Functional Evaluation of the Solid Model Creation using 3D Direct Drawing System

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Abstract: 3D model of computer is usually created using 3D CAD software, but 3D direct drawing method is still developing the research. In this paper, we suggest and construct the 3D direct drawing system with ARToolKit and develop the required creating methods and tools. The method is the creating solid algorithm using projective methods. The algorithm is the converting multiple surfaces into a solid. After that, the functionality of the methods and tools are evaluated using the Taguchi method (quality engineering). In addition, we investigate the optimal condition of the creating methods and tools required for modeling.

1 INTRODUCTION

Recently, most of products have been designed via 3D CAD models. In order to get a good appearance, the products developed for the consumers have many solid models. Then, the requirement for developing solid models is increasing, and these solid models are designed using 3D CAD software. 3D CAD software, which are CATIA™, SolidWorks™, Rhinoceros™, etc., is used for creating 3D solid models. A mouse and a keyboard are key components for using the software. However, creating 3D solid models needs special skill and training. Intuitive 3D modeling based on conceptual design is very difficult.

On the other hand, 3D direct modeling methods without using 3D CAD software have been proposed, in order to carry out 3D modeling easily. According to haptic devices, the space to draw is decided in advance to give a kinesthetic sense (Keefe, Zeleznik, Laidlaw, 2007), or an existing model is deformed by cutting and modifications (Chen, Yan, Lian, 2005), (Akgunduz, Yu, 2004). However, the 3D model cannot be created intuitively. In addition, it takes a long time to form as a conceptual model. In contrast, 3D direct drawing researches have also been done. They involve drawing/creating using a sensor (Wesche, Seidel, 2001), (Bruno, Luchi, Muzzupappa, 2002) or camera (Cheok, Chuen, Eng, 2002). However, they are not efficient system, because their equipment is complicated and needs a large space. The conceptual design modeling is difficult without haptic sense. Therefore, they are neither popular nor innovative.

In previous papers, the algorithm to create a polygonal model and a curved surface model is suggested and investigated (Mitsuhashi, Yoshida, etc.…, 2014). However, we have never researched the 3D solid model, because creating method of solid model is various. The conventional method is B-Reps (Boundary representation) method or CGS (Constructive Solid Geometry) method (Llamas, Kim, etc.…, 2003). They make the 3D model rapidly, but are difficult to operate only visual sensation and too many commands.

In this paper, we construct the method for creating a solid model in a 3D direct drawing system, so as to create a 3D solid model easily. Then, the algorithm to create a solid model is suggested. The algorithm is a projective method, which is used as a third angle projective method in mechanical design. Some conventional methods used for surface drawing are employed in 3D drawing, and the functionality of these methods is evaluated by the Taguchi method (quality engineering) to search for the most effective method (Roy, 1990), (Yokoyama, 1988). In particular, the function of creating methods or tools in 3D direct drawing is evaluated, and the optimal method for drawing curved surfaces is proposed.

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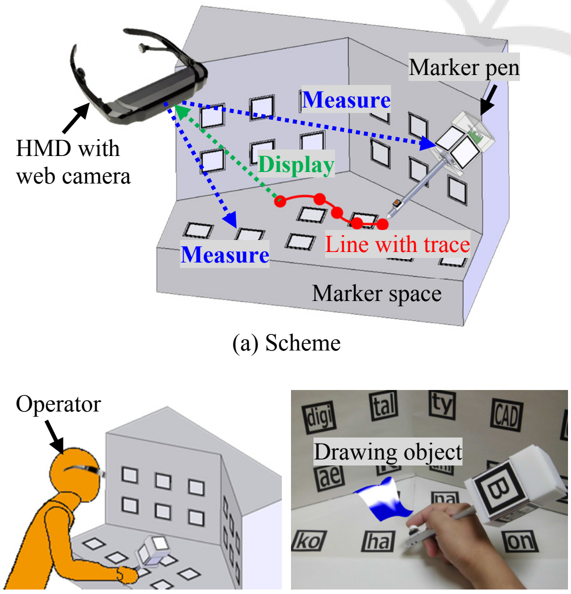
2 3D DIRECT DRAWING SYSTEM WITH ARTOOLKIT

Many kinds of 3D direct drawing systems exist, but no popular drawing system exists, because they are expensive, difficult to operate, and require a large space. In contrast, 3D drawing using AR (Augmented Reality) with markers can be used to display 3D models easily. Therefore, we use ARToolKit in the 3D drawing system. ARToolKit is a programming library for C/C++ language to support AR implementation. It is an open source, and the source code is available easily. It has many functions, such as the recognition of marker detection and patterns, measurement of the position and posture of the marker, and composition display of the photographic image and the 3D CG model.

