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DESIGN OPTIMIZATION OF ROBOT CHASSIS USING PROTOTYPING PROCESS

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ABSTRACT

This paper presents the optimization of robot chassis design using Fused Deposition Modeling rapid prototyping process. In this work, the optimal design is determined by the time consumed and the material needed during the building process. Building time and material needs both for support and model depend on the part's configuration and orientation. The methodology involves several design phases and was concluded by a ready-made product or prototype. Process of optimization is based on best orientation guideline form by Jacobs's. Although the process is different but the guideline is applicable to the case studied. As a result, the best optimal robot chassis is identified.

***Keywords**: Rapid prototyping, Design optimization, Part orientation*

1.0 INTRODUCTION

Design process can be described as a transformation of an idea into ready-made product or prototype [1]. Rapid prototyping process is among the best practice in developing a prototype. The optimal prototype will save a lot of time and cost. This work was initiated from the development of robot chassis for ABU Robot Contest 2002. The main function of the robot chassis is to support the robot's structure and mounting for the motors, wheel and roller (Figure 1). Since the motors are connected directly to the wheels, the position of the motor mounting will affect the alignment of the wheels. Several modification and optimization on the design parameters were made in order to achieve optimal robot chassis design with the required functionality. The optimization of the robot chassis design is made based on build time and material used.

The orientation of the part is one of the main criteria that will affect the development time, mechanical properties, surface quality and the amount of support structure required. It was proven that in order to have optimal design, stairstepping effect must be avoided [2]. Most of the past research, presented and discussed the effect of parts with stair-stepping effect on symmetrical model such as cone, sphere and rectangular structure but less for the complex shape. The objective of the study is to evaluate the effect of part configuration and orientation on the build time and amount of material used in building the robot chassis using Fused Deposition Modeling (FDM) rapid prototyping machine.

The paper is organized as follows. It begins with the introduction and problem statement of the study. A literature survey on the related work and basic rapid prototyping process is then presented. The development of the robot chassis is then described in the form of a flow chart, followed by the analysis of the part orientation. The result obtained is then discussed followed by a conclusion.

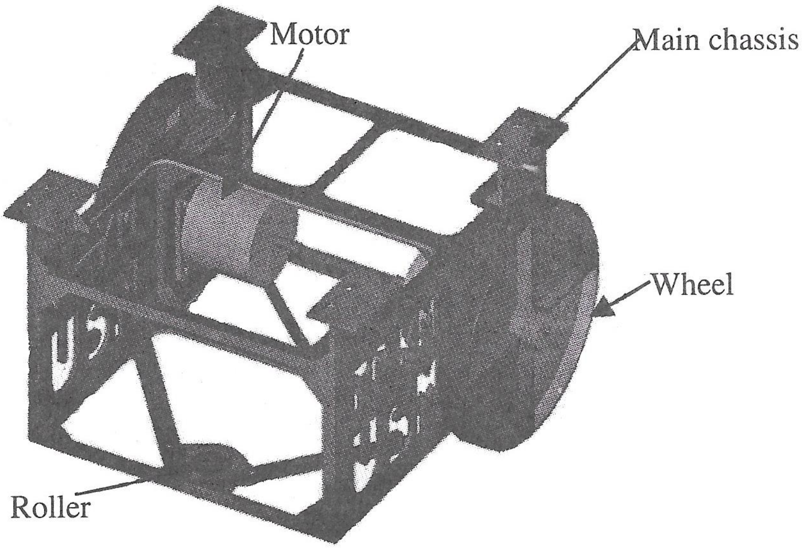

Figure 1 Robot chassis design

2.0 RELATED WORK

Determination of the ideal part orientation during prototyping process has been the subject of research for some time. Allen and Dutta [3] developed a methodology to decide the good parts orientation by computing the support structure. Frank and Fadel [4] constructed an expert system tool that can recommend optimal parts orientation for FDM rapid prototyping process by taking into consideration various parameters that affect the prototype development. Seeram and Dutta [5] determined the best parts orientation based on variable slicing thickness for polyhedral object. Rattanawong et al. [6] developed a part-build orientation system by considering volumetric error (VE) encountered in parts during prototyping process. Masood et al. [7] extended the work by developing a generic mathematical algorithm for best part orientation. All of them used FDM in their research.

