

PARAMETER IDENTIFICATION OF SCANNING QUALITY IN 3D LASER SCANNER: HARDWARE AND LIGHT INTENSITY SETTINGS

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ABSTRACT

Reverse engineering is a solution to develop product faster with lower cost. 3D-scanning which is an initial stage of reverse engineering is necessary to obtain geometric CAD model that subsequently is use for modification and prototyping. This research aims to identify best parameter in 3D scanning process. DAVID Laser Scanner (both hardware and software) is used to acquire 3D-point data for 3D modeling. The accuracy of 3D scanning is sensitive to the parameter settings. Thus, parameter setting is important to obtain best geometric data. This paper presents the design of experiment for two parameters: result filtering and color of the objects. Using an RCBD two-factor factorial and ANOVA, the experiment found that the combination of result filtering with the weight of interpolation=4, smooth average=2, and smooth median=0 gives best result. Also, object with more red color is easier to capture and gives better accuracy than green and blue colors.

Keywords: Reverse Engineering, Design of Experiment, 3D Laser Scanner, result filtering

1. INTRODUCTION

Reverse engineering is an engineering process to generate digital data of 3D product by modifying existing objects or prototypes (Raja & Fernandes, 2008). Reverse engineering is a solution to develop product faster with lower cost. In rapid developing industries, which produce wide variety of products, reverse engineering is considered to be a solution to give many technological and design benefits. It can help industries to shorten product development process and create products faster than forward engineering or which is so called computer-aided engineering (Raja & Fernandes 2008).

To generate 3D data, there are three types of processes: contact reverse engineering, non-contact reverse engineering and destructive reverse engineering (Raja & Fernandes 2008). Non-contact reverse engineering obtains a geometric CAD model from 3-D points acquired by scanning or digitizing existing. Data acquisition is performed by triangulation or wave inference (Raja and Fernandes 2008). Non-contact reverse engineering gives some advantages, for instance relatively faster

digitalizing process, the accuracy and resolution are sufficient, can identify color differences, no physical contact with the objects. Some disadvantages of non-contact reverse engineering are accuracy as not as good as contact reverse engineering, and data acquisition may be limited if the objects are transparent or have glossy surface.

To get the best advantage of the use of 3D laser scanner, it is important to identify the best parameter for scanning. This research aims to identify what parameters in 3D scanning process that gives significant impacts in scanning quality and what levels should be chosen for good-quality of scanning.

DAVID Laser Scanner is used to acquire 3D-point data for 3D modeling. Two parameters related to the software and scanning objects are the focus of this paper. Another paper, titled "Parameter Identification of Scanning Quality in 3D Laser Scanner: Hardware and Lighting Settings" complements this paper for better understanding of 3D laser scanning settings.

2. 3D LASER SCANNER

There are wide varieties of 3D Laser Scanner in the markets, from the low budget scanner to high-end ones. The laser scanner used in this research is the affordable one, DAVID laser scanner. Based on the setting of scanning, David Laser Scanner can be set up with three different modes: hand-held laser setup, motorized laser setup, and structured light setup ([://www.david-lasescanner.com](http://www.david-lasescanner.com)).

Hand-held laser setup is the simplest one, laser scanner is moved manually by hand for the object (See Figure 1). It is the least precise modes as the speed of the hand movement may not be constant.



Figure 1. Hand-held laser setup (<http://www.david-lasescanner.com>)

Motorized laser setup is a setting of 3D Laser scanner by adding a hand-held aid to hold laser to move in static movement (See Figure 2). This method increases the accuracy of scanning and it is mostly used by DAVID users.

Structured light setup is a setting that uses a projection of projector rays to define an object instead of the laser. This mode is a 3D scanning with a video projector instead of the laser. A video projector is used to project a number of stripe patterns onto the object and the camera will watch that from a different point of view (above, below, left or right of the projector) and take (at least) one image of each pattern. Based on the deformations of the stripe patterns in these images, the software computes a precise 3D mesh of the object surface (http://wiki.david-3d.com/david3_user_manual/structured_light). The structured light setup is illustrated in Figure 3. This is the most expensive method of scanning compared to the other two.



Figure 2. Motorized Laser Setup (<http://www.david-lasescanner.com>)



Figure 3. Structured Light Scanning (<http://www.david-lasescanner.com>)

3. DESIGN OF EXPERIMENT SETTINGS

The accuracy of 3D scanning is sensitive to the parameter settings. Thus, parameter setting is important to obtain best geometric data. To determine the best parameter settings to obtain the best resolution and accuracy of geometric data, we do design of experiments.

This paper focuses on two factors: software setting and object color. To start the design of experiment, the hardware is firstly set.