Figure 1 shows the schematic and the photograph of the 3D drawing system with ARToolKit. An operator carries the pen-type marker for carrying out commands in the arranged marker for determining space, equipping a Head Mount Display (HMD), and controlling a web camera. The web camera measures the distance between a marker for command and space, and reads the contents of the marker command. It has a resolution of 640×840 pixels. After measuring the distance and reading the command, points, lines, and surfaces (only when lines are created) can be output from the pen's nib and displayed by the HMD in the drawing space. Display of objects, such as points, lines, and surfaces, is carried out via the OpenGL library. Two light sources are set above the drawing space. The objective color can be selected from red, green, and blue. It should be noted that points or lines are always output only by indication of the marker. However, the operator cannot have yet drawn concept shapes using only virtual reality and graphic software. Then, the button switch having an ON/OFF function is equipped on the fingertip of the pen. This function enables the operator to control the output of points or lines. Furthermore, the operator moves unexpectedly in many cases, which causes the arm, head, or body of the operator to swing. For this reason, a drawing speed of 1.0 - 10.0 mm/s is adopted. Thus, the creation of unexpected points or lines can be prevented. The contents of the AR command markers determine of the color of the object, the output of a point or line, creation of a surface, and movement or elimination of a point or line. Space markers are set at the bottom of the wall in drawing space. The area of the large marker is 50mm×50mm, whereas that of the small marker is 20mm×20 mm. After the web camera has detected the position and direction of space markers and command markers, the drawing object is displayed from the fixed space markers.



(a) Scheme

(b) Situation from outer (c) Situation from HMD

Figure 1: 3D direct drawing system with ARToolKit.

3 METHOD AND TOOL FOR CREATING SOLID

Many kinds of 3D drawing methods exist, but none of them is effective. Then, we constructed and investigated the methods and tools with ARToolKit. We explain an example of these methods in the following sections.

3.1 Command Marker Pen

For drawing points, lines, and surfaces in the drawing space, it is necessary to use the 3D direct drawing tools. In this paper, we use the AR marker in a manner similar to that in a previous study. AR markers enable operators to give more commands than a point marker. Furthermore, we can control the drawing time by the use of an ON/OFF draw switch equipped on the fingertip. It is difficult to say which type of AR marker pen is the most effective because of their various applications. Hence, we developed three kinds of the command marker pen in this study in Figure 2. The first is the large marker pen (in Figure 2(a)). It is generally called the AR marker rod in ARToolKit. The second is a small marker that has reduced weight and that divides the command function and the drawing output (in Figure 2(b)) (Cheok, Chuen, Eng, 2002). The third is a small marker equipped on the fingertip similar to the one used in a previous study (in Figure 2(c)). We investigate which pen is useful.

3.2 Drawing Space

When 3D direct drawing is performed with ARToolKit, it is necessary to prepare the fixed marker space. Generally, it is said that a good result is obtained as many established markers are set in the entire drawing space. However, the computational complexity is enormous, and it is difficult to set the space because of the presence of obstacles. Then, we prepared three kinds of drawing spaces, which are shown in Figure 3. The first is a plane drawing space (only XY plane), similar to the one used in a previous study (in Figure 3(a)) (Cheok, Chuen, Eng, 2002). The second space consists of two right-angled planes (XY plane and XZ plane) so as to observe the top and bottom direction (in Figure 3(b)). The third space consists of three planes where the XZ plane is bent to form an angle of 120 degrees in order to widen the angle of the space (Figure 3(c)). We investigate which drawing space is useful.

