A PART ORIENTATION ANALYSIS BASED ON SUPPORT STRUCTURE

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ABSTRACT

Rapid prototyping technology (RP) is a technology to construct prototype layer by layer directly from a computer file (CAD Model). To minimize construction time and volume of material, a part orientation is an issue for RP planning process. This paper presents an algorithm to analyze part orientation according to minimize building time and material. A concept of bounding box has been applied to determine part orientation on a minimum volume of support structure.

Keywords: Rapid Prototyping technology (RP), layer by layer, part orientation, support structure

1. Introduction

Rapid prototyping process is a manufacturing process that manufactures products directly from CAD model without mold and die. It was introduced to shorten prototype construction time. This process converts a 3D CAD model to be a stack of 2D contours which are used to generate machine commands to build an object layer by layer. In this process, material is added to produce a part layer by layer. Several techniques have been developed for rapid prototyping process and they can be classified into 3 categories based on the initial state of materials [1] liquid-based, solid-based and powder-based. Stereolithography apparatus (SLA), a popular technique in a liquid-based system, is the first commercial rapid prototyping system. In this technique, UV laser is used to solidify photo-curable liquid polymer to form layers. Selective Laser Sintering (SLS) is a famous technique in a powder-based rapid prototyping system. This technique is similar to SLA but instead of curing liquid polymer with UV laser, CO_2 laser is used in SLS to sinter powder to form a layer. Similarly, 3D printing is also a popular technique in a powder-based rapid prototyping system. Besides using UV laser, glue had been applied. Last group of rapid prototyping system is solid-based. In this group, there are several types of solid material used including wire, roll of laminated sheet and pellets. Popular techniques of this group are Laminate Object Manufacturing(LOM) and Fused Deposition Modelling (FDM) [2]. For RP technique development, there are three issues base on process step such that the STL File modeling, a model slicing analysis, a tool path planning of RP process and an part orientation analysis.

STL file has been introduced as a neutral format to converse 3D CAD models to be ready for use in rapid prototyping. The STL file presents 3D solid model as the surfaced model patched by triangular facets. Although the STL file has been used in RP process, it has some disadvantages such as data redundancy and several defects [3]. So, the direct slicing from 3D CAD model and engineering drawing had been introduced [4], **[5]**.

Staircase effect, actually, is an inherent error of layer manufacturing that can be reduced by using smallest thickness. However, if this solution is applied to all layers, fabrication time is increased significant. To improve model accuracy while minimizing prototype construction time, an adaptive slicing concept and an adaptive direct slicing concept have been proposed to slice a model with non-uniform thickness in which the first concept is for slicing STL model while the second concept is for slicing CAD model directly., 2000).[6]

A tool path planning is also an research issue to minimize RP processing time in which TSP had be applied to identify the optimize tool path **[7]**. Additionally, a part orientation has been investigated in order to identify a support structure and a creating time [8]. An appropriate part orientation can be presented the optimum cost according to a consuming raw material for support structure, use to create RP model.

In order to explore an effect of part height, cross-sectional area and building time to part orientation, this paper presents an algorithm to analyze part orientation according to minimize building time and material. A concept of bounding box has been applied to determine part orientation based on a minimum volume of support structure.

2. Literature Review

Part deposition orientation is very important factor of layered manufacturing as it effects build time, support structure, dimensional accuracy, surface finish and cost of the prototype[9-11]. The build-up orientations present several effects such as stair-stepping effect, support structure and number of layers by variable thickness, shown in Figure 1.

An analysis of the part in the optimum direction has been studied by various researchers [10-16]. The bounding box and projecting contours had been introduced to determine the minimum oriented bounding box for arbitrary solid. This approach simplifies a complex-dimensional problem by projecting the solid onto three principal planes and makes use of the projected contour for analysis[10]. The optimal part orientation also applied to establish the average weighted surface roughness (AWSR) generated from the stair stepping effect[11]. In addition, process parameters of deposited process have been also applied to determine the build orientation[12]. Analysis of the morphology and the creation of the base material were applied based on the strength of part,time to create with short pieces, size and surface characteristics, an accuracy and low cost of building materials[13]. To analyze a shape of base material, a part application and direction of the molding have been considered the character resembles a tilted surface to reduce the amount of raw material [14]. A calculation of the direction of creating a piece of work, including the base metal has been proposed to present the support structure [15].

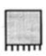
Defect	Build up orientation	
	optimised	Non-optimised
Minimise stair stepping effect		
Minimise support structure		
Minimise number of layer		

Figure 1: Determination of build-up orientation to minimize stair-stepping effect, minimize support structure and minimize number of layers by variable thickness[9]

3. Experiment

An analysis of part orientation and build-up direction of a rapid prototype considers a minimum volume of support structure. The input of this approach is the 3D model of prototype and the output is an appropriate part orientation, as shown in Figure 2.The bounding box of 3D model is created after 3D model is assigned. Then, Boolean operation is applied to determine support structure by subtracting the bounding box with 3D model of prototype. The remaining model is utilized to calculate volume of support structure according to the build-up direction. Finally, the suitable build-up direction with the minimum volume is assigned as part orientation.

3.1 Creating 3D Model

The 3D model, created based on Solidwork, was applied, as shown in Figure 3.