3.1. Hardware Setting

The hardware consists of DAVID Laser scanner, calibration board, software, red laser, webcam, controller and laser fixture, and also rotating table for the object. Figure 4 shows the setting of the scanning.

Laser fixture and rotating table were designed using LEGO Mindstorm NXT 2.0 yang dirakit and they were setup exactly as

the need of the design of experiment. The object for this experiment is

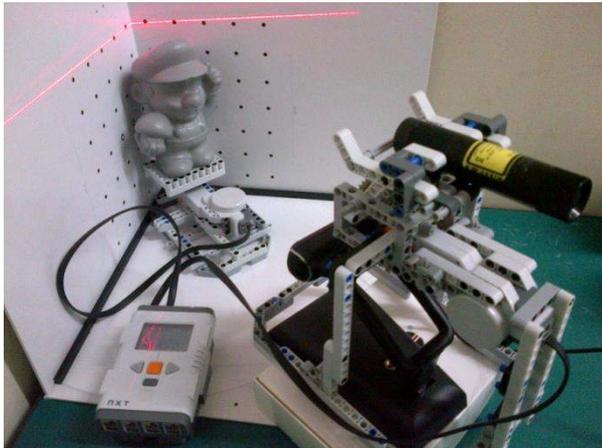


Figure 4. Design of Experiment Setting

The gray object is used for the reference object while for the design of experiment, three colors are selected: red, green and blue (based on RGB color range) (See Figure 5). Grey color is used based on the recommendation from Zaimovic-Uzunovic & Lemes (2010), as they suggested that grey color can be a neutral reference to the other color.



Figure 5. Three objects for design of experiment

The design of experiment was conducted with this certain condition:

The scanning mode: Motorized Laser Setup
 Camera Properties
 Resolution per frame: 1600x1200 @5fps
 Base Color: RGB
 Autofocus: Manual
 Exposure: 50%
 Gain: Manual 50%
 Brightness: 50%
 Contrast: Default

White Balance: Manual 50%
 Calibration board
 Type: V3 pattern
 Scale: 120.0mm
 Speed of laser movement (vertical): 3,5cm/minutes.
 Lighting: minimum light exposure.

Based on this setup, design of experiment is performed with two parameters: the result filtering for software setting and the color of the object. Each parameter has three levels, as described in Table 1 and Table 2.

Table 1. Level of result filtering

Level	Software parameters	Index
1	Interpolation	1
	Smooth Average	0
	Smooth Median	0
2	Interpolation	4
	Smooth Average	2
	Smooth Median	0
3	Interpolation	7
	Smooth Average	5
	Smooth Median	2

Table 2. Color of the object

Level	Software parameters
1	Red
2	Green
3	Blue

3.2. Randomization and Treatment

Design of experiment is done using the randomized complete block design (RCBD) multifactor experiment. Randomization is used to ensure that there is no hidden nuisance factor. Design technique with systematic blocking is used to eliminate effect of statistical comparison to treatments when variability of nuisance factor is known and controllable (Hicks, 1982; Montgomery, 2009). The nuisance factors that are controlled are the speed of the laser movement and the lighting condition. To ensure that the randomization and blocking worked properly in the design of experiment, the speed of laser movement and the lighting are always set exactly at the same level for all treatments.

For each treatment, we use three replication. Table 3 shows the randomization and blocking for the experiments. The

randomization is done for both software setting and each color of the object.

Table 3. Randomization dan Blocking for RCBD Two-Factors Factorial

Experiments Table			RGB					
			Red		Green		Blue	
Software	Interpolation	1		RS-3-1	GS-2-1	GS-2-1	GS-1-1	
	Smooth Average	0	RS-3	RS-3-2	GS-2-2	BS-1	GS-1-2	
	Smooth Median	0		RS-3-3	GS-2-3		GS-1-3	
	Interpolation	4		RS-1-1	GS-3-1		GS-3-1	
	Smooth Average	2	RS-1	RS-1-2	GS-3-2	BS-3	GS-3-2	
	Smooth Median	0		RS-1-3	GS-3-3		GS-3-3	
	Interpolation	7		RS-2-1	GS-1-1		GS-2-1	
	Smooth Average	5	RS-2	RS-2-2	GS-1-2	BS-2	GS-2-2	
	Smooth Median	2		RS-2-3	GS-1-3		GS-2-3	

3.3. Scanning Quality Identification

To identify the output of the treatment, scanning quality of the treatment is compared to a reference value. To identify the reference value, three steps were conducted:

1. Do multiple scanning for grey object to obtain geometric CAD data based on a set of point clouds. The data of multiple scans are overlaid and refined to obtain the best solid model, using CAD software (Rapidform).
2. Do scanning for each treatment
3. Compare the scanning quality of the treatment (no 2) and the ideal one (no 1) using mesh-deviation that is available in Rapidform software (EXPLORER v.2). The absolute score is used (no negative value) as the ourput of design of experiment.