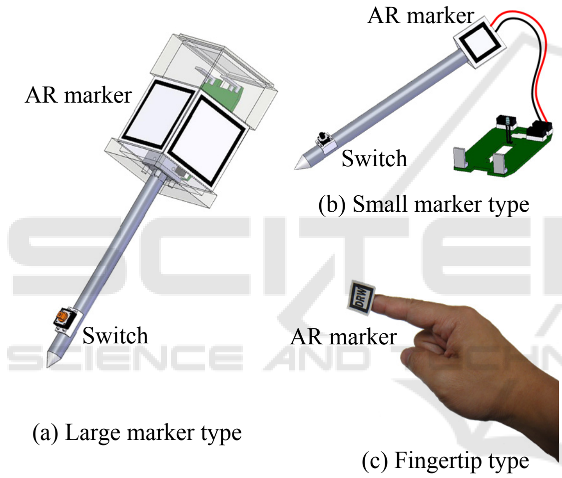


Figure 2: Drawing pen.

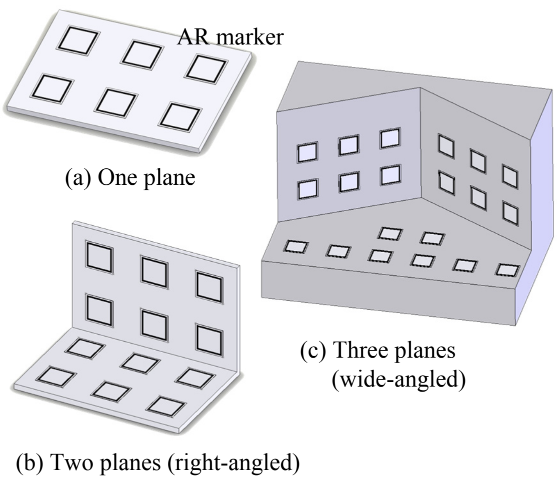


Figure 3: Drawing space.

3.3 Polygonal Surface Drawing

We should create the some polygonal surfaces to create a solid model. The creating method of polygonal surface is shown in Figure 4. First, line segments (or point clouds) are drawn by detecting the position of one hand using Kinect. Then, all the drawing points are projected to the one plane using the Least squares methods. Second, the center point is calculated from all the points, and the most distant point is elected from the center point (Mitsuhashi, Yoshida, etc.…, 2014). It is a 1st vertex of polygonal surface. In a square, the segment between the center and 1st vertex is rotated 90 degree counterclockwise towards the normal vector of the one plane. In a triangle, the angle is 120 degrees. In a n-polygonal, the angle is $360/n$ degree. Polygonal surface is created by connecting among the neighbor vertexes.

3.4 Design Support Tool

PC software can create a straight line or rectangular or square, but freehand drawing in 3D space is difficult for them. Then, we suggest the design support tools. Figure 5 shows the straight edge ruler, Figure 6 shows the absorption plane ruler. Both rulers are made of acrylic material with AR marker, because acrylic material prevents the rulers from disappearing drawing space markers. The straight edge ruler in Figure 5 can draw the straight line or segment, because the drawing points are absorbed on the ruler. The absorption plane ruler can draw the segment or face on one plane, it has the same function. It is a necessary tool, because a plane drawing in 3D space is difficult. Therefore, we can create the segment and the face (polygonal surface, circle, etc.…) easily.

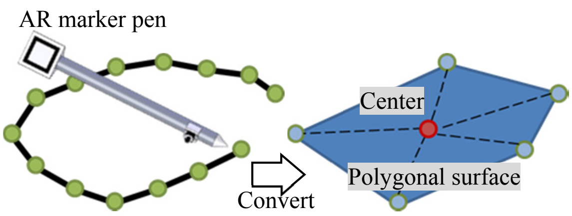


Figure 4: Drawing method of Polygonal surface.

Then, we investigate the effects of design support tools.

4 SUGGESTIONS OF ALGORITHM FOR CREATING SOLID

4.1 Solid Creating Method

Drawing a point, segment, and surface in gesture is easy, but solid is difficult. Because human recognition and image 2D objects, can't image 3D objects in detail. The conventional 3D modeling method is B-Reps (Boundary representation) method or CGS (Constructive Solid Geometry) method (Akgunduz, Yu, 2004), (Llamas, Kim, etc.…, 2003). B-Reps method transforms many closed points to segment, many closed segments to surface, many closed surfaces to solid. It has the information about the position and vector of vertex, edge, and face. It is easy to create a complicated shape, but it must close all the face. Therefore, we must draw many surfaces with great difficulty. We are pained to draw and close many surfaces and can't create the solid well in