3.2Creating Bounding Box

A bounding box is the smallest boxes that can be covered particular part without any of the parts over the limit[16].When the particular bounding box was created, subtract operation was applied. Then, the remaining parts from this operation were used to analyze support structure, as shown in Figure 4.

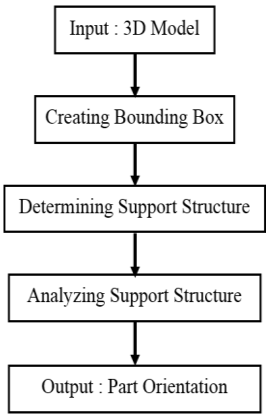


Figure 2: Flow chart of part orientation analysis

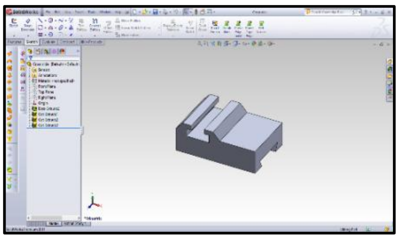


Figure 3: Creating 3D Model

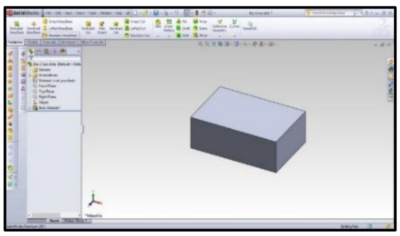
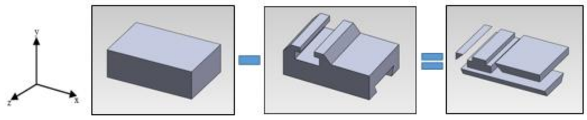


Figure 4: Creating Bounding box

3.3 Determining Support Structure

To determine the remaining model, the subtraction operation has been applied, as shown in Equation 1.



$$\beta_{BB} - \beta_{3D} = \beta_{st} \quad (1)$$

When β_{BB} isa bounding box
β_{3D} isa 3D model
β_{st} is the remaining of bounding box
While $\beta_{st}(P(x_i,y_i,z_i))$ is the corner point
x_i is an axis position ofx ati
y_i is an axis position ofy ati
z_i is an axis position ofz ati
i is equal 1, 2 . . . , n
n is total number corner of β_{st}

3.4 Analyzing Support Structure

The remaining of bounding box is investigated for support structure. All corner points of the rest of bounding box, β_{st} $(P(x_i,y_i,z_i))$, are analyzed based on conditions as shown in Table 1.Since the model could be crated along any direction, x+, x-, y+, y-, z+ and z-, those conditions are investigated on six times. The focus on each condition is to identify support structure. So, the rest of bounding box that is over bound of model is ignored other it is defined as the support structure. Moreover, there may be more than one build-up direction that the support structures are identified. The build-up direction, establishes minimum volume of support structure, is assigned.

Define symbol in Table 1:

- (hatched) = Bounding box (β_{BB})
- (black) =The rest of bounding box (β_{st})
- (white) = Space (E)

Max $Ø_1$ is the highest pointalong $Ø_1$ axis

Max $Ø_2$ is the highest pointalong $Ø_2$ axis

Min $Ø_1$ is the lowest point along $Ø_1$ axis

Min $Ø_2$ is the lowest pointalong $Ø_2$ axis

$Ø_1$ = x±, y±, z± Ø2 = x±, y±, z±

4. Result

By applying process analyze in section 3, the model, as show in Figure 3, was investigated. The results showed that apart orientation along x+ was selected because this direction presented lowest support volume, 1.89×10^4 mm^3.

Table1: Conditions for identifying support structure

Deductive parts	Case	Analysis condition	Result	Support structure shape
		If Max$_{Ø1}$ {β_{st}} = Max$_{Ø1}$ {β_{BB}}	β_{st} is not support structure	None
		If Min$_{Ø1}$ {β_{st}} = Min$_{Ø1}$ {β_{BB}}	β_{st} is support structure	
		If Max$_{Ø1}$ {β_{st}} <= Max$_{Ø1}$ {β_{BB}} and Max$_{Ø2}$ {β_{st}} <= Max$_{Ø2}$ {β_{BB}}	β_{st} is support structure	
		If Max$_{Ø1}$ {β_{st}} <=Max$_{Ø1}$ {β_{BB}} and Min$_{Ø1}$ {β_{st}} >= Min$_{Ø1}$ {β_{BB}}	β_{st} is support structure	
		If "E" is a space then Max$_{Ø1}$ {E} <= Max$_{Ø1}$ {β_{BB}} and Min$_{Ø1}$ {E} >= Min$_{Ø1}$ {β_{BB}}	Below(E) is support structure	

Table 2: The results of experiment

Direction	Support structure position	Support structure shape	Support structure volume (mm^3)
Direction x+			1.89×10^4
Direction x-			3.86×10^4
Direction y+			3.08×10^4
Direction y-			4.05×10^4
Direction z+			2.55×10^4
Direction z-			2.55×10^4

5. Conclusion

The part orientation is determined by using concept of bounding box. The conditions for identifying support structure are applied to determine support prior support structure volumes are established. The part orientation along axis that presents minimum volume of support structure is selected. Future work will be considering on the shape of support structure.

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