3.0 STAIR-STEPPING EFFECT

In rapid prototyping process, generally there are three conditions or orientations of parts during the building process. For example for the triangular block, the stair-stepping effect will not be noticed if it is built on the flat faces as shown in Figure 2(a). The effect will increase as the slope of the face increases with respect to the vertical axis (build direction) as shown in Figures 2(b) and 2(c).

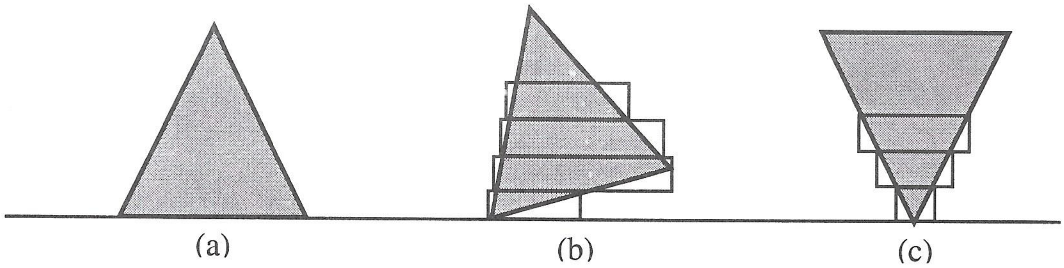

Figure 2 Three basic orientations of parts during building time, (a) no stair-stepping effect, (b) more prominent on the bottom face and (c) prominent on all faces.

Build orientation is important for several reasons. First, properties of rapid prototypes vary from one coordinate direction to another. For example, prototypes are usually weaker and less accurate in the z (vertical) direction than in the x-y plane. In addition, part orientation partially determines the amount of time required in building the model [8]. The orientation of parts also affects other factors such as the complexity of support structure, shrinkage, curling, trapped volume and material flow in some rapid prototyping process [9]. Placing the shortest dimension in the z direction reduces the number of layers, thereby shortening the build time. Jacob [10] has listed the guideline in determining the best part orientation in Stereolithography Apparatus (SLA) prototyping process :

i. The height of the object along z-axis (build direction) should be minimized.
ii. All plane should be built parallel to the build direction.
iii. Simple curved surfaces should be oriented in the horizontal plane normal to the build direction in order to achieve higher resolution of the surfaces.
iv. Object with internal volume should be oriented such that the trapped raw material for the process can be easily removed.

The above guideline may also be applicable in FDM prototyping process.

4.0 RAPID PROTOTYPING PROCESS

Rapid prototyping (RP) is widely used in the automotive, aerospace, medical, and consumer products industries. Although the possible applications are virtually limitless, nearly all of them fall into one of the following categories: prototyping, rapid tooling, or rapid manufacturing. From several rapid prototyping techniques studied, all seems to employ the same basic five-step process as illustrated in Figure 3.