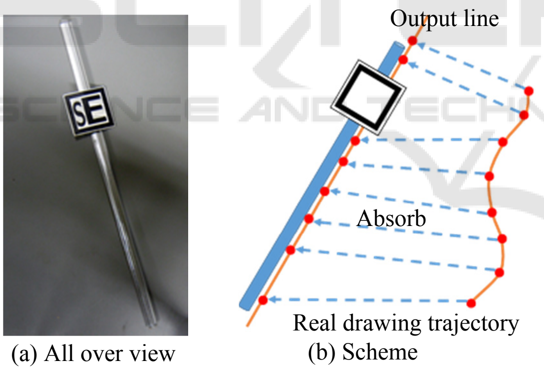


Figure 5: Straight edge ruler for 3D space.

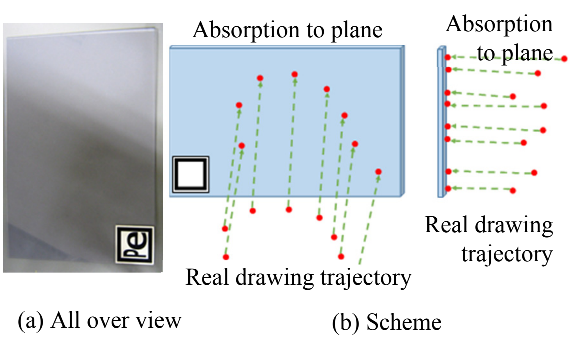


Figure 6: Absorption plane ruler for 3D space.

previous papers (Mitsuhashi, 2012). On the other hand, CSG method gives the primitive objects that are cuboid (cube), cylinder, cone, pyramid, and spheroid (sphere). And the primitive objects are assembled into the complicated shape using Boolean operations. CSG method has the information about the primitive shape, position, size, combination. The information has simple tree structure. So we can use the function Redo or Undo easily. However, the complicated shape takes many Boolean operations, that is difficult, painful, and not intuitive. Because we create or draw lots of the 2D models in 3D modeling. In addition, CSG method can't deform the solid model intuitively. So we suggest an algorithm to create solid model using the projective method. It is already introduced at MasterCAM™, Solidworks™. When two or more of polygon surface are created, they can be converted to a solid. However, it has never used in 3D real space. So we suggest an algorithm to create solid model using the projective method in 3D real space.

4.2 Solid Creating Projective Method in 3D Real Space

We construct the program using the projective method in 3D real space, in order to create solid model. Figure 7 shows the schematic diagram of a projective method in 3D real space. Solid model is projected and created from front, side, and top surface in Figure 7. Thin lines are prism edges. The scheme is that two or more of polygonal surfaces are drawn at first, after that they are converted as a section of prism, and an infinitely long prism is created. Then, the scheme (program) finds the intersection of all prisms, it calculates the boolean logical product (AND operation), and the intersect solid model is created. These algorithms are calculated by OpenCSG and OpenSCAD library. Creating solid data is converted to STL (Stereo Lithography) file or OFF (Object File Format) file.

Figure 8 shows the solid made by the projective method in 3D real space. When a polygonal surface is created, prism edges are the role of the guide from Figure 8. The solid is displayed by many polygonal surfaces using OpenGL and ARToolKit. The operator can decide the position of solid with watching the guide.

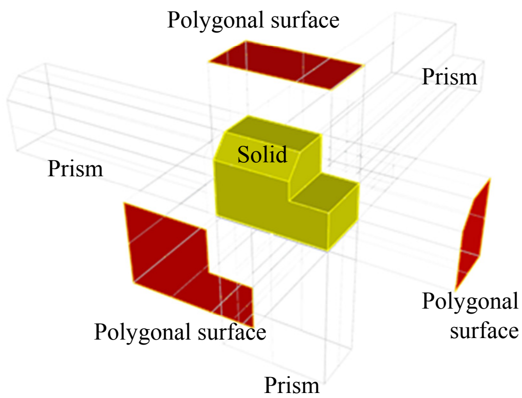


Figure 7: Solid creature projection method in 3D space.

