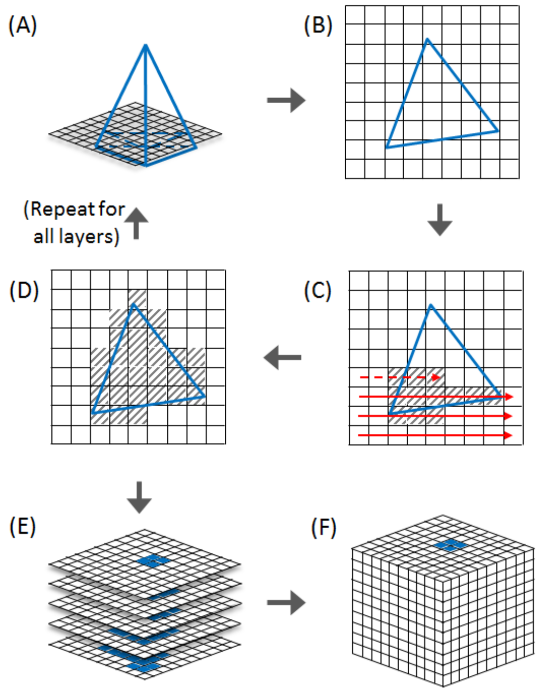


Fig. 6 Algorithm of middleware.

According to the simulation of projection, it is possible to increase the resolution, in other words the number of micro voids, to over 10000. However, at the current stage of the first prototype apparatus, there are only approximately 3600 pixels inside the cuboid display as the calibration for correct projection is at a testing stage.

4.2 Design of the middleware

Respective models which require observing with auto-stereoscopic display are polygon models used for 3DCAD, point cloud data acquired using RGBD cameras such as Microsoft Kinect and grid models used in fluid dynamic. In order to use these data, brightness and RGB data calculated individually from the original data must be assigned. To make LuminantCube easy to use for any user, we need to design the apparatus usable without considering the differences of each model type, position of the

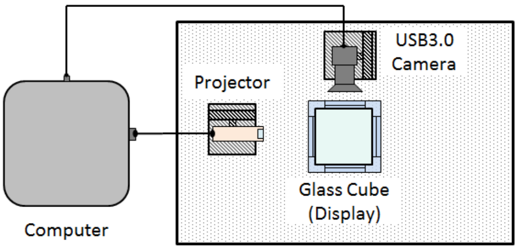


Fig. 7 Hardware composition for calibration.

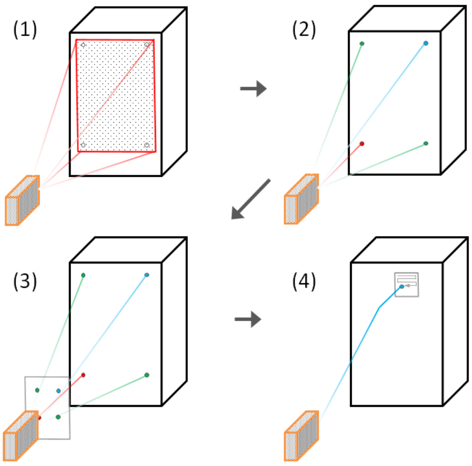


Fig. 8 Calibration algorithm (Limited Region Scanning Method).

pico-projector and the coordinates of the micro voids. Hence, in the present study a middleware which calculates the projection information from several kinds of data types automatically is developed. Below explains the conversion procedure from STL format, which is a commonly used format in 3DCAD, to a state of projectable data.

3D data in an STL format is written with vertices coordinates of the models surface divided into micro triangles, meaning that it doesn't contain the data of inner filling. Therefore, in order to show a solid model, a procedure to add the inner data is required. In the present middleware, the 3D model is put in a cubic lattice shown in Fig. 6 and interferences between the two are detected. First, (A) the cubic lattice is divided into horizontal layers and lines of intersection between the 3D model are detected. We call each of the horizontal layers the "grid" and each line of intersection the "frame". (B) Here, on that layer a shape framed by multiple lines of intersection are formed. Next, (C) for each line on the grid from left end to right, each square is scanned whether it's crossing over a frame and the number of n^{th} square to be detected as so on that line. Here, each square on that line between the odd and the even number of times are recorded as "the internal part" of the 3D