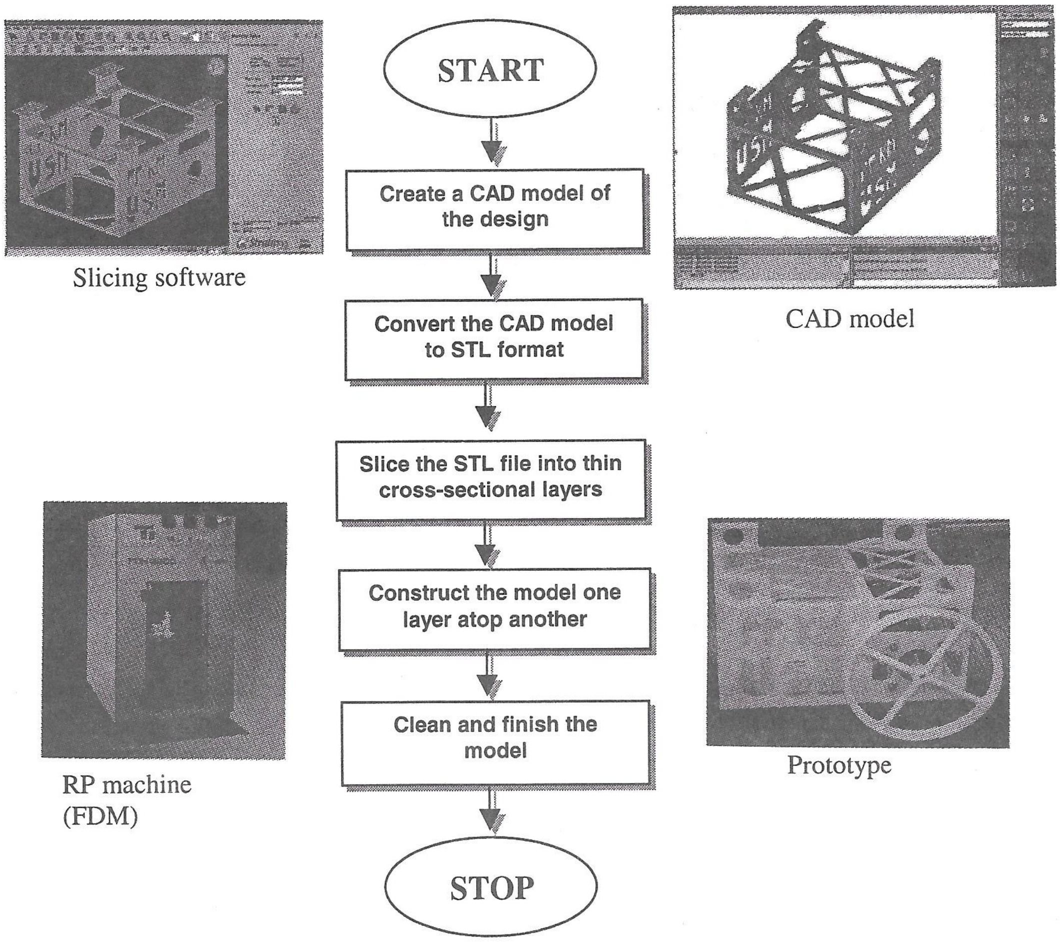

Figure 3 Rapid prototyping process flow chart

Firstly, the object to be built is modeled using the Computer-Aided Design (CAD) software package solid modelers. Next, the CAD model is then converted into STereoLithographic (STL) format to establish consistency. This has been adopted as a standard for rapid prototyping systems including FDM. The STL file represents the surfaces of a solid model as a mosaic of small triangles. Several programs are available in the market such as Insight that allows the user to adjust the size, location and orientation of the model. The STL file is then sliced into a number of layers depending on the build technique. Auxiliary structures to support the model during the building process including delicate features such as overhangs, internal cavities and thin-walled sections are then constructed. The fourth step involves the construction of the actual part by using FDM rapid prototyping machine. The process builds the parts layer by layer at a time utilizing polymers type Acrylonatrile Butadeine Styrine (ABS) material i.e ABS 400 for model and ABS 400R for support. The final step is post-processing, which involves removing the prototype from the machine and detaching any supports. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability. Placement of support structures and part orientation is not always obvious at the beginning of the process. Many factors must be considered such as shrinkage, cure depth, and draw speed which requires a lot of practices and experimentation.

5.0 METHODOLOGY

At the conceptual phase, the requirements and mission of the robot need to be clearly understood before the design proceeds to the development phase. After that, the CAD model is developed and then converted into slicing model. Simulation on available softwares can indicate the estimated time and material needed for the model. The process of optimization is repeated until the optimal design is achieved. The actual prototyping process on the machine can begin when there is no more modification. The methodology of the optimization process is demonstrated in Figure 4.

The optimal design can be determined by the following criteria;

1. The lowest material ratio by using this relationship

$$\text{Material ratio} = \frac{\text{Support Volume} + \text{Model Volume}}{\text{Actual Part Volume}} \tag{1}$$

Note that the best material ratio is 1. Volume for support and model material can be simulated from slicing software after the slicing process, whereas actual volume of the part can be obtained from the CAD drawings. The proposed indicator is developed to compare performance between the models.