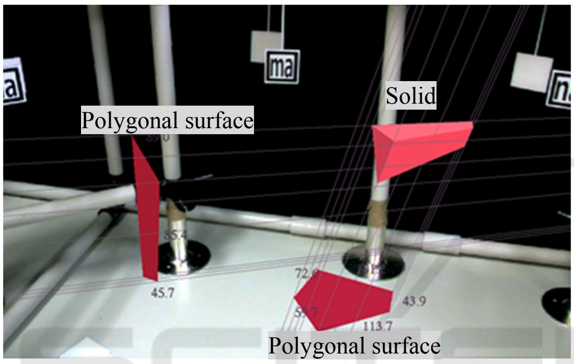


Figure 8: Situation of projection method.

4.3 Creating Algorithm for Cube/Cuboid and Pyramid

The algorithm of creating a solid is to convert multiple polygon surfaces using the projective method from the preceding section. Figure 9 shows the creating algorithm for cube or cuboid. The operator can use single hand or double hands or both, in creating a polygonal surface using Kinect, but can't create multiple surfaces at the same time. If two or more of rectangular surface is drawn, a cube/cuboid is created. Therefore, the operator can create the solid like gesture experiment results. Figure 10 shows the creating algorithm for a quadrangular pyramid. If two or more of triangle surface is drawn, a quadrangular is created. Then, triangular pyramid is the same algorithm. On the other hand, the same algorithm enables to create a sphere or spheroid theoretically, but the operator must create the infinite circle or curved surface. A polyhedron like sphere/spheroid can be created, it is not sphere/spheroid. So the creating algorithm for sphere/spheroid is in future work.

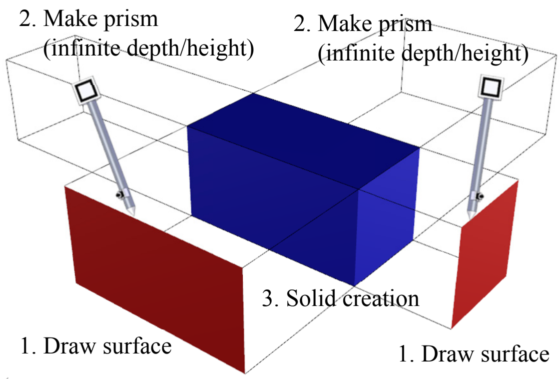


Figure 9: Creating algorithm of cuboid/cube.

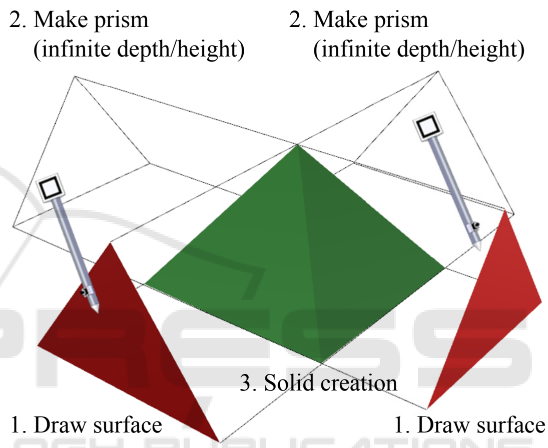
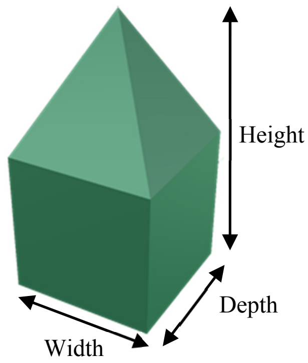


Figure 10: Creating algorithm of pyramid.

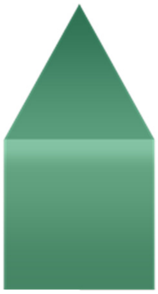
5 FUNCTIONAL EVALUATION OF 3D DRAWING USING THE TAGUCHI METHOD

There is extremely little research on the evaluation of the functionality of 3D direct drawing methods and tools. Evaluating the constructed methods and tools requires a large number of experiments. We investigate the functional evaluation of the drawing methods and tools via experiments using Taguchi's L18 orthogonal array in this paper (Roy, 1990), (Yokoyama, 1988).