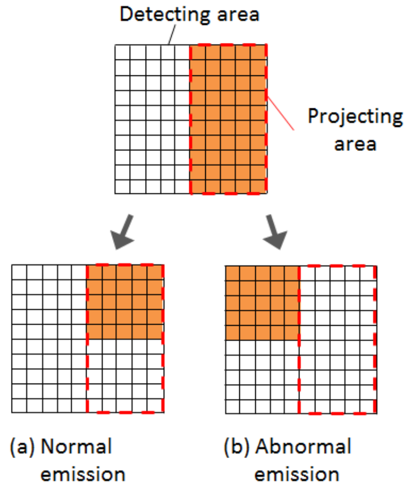


Fig. 9 Bisection Scanning method algorithm.

model. (D) These procedures are repeated for every line on the grid. Then, each square that are detected as the surface or the internal part of the 3D model will be recorded as regions to be projected, given with optimal brightness and RGB data based on the original 3D model. (E) Then the whole procedure is repeated for every grid and the data is combined to make a database of brightness and RGB data for the entire cuboid. (F) Finally, database from (E) is matched with the projector-pixel-to-void-coordinate conversion database to make an image output to the projector. This procedure is repeated for each frame to show animations.

4.3 Calibration algorithm

In order to project accurate enough to hit individual micro voids, calibration to adjust the position and the direction of the projection is required. Therefore, in the present apparatus, a camera placed as shown in Fig. 7 is used to detect the conditions and the positions of the voids' emission when light is projected from the projectors and to adjust the projection accordingly. There are mainly two methods to scan whether the voids are emitting correctly. First is "Total Pixel Scanning Method", which is to project every projector pixel with one pixel at a time starting from the upper-left corner to the bottom-right corner and detect the state of the emission each time. Second is "Limited Region Scanning Method" shown in Fig. 8, which limits the detecting pixel area according to the trajectory of the projection calculated from the position of the projector and the coordinates of the voids. The former is simple but the required time for the process

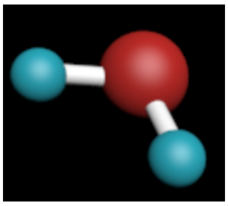


Fig. 10 Design of 3D content prototype.

increases according to the total number of pixels. However, as the required time for the process of the latter only increases according to the total number of voids, the total processing time can be much shorter. Hence, for the present design, Limited Region Scanning Method is used. The detailed procedure is written below.

First, (1) the position of the projection is adjusted so that the void processed area of the cuboid fits inside that area. Then, (2) the pixel areas of the projector which can project the four markers processed on one of the surface of the cube are calculated. Next, (3) perspective-4-point problem using markers' coordinate and the corresponding pixel coordinate is solved and the position and the orientation of the projector are estimated. Finally, (4) since the estimation based on P4P contains some errors, the pixel detection area is set to a relatively wide area and then narrowed down using "Bisection Scanning Method" shown in Fig. 9. The present method narrows down the estimated pixel detection area by repeating the procedure of projecting only half of the pixels in the estimation and detecting the emission. If the emission is detected, it repeats the procedure with half of the area and if not, does the same with the other half of the area. If we set the pixel detection area to n by n pixels per void, scanning every pixel would take n^2 times the process, whereas the present method can reduce the process to $2\log_2 n$ times.

5 Results of projecting prototype 3D content

5.1 Design of prototype 3D content demo

LuminatCube can be observed from any direction with naked eyes and is optimal for showing various kinds of 3D models. We focused on molecular structures which are combination of primitive shapes and intuitive. Generally, 3D plastic hard models are used to replicate molecular structures, however assembling and disassembling by hand are required and they are not optimal for showing structural

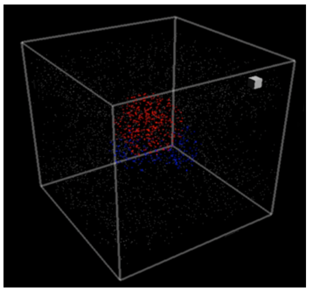
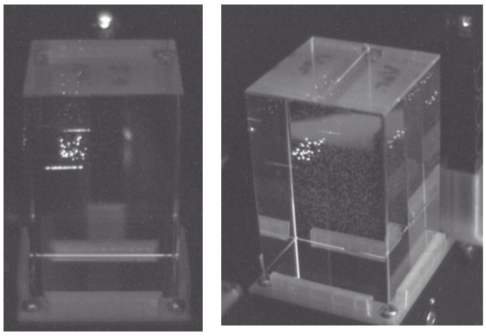


Fig. 11 Simulation of projecting 3D content



prototype.