2. The shorter time consumed in building process, t_{RP}.

In the prototyping process, the process parameters that are likely to affect the performance of the FDM parts are controlled to be the same for every model. The parameters are;

i. Bead (road) width: 0.5080 mm
ii. Nozzle type: T12 (0.3048 mm)
iii. Air gap: 0.05080 mm
iv. Build temperature: Model (270°C), support (235°C) and envelope (70°C)
v. Raster angle: 45 degrees

Generally, the process parameters used in the study are the default values as recommended and the values are fixed for each model.

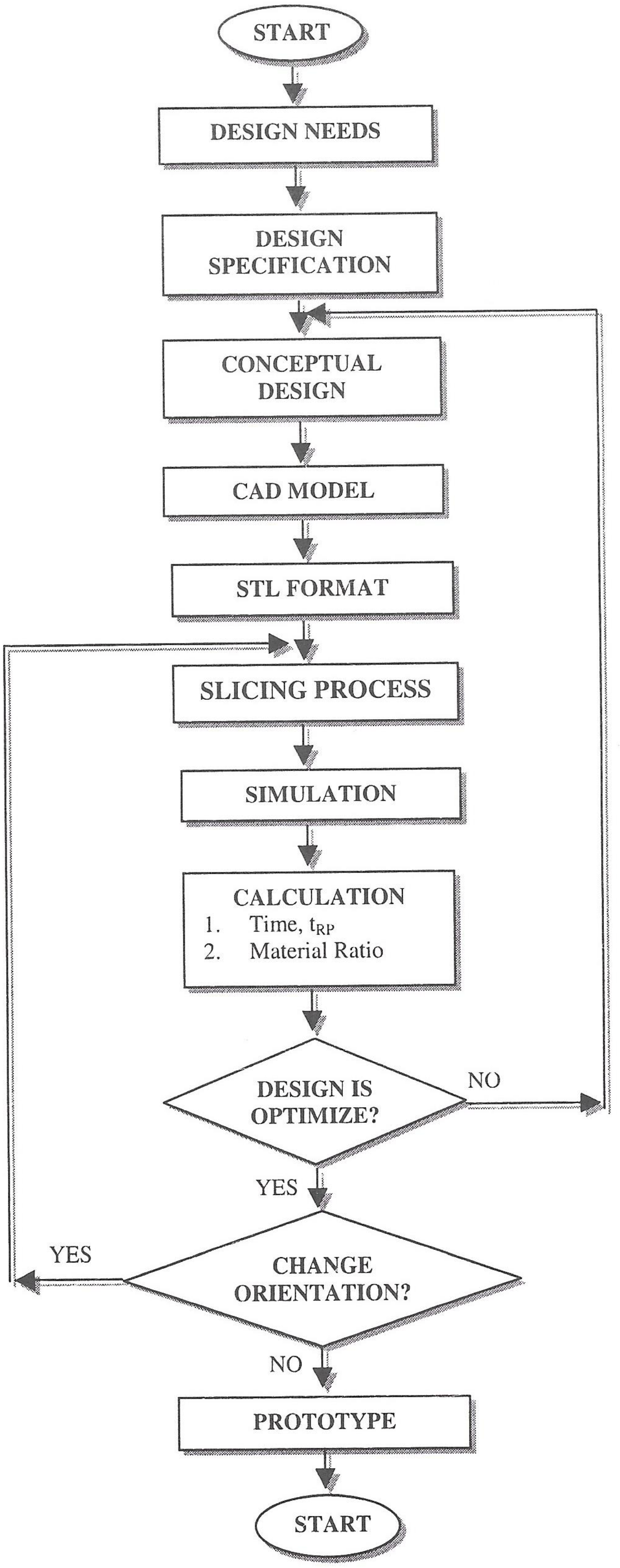

Figure 4 Process flow of design optimization

6.0 RESULTS AND DISCUSSION

Basically, robot chassis is a rectangular block with thin walls. There are two holes to mount the motors on both sides and a hole for the roller at the bottom front of the block. T-beams with 4 holes are used to support the upper robot structure. After going through the product design process, the first prototype is developed as shown in Figure 5(a). The size of the chassis is 240mm length, 100mm height and 180mm width, with 2mm wall thickness and four T-beams in each edge. Due to the size constraint of the workspace volume (254mm x 254mm x 500mm), the robot chassis can only be built in the direction indicated by the arrow in Figure 5(a). It is not practical to develop parts for more than three days for model 1 as indicated in Table 1. Therefore, an improvement is required to overcome this problem while maintaining the basic configuration.