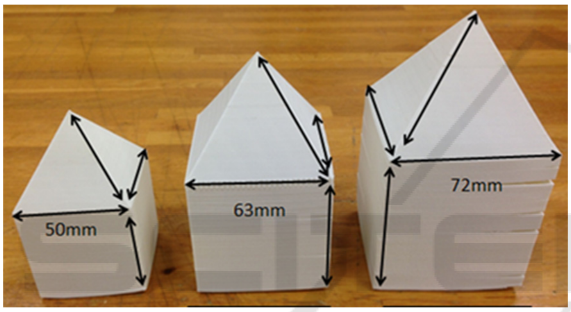
(a) Perspective

(b) Top view



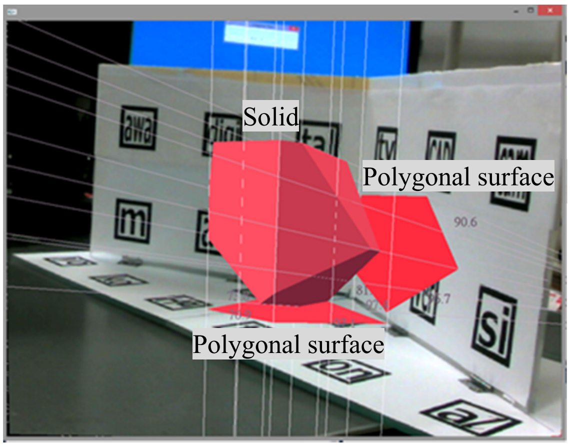
(c) Front view

Figure 11: Sample model (cube + pyramid).

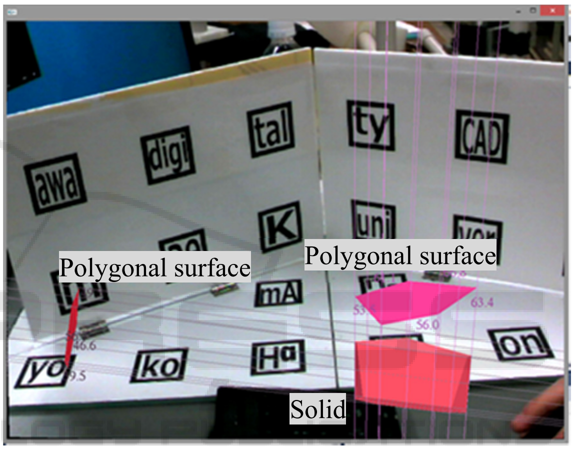


(a) Default (b) Two times (c) Three times

Figure 12: Change the volume sample model.



(a) Using the rulers



(b) Useless the rulers

Figure 13: Creating solid model.

5.1 Experiment

We evaluate the shape of the solid model. The use of any of the three methods should yield the required model. We adopted a combination solid model of the pyramid and the cube, which is usual to create with 3D-CAD software. Because a large number of models must be evaluated, as stable solid models cannot be drawn repeatedly, it is difficult to evaluate shape error by using static characteristics. Thus, we adopt dynamic characteristics, not static characteristics. Figure 11 (a) shows an example of the solid model. The bounding box is 50mm wide, 50mm deep and 93mm high. The change in the edge of the solid model in the bounding box is considered as the signal factor. The volume is output when the edge is changed. Figure 12 shows the shape when the edge is changed. The relations of the edge M' and the volume y' are (a) M'_1=50mm, y'_1=160833mm^3, (b) M'_2=63mm, y'_2=321667mm^3, and (c) M'_3=72mm, y'_3=482500mm^3. Then, we calculate the proportional reference point expression based on 50mm height. Proportion relations of $y=\beta M^3$ are obtained as results. The operator traces the preparation guide of the solid model. Figure 13 shows an example of the creating process.

5.2 Determination of Control and Noise Factors in the L18 Orthogonal Array Experiment

Seven control factors of the three levels and one control factor of two levels are set, for the experiment, to evaluate the functionality of the drawing methods and tools. The control factors are type of input method for the drawing tool, type of drawing space, and support tool. The other factors are the edit function of the drawing point, the guide character, the 3D display function, the change section size of the pyramid, and the number of the necessary faces (surfaces) for projective method. The edit methods involve the removing or moving function, which changes a polygonal surface shape. The display function of the guide character is CG model, real model, and nothing. The number of necessary faces in the solid model is 2 or 3. The noise factor indicates the change in the shape caused by the operator, and its effect was examined with the help of two 30-years-old men (noise factor: N_1, N_2). Tables 1-3 list the control factors, the results of the L18 orthogonal array experiment, and the relation of the output to the signal factor and the noise factors, respectively. Here, the third level of the control factor E and F are assumed as a dummy level because this factor has only two parameters.