Fig. 12 Actual projection of 3D content prototype. Front view (left) and diagonal view (right).

change according to time. By using LuminantCube, any structure and time change with any chemical reaction can be reconstructed. The prototype design based on the above mentioned factors are shown in Fig. 10. For the future plans, methods to enhance the spatial effect for more complex shapes will be installed. For example, many methods have been reported that by adding shades and colour gradient according to a virtual light source or enhancing the outline can aid the recognition of the content's shape and physical relationships[19-24]. Also, by adding contrast of brightness between the wireframe and the body is added purposefully at the point of rendering procedure the spatial effect can be enhanced and the recognition can be aided[25].

5.2 Results of projecting the content

The projection simulation example and the picture of each dimension of the actual projection are shown in Fig. 11, 12. Here, the shape of the voids processed by High-power Laser Engraving Method highly depends on the direction of the laser, resulting a vertically long octahedral. Therefore, if the projection is hit from the longitudinal direction of the octahedral, the light will not diffuse evenly and most will penetrate making the emission not bright enough. This highly affects the stability of the calibration as the camera will not be able to detect the emission correctly meaning that the projection will be inaccurate and the content will not be shown as intended. As shown in Fig. 12, part of the content can be recognized but it is incomplete. Hence, the direction of which the processing laser is projected to achieve more brighter and stable diffusion must be carefully considered.

6 Summary and future works

6.1 Summary

In the present research, an omnidirectional and auto-stereoscopic 3D display using diffusion of laser light within a micro region was proposed. The first prototype was designed to be made out of glass cuboid with a height of 80 [mm], width and depth of 50 [mm] with 3600 micro voids which are approximately 0.3 [mm] in size processed inside. Also, a middleware able to read STL format 3D data and convert to projection data for showing optimized content was developed. A calibration algorithm for adjusting the position and direction of the projection was also installed, however the emission of each void was not bright enough for the camera to stably detect it. Therefore, precise projection for every void isn't achieved yet at the present stage.

6.2 Future works

As for the main improvements for the future, resolution and contrast ratio are prior. As shown in Fig. 13, by projecting from multiple projectors against one single micro void the contrast ratio and maximum brightness can be improved. It is necessary to make clear that how much brightness must be improved in order to use the present display in normal lighting environment. As for the resolution, number of projectors to be used will be increased. This means that the number of micro voids that are able to be projected without conflicting other projection paths will also be increased as shown in Fig. 14. As a result of achieving these improvements, showing more complicated shapes with more vertices will be possible, meaning that there will be more options of applications to be considered in the future.

Apart from specification improvements, major updates such as installment of depth camera and making a larger version of the display are considered. For the former, as the middleware is designed exclusively for this system is already in shape, the

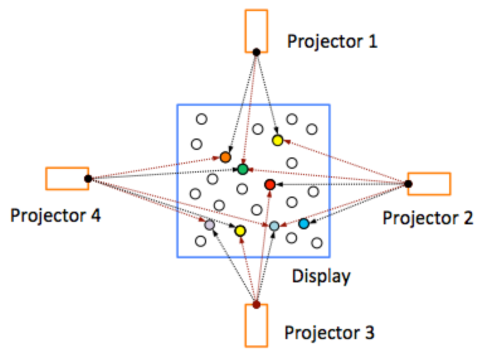


Fig. 13 Method to improve contrast ratio.

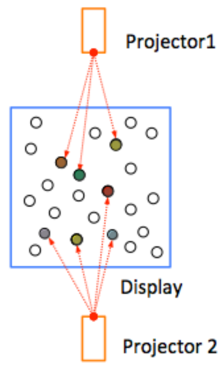


Fig. 14 Method to improve resolution.

conversion from point cloud data acquired from depth camera to volumetric pixel coordinates is relatively easy. By installing multiple depth cameras placed to surround the target, a real time object replication can be done using the present display. For the latter, the display is expected be able to be enlarged to a cube of more than 600 [mm] in height in terms of both processing limits and transparency limits. As seen in common large aquariums the thickest plate of acryl glass used for water tanks are approximately 600 [mm], still maintaining the clearness enough to see the contents inside. This can result in applications such as 3D digital signage.

Acknowledgement

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