The example of scanning quality comparison is shown in Figure 6. Each treatment has the average value as in Figure 6 is 0.0192 (of treatment RS-3-1).

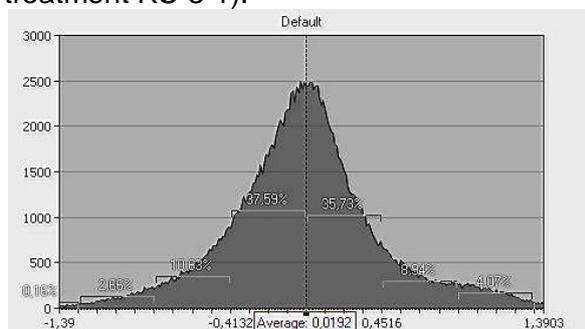


Figure 6. Mesh deviation of RS-3-1

4. RESULTS

After completing 27 experiments, all scanning quality values are compiled (See Table 4).

Table 4. Design of Experiment Scanning Quality Results

Mesh Deviation Experiments Table	RGB		
	Red	Green	Blue
Interpolation (1), Smooth Average (0), Smooth Median (0)	0.0192	0.052	0.0894
Interpolation (4), Smooth Average (2), Smooth Median (0)	0.0459	0.1125	0.051
	0.0228	0.0023	0.1053
Interpolation (7), Smooth Average (5), Smooth Median (2)	0.0018	0.0684	0.0665
	0.0056	0.0429	0.0698
Interpolation (7), Smooth Average (5), Smooth Median (2)	0.031	0.0326	0.127
	0.0413	0.1745	0.0648
	0.0863	0.1829	0.1259
	0.0177	0.1163	0.0537

Subsequently, hypothesis tests were conducted to identify the significance of each parameter. There are three hypoteses to be tested:

1: The significance of result filtering (τ) (software) to the scanning quality.

$$H_0: \text{All } \tau_i = 0$$

$$H_1: \text{There is at least one of } \tau_i \neq 0$$

2: The significance of object color (RGB) (β) to the scanning quality

$$H_0: \text{All } \beta_j = 0$$

$$H_1: \text{At least there is one of } \beta_j \neq 0$$

3: The interaction between result filtering and object color:

$$H_0: \text{All } (\tau\beta)_{ij} = 0$$

$$H_1: \text{There is at lease of of } (\tau\beta)_{ij} \neq 0$$

To answer the hypothesis test, ANOVA (Analysis of Variance) was conducted. Based on the calculation, Table 5 shows the ANOVA results.

Table 5. ANOVA Results

ANOVA	SS	DoF	MS	F ₀	P-Value
Result filtering	0,0115	2	0,0057	5,247	3,55
Color - RGB	0,0184	2	0,0092	8,414	3,55
Interaction	0,0131	4	0,0033	3,008	2,93
Error	0,0197	18	0,0011		
Total	0,0626	26			

The ANOVA calculation shows that:

1. For result filtering, the hypothesis testing shows that $F_{0A} > p_A$, hence H_0 is rejected.
2. For color, similar to the result filtering testing, $F_{0B} > p_B$, hence H_0 is rejected.
3. To see the interaction between result filtering and color, the hypothesis testing shows that $F_{0AB} > p_{AB}$. Thus, H_0 is rejected.

Based on the result above, it can be concluded that both parameters (result filtering & the color of object) have significant effect to the quality of scanning. Also, the interaction between those parameters also gives significant effect to the scanning quality.

To further identify how strong each parameter or the interaction of the parameters give effect to the model:

The value of R^2 is to identify the percentage of the scanning quality is influenced by the parameters. For instance, the scanning quality represents 54.67% of the overall model.

The scanning quality of RGB color represents the goodness of result filtering parameter color to represent the model. Based on the calculation, 18,3038% of the goodness of the model represented by the result filtering options.

The scanning quality of RGB color represents the goodness of color parameter color to represent the model. Based on the calculation, the model is 29,3404% represented by the color level.

Finally, the scanning quality is also influenced by the interaction between software (result filtering) and the color of the object. The model shows that 20,9711% is

represented by the interaction between two parameters tested.

5. CONCLUSION

This paper explores the setting of reverse engineering, in particularly, the effects of color and software for obtaining the best scanning quality.

Based on 2 parameters with 3 level for each parameter, it is found that all parameters including the interaction between the parameters significantly influence the scanning quality.

To obtain the best scanning quality, the combination of result filtering with the weight of interpolation=4, smooth average=2, and smooth median=0 gives the best result. Also, object with more red color has proven to generate better scanning quality compared to green and blue objects.

6. REFERENCES

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