5.3 SN Ratio

After an experiment is carried out, we must evaluate the SN (signal-to-noise) ratio η. The SN ratio η is an index for expressing the stability of the noise level. Therefore, SN ratio η were calculated in this study. The expressions of η [dB] are as follows.

$$\eta = 10 \log \frac{S_\beta - V_e}{2V_N \sum_{i=1}^{3} M_i^2} \tag{1}$$

Here, S_β is the promotional variation, S_e is the error variation, V_e is the error variance, and V_N is the noise variance. The expressions are as follows.

$$S_\beta = \frac{\left(\sum_{j=1}^{2} \sum_{i=1}^{3} M_i y_{i,j} \right)^2}{2 \sum_{i=1}^{3} M_i^2} \tag{2}$$

$$V_e = \frac{S_e}{(2 \times 3 - 1 - 1)} = \frac{\sum_{j=1}^{2} \sum_{i=1}^{3} y_{i,j}^2 - S_\beta}{4} \tag{3}$$

$$V_N = \frac{\sum_{i=1}^{3} M_i \left(y_{i,1} - y_{i,2} \right) + S_e}{(2 \times 3 - 1)} \tag{4}$$

Then, the optimum control factor is decided by η, wh ich is remarkably high.

Table 1: Control factors (*: Current condition).

	1st level	2nd level	3rd level
A: Face	2 pieces*	3 pieces	-
B: Pen type	Large	Small	Fingertip*
C: Space	1 plane*	2 planes	3 planes
D: Edit	Translate	Erase	Nothing*
E: Edge ruler	With	Without*	-
F: Plane ruler	With	Without*	-
G: Guide Display	Real	CG	Notihing*
H: Section size	1 time*	2 times	3 times

Table 2: L18 orthogonal array experiment.

No.	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	2'	2'	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	2'	2'	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	2'	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	2'	2	1	2
10	2	1	1	3	2'	2	2	1
11	2	1	2	1	1	2'	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	2'	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	2'	2	1
16	2	3	1	3	2	2'	1	2
17	2	3	2	1	2'	1	2	3
18	2	3	3	2	1	2	3	1

Table 3: Relation of outputs to signal factors and noise factors.

	M_1	M_2	M_3
N_1	y_{11}	y_{21}	y_{31}
N_2	y_{12}	y_{22}	y_{32}

5.4 Results and Repeatability

Table 4 shows the averages of SN ration according to the level of all the control factors. Figure. 14 shows the graphs of their factorial effects. We selected the optimum levels where the SN ratio is remarkably high. In other words, we give priority to the difference in the SN ratio only when a change in the SN ratio made a slight difference. Therefore, it was found that the factors affecting the SN ratio are the number of faces, the drawing space, the display of guide model, and the editing function. If there are too less faces, a

Table 4: Average of SN ratio at all control factors level.

	SN ratio [dB]		
	1	2	3
A	-12.11	-4.78	
B	-8.75	-6.34	-10.25
C	-8.75	-12.59	-4.00
D	-5.93	-11.97	-9.77
E	-8.09	-9.16	-9.16
F	-9.50	-6.34	-6.34
G	-11.57	-3.52	-10.25
H	-8.45	-12.20	-10.30

shape can be wrinkled and be different from the conceptual shape; however, the change in the shape decreases if there are too many faces. With respect to the guide model displayed, it is difficult to determine a position if the guide model cannot display. With respect to the editing function, the SN ratio of the point translate function is the best, because it is believed that the unintentional removal point occurs. In terms of the drawing space, the SN ratio of the 120° wide model is the best, because the range of vision is spread out. Determining the optimum method for drawing a solid model becomes the future problem. Other factors have little influence on the modeling. Therefore, the optimum condition for drawing solid models is assumed as $A_2B_2C_3D_1E_1F_1G_2H_1$.

It is necessary to check the repeatability of this optimum condition, in addition to determining the current condition. The condition is assumed as $A_1B_3C_1D_3E_2F_2G_3H_1$ from conventional research. Experiments under the two conditions were carried out for validation. Table 5 lists the results of the confirmation experiment and the estimation of the SN ratio. Here, the estimation is carried out using the averages, according to the level of all control factors. From the results, it was found that the optimum condition showed a higher SN ratio than the current condition. Therefore, the repeatability of this optimum condition was confirmed. However, further research on the few kinds of drawing tool proposed, re-investigation of the method for the drawing another solid model.