As a result, model 2 as shown in Figure 5(b) was developed. Several modifications have been done in terms of parts' size. As an example, the length is reduced from 300mm to 240mm to fit the workspace area. Total height of the chassis is increased from 50mm to 100mm to accommodate the electronic components such as the electronic board and batteries. The wall thickness is increased, from 2mm to 3mm to strengthen the body. The resulting prototype indicates that there are reduction in terms of the time consumed which is reduced by 8.7% and in terms of material ratio where the model material is reduced by 21.9%, although the support material used is increased by 40.4%.

However, there are problems with mounting the controller and batteries to the robot chassis. There is no mounting platform for microprocessor and the wiring arrangement will be too complex. In order to avoid this situation, model 3 is developed (Figure 5(c)). The height is then increased from 100mm to 115mm, while the T beam is now changed to L beam. The X shape on the top wall will increase the strength of the chassis and will allow a better platform to mount controllers, microprocessors and other additional accessories. As a result, there is some increase in terms of time and material ratio.

The final robot chassis design (model 4) as shown in Figure 5(d) is developed after tremendous changes by cutting out the top and middle-side walls. An aluminum sheet will be placed on top in order to strengthen the structure. The result indicates that the time consumed is reduced by 27.2% and the material ratio is decreased to 1.15. The overall comparison between the models is shown in Table 2. The first design is taken as the datum and then compared to the other models in terms of percentages.