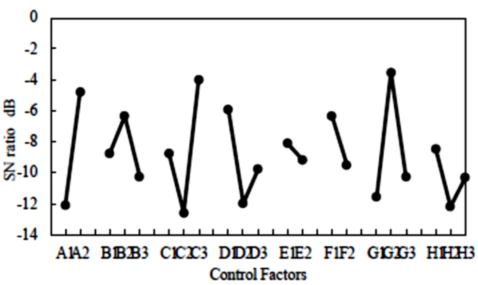


Figure 14: SN ratio of factorial effects.

Table 5: Confirmation experiments.

	SN ratio [dB]	
	Estimate	Confirm
Current	-1.96	-7.29
Optimum	-0.24	-0.70
Gain	1.72	6.60

6 CONCLUSIONS

In this paper, we construct the method for creating a solid model in a 3D direct drawing system, so as to create a 3D solid model easily. Then, the algorithm to create a solid model is suggested. The algorithm is a projective method. After that, the functionality of the methods, tools, and factors in 3D drawing is evaluated using the Taguchi method (quality engineering). In this result, we find that the effective control factors are the number of faces, the drawing space, the display of guide model, and the editing function. Furthermore, in order to investigate the repeatability of this optimum condition, the supporting experiment was performed for verification. Further work can be focused on the kinds of drawing tool proposed, re-investigation of the method of drawing another solid model.

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REFERENCES

Daniel F. Keefe, Robert C. Zeleznik, and David H. Laidlaw, Drawing on Air: Input Techniques for Controlled 3D Line Illustration, *IEEE Transactions on Visualization and Computer Graphics*, Vol. 13, No. 5, 2007

Yonghua Chen, Zhengyi Yang, and Lili Lian, *On the Development of a Haptic System for Rapid Product Development, Computer-Aided Design*, Vol.37, No.5, pp. 559-569, 2005

Ali Akgunduz and Hang Yu, Two-Step 3-Dimensional Sketching Tool for New Product Development, *Proceedings of the 2004 Winter Simulation Conference*, pp.1728-1733, 2004

Gerold Wesche, and Hans-Peter Seidel, *FreeDrawer – A Free-Form Sketching System on the Responsive Workbench, VRST'01*, November, pp. 15-17, 2001

F. Bruno, M. L. Luchi, M. Muzzupappa, and S. Rizzuti, A Virtual Reality Desktop ConFigureuration for Freeform Surface Sketching, In *Proceedings of XIV Congreso Internacional de Ingeniería Gráfica,* ed. F. F. Salazar and A. A. Badiola de Miguel, Santander, Spain, 2002

Adrian David Cheok, Neo Weng Chuen Edmund, and Ang Wee Eng, Inexpensive Non-Sensor Based Augmented Reality Modeling of Curves and Surfaces in Physical Space, *Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR' 02*) ISMAR 2002, 2002

Ranjit Roy, *A Primer on the Taguchi Method*, Society of Manufacturing Engineers, 1990

Y. Yokoyama, *Quality Engineering Lecture 4: Experimental Design for Quality Designs*, Japanese Standards Association, 1988

Kaoru MITSUHASHI, *Functional Evaluation of the Curved Surface Created by 3D Direct Drawing*, The 2nd IFToMM (International Federation for the Promotion of Mechanism and Machine Science) Asian Conference on Mechanism and Machine Science 2012, November7-10, Tokyo, Japan, 2012.

Kaoru MITSUHASHI, Ikuo YOSHIDA, Jin-Hua SHE, Yasuhiro OHYAMA, "*Suggestion of 3D Direct Drawing Method by Microsoft Kinect",* 15th International Conference on Precision Engineering (ICPE2014), July23-25, Kanazawa, Japan, 2014

Ignacio Llamas, ByungMoon Kim, Joshua Gargus, Jarek Rossignac, and Christopher D. Shaw: Twister: a space-warp operator for the two-handed editing of 3D shapes. *ACM Trans. Graph. 22(3),* 2003, pp.663-668