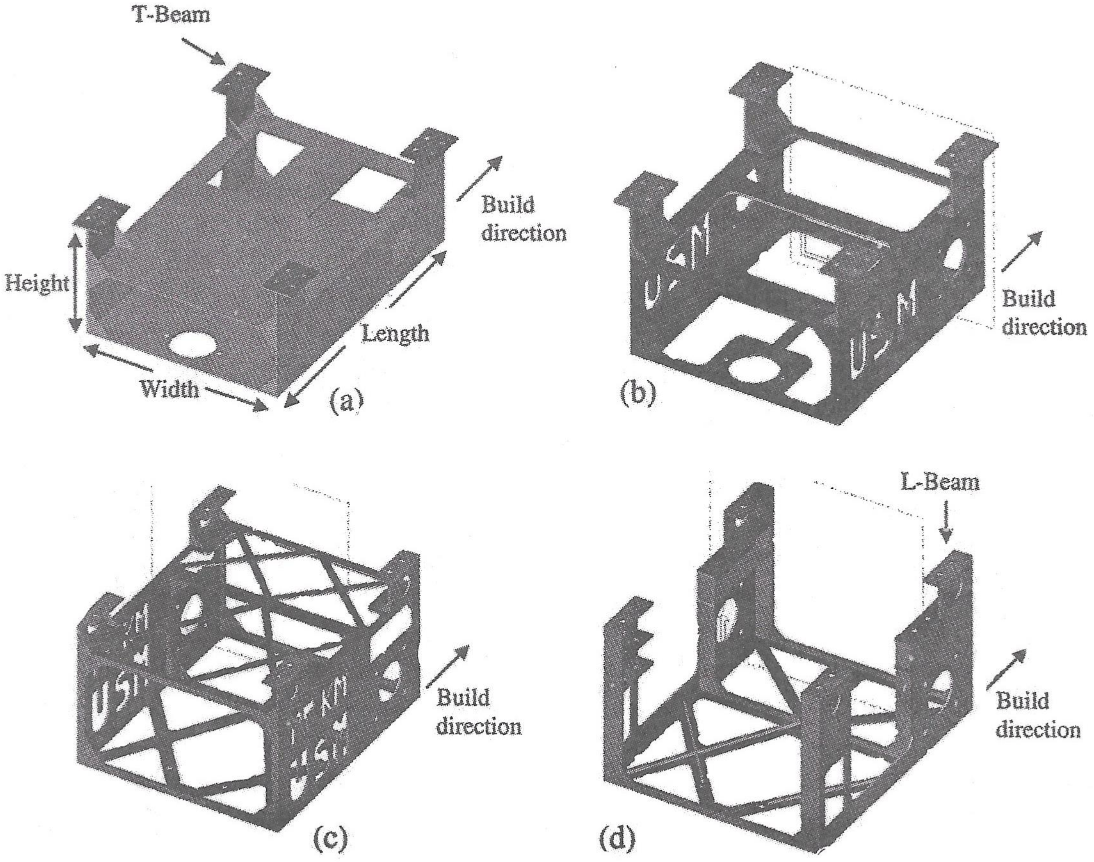

Figure 5 Robot chassis models, (a) model 1, (b) model 2, (c) model 3, and (d) model 4

Table 1 Time, material ratio and volume of material used in prototyping robot chassis design

Robot Chassis	Actual Volume (mm^3)	Material (mm^3)		Time, t_{RP}	Material ratio
		Support	Model		
Model 1	342000	218000	356000	89 h 30 min	1.68
Model 2	303000	306000	278000	81 h 44 min	1.42
Model 3	277000	338000	207000	85 h 57 min	1.59
Model 4	184000	135000	177000	65 h 9 min	1.15

Table 2 Comparison for different models of robot chassis
(Positive value means increment)

Robot Chassis	Comparison (%)		
	Material (Support)	Material (Model)	Time, t_{RP}
Model 1	Datum	Datum	Datum
Model 2	+40.4	-21.9	-8.7
Model 3	+55.0	-41.8	-3.9
Model 4	-38.1	-50.3	-27.2

After the best model is selected, the best build direction needs to be determined. There are four built directions identified as shown in Table 3 and the axes are shown in Figure 6. The result indicates that the z-axis is the best build direction. This is because of the optimal volume required and shorter time needed to build the model.

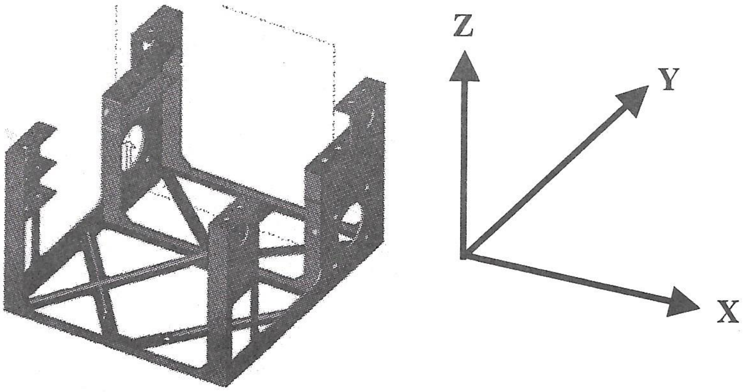

Figure 6 The best orientation for prototyping process

Table 3 Time and material used for different orientations

Build Direction	Time, t_{RP}	Material used (mm^3)			Material ratio
		Support	Model	Total	
Z-axis	44 h 13 min	135000	177000	212000	1.152
Y-axis	65 h 9 min	238000	176000	314000	1.706
-Z-axis	89 h 41 min	515000	177000	692000	3.761
X-axis	90 h 57 min	492000	176000	668000	3.630

7.0 CONCLUSION

The paper has looked into the effect of part's configuration and orientation of robot chassis to the FDM prototyping process. The results have shown that changing the configuration of the part's design can optimize the FDM prototyping process tremendously in terms of prototyping time and material ratio. This work has referred to the guideline in determining the best part's orientation during the building process. In order to get the best result in terms of building time and amount of material needed for both model and support while maintaining the robot chassis functionality, the orientation must be in the Z-axis. The optimal design obtained conforms to the guideline proposed by Jacob [10]. Although the guideline is developed for SLA prototyping process, it can still be used as a guide for FDM rapid prototyping technique as indicated from these findings. Since the results for the material ratio are consistent with time, the proposed equation can be used as a performance indicator.

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