VOL. 10, NO. 11, JUNE 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DIVERSE APPROACHES IN MINIMIZING THE BUILD TIME FOR DIFFERENT RAPID PROTOTYPING PROCESSES

S. Malligarjunan[1], M. Chandrasekaran[2] and P. Malliga[3]
[1]Department of Mechanical Engineering, Panimalar Institute of Technology, Chennai, Tamilnadu, India
[2]Department of Mechanical Engineering, Vels University, Chennai, Tamilnadu, India
[3]Department of Industrial Engineering, Anna University, Chennai, Tamilnadu, India
E-Mail: smarjun23@gmail.com

ABSTRACT

Build time is a vital factor of layered manufacturing as it affects cost of the prototype. Reducing the manufacturing time of the products is an endless process, without compromising the quality of the model. Various approaches have been employed for reducing build time in different RP methodologies. Reduction of build time is a complicated task as one has to cope-up a contradicting objective like part surface finish. This paper describes the various attempts made to reduce the build time.

Keywords: build time, rapid prototyping, layered manufacturing.

1. INTRODUCTION

Rapid Prototyping & Manufacturing (RP & M) technologies or Layer Manufacturing (LM) technologies are an incipient group of technologies appeared in the dynamic field of Advanced Manufacturing systems. Fundamental principle of operation is virtually same for all these technologies, which is to build components from sundry materials in a layer-by-layer approach, virtually directly from CAD data, without utilizing any machine tools. RP is a key technology in reducing the manufacturing lead time of a product up to 30-50 percent even when the relative part involution is very high [1]. The sequence of manufacturing processes in rapid prototyping, is predicated on geometric model creation, slicing, generation of material deposition paths or laser scanning paths, layer-by-layer deposition and then post processing. A drastic reduction in time from product launch to market is a major contribution of RP to the world of manufacturing industries.

The three phases composing layer manufacturing process are,

1) Pre-build or Preparation phase, during which several pre-build tasks like CAD model creation, support generation and slicing are performed,

2) Build or Fabrication phase, during which the actual fabrication or building of the part is carried out, and

3) Post-build or Finishing phase, during which the part is cleaned and neatly finished.

The total build time can be reduced by reducing the time involved in any or combination of the above phases [2]. The most time consuming and costly phase is the build phase. The time required in this phase is critical to predict, because this phase consists of lot of activities such as job pricing and quoting, job scheduling, benchmarking, selecting of build parameters like layer thickness and part orientation etc. [3].

This paper presents a detailed overview of various approaches published for minimizing the build time in various layered manufacturing processes. In addition, it deduces some future trends for research.

2. STRATEGIES FOR BUILD TIME REDUCTION

a) Hollowing out a solid model

Unlike the conventional subtractive methods, most of the RP techniques build a part in layer by layer by adding the material. Hence, build time is greatly influenced by the area of the layer. Therefore, build time is reduced significantly by hollowing out a solid model [4]. Moreover, built area is decreased by the hollowing operation. In addition to the reduction of the build time, the material cost will also be decreased.

There are several important methods in hollowing out a solid model [5–7];

1) Spatial surface offset method: Because of complex spatial surfaces, this method is difficult to implement.

2) Voxel representation method: According to the distance between the scattered voxels of spatial surfaces, scattered cubes are selected. The scanning path is directly affected by the staircase effect and "Z" shape surfaces produced by the Voxel method.

3) One-dimensional Boolean operation method: One-dimensional Boolean operations are used on the solid CAD model between the ray representations and voxel elements. The ray representation of the hollowed model in turn, produces the direct slice files as output to the rapid prototyping machine.

4) Two-dimensional hollowing method: All the existing methods need a new CAD file for hollowing a model. Hence, hollowing the model and product manufacturing are separately carried out. However, during the actual building process, it is possible to directly adopt the hollow build or direct build. It helps in offsetting the profile loops which stand for the hollow contours obtained by slicing.

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Also, the profile loops are offset without modifying the CAD model file. Because of this reason, two dimensional hollowing method becomes significantly demanding.

The algorithm was tested on a Selective Laser Sintering (SLS), but it is also applicable to other RP processes such as Stereolitho graphy (SLA) and Fused Deposition Modeling (FDM) [8].

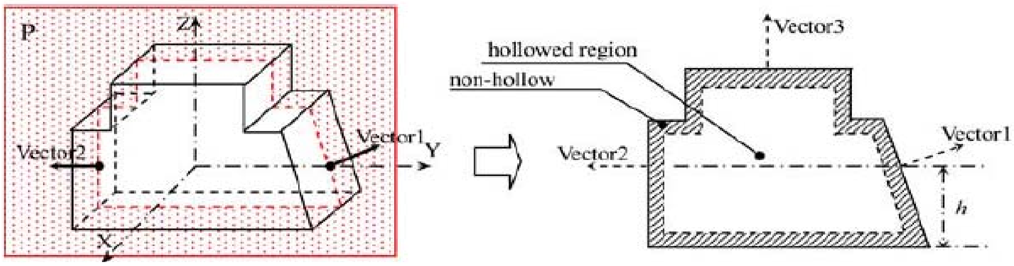

Figure-1. Hollowed region and normal vector.

b) Double-sided building

In double-sided building process, the part is oriented to align with the z axis, and then it is divided into two regions by a horizontal parting plane.

These regions can be manufactured without supports one by one when the top section is build right-side up and the bottom section is built upside down. After building the bottom section, it is flipped over, then adding the layers for the top section directly onto the top surface of the inverted bottom section. Both the parts are successfully built with FDM.

In order to hold the bottom of the part after flipped over, small tabs are added upto a standard height and width protruding along the parting plane during the first stage (Figure-2 a). Small jigs are used to support the inverted bottom section with its tabs in the second stage (Figure-2 b).These jigs are also built by the FDM machine. The jigs are left with the build platform between runs so that they can be re-used. No support material is needed for overhangs, if any, for bottom section [9]. Build time will decrease with the decrease or elimination of support structure.

c) Slicing of CAD model

Slicing of CAD model with a large slice thickness leads to small build time. At the same time, the surface finish is very bad due to staircasing. This contradiction has led to the development of number of slicing procedures. The slicing algorithms can be broadly classified as slicing of tessellated CAD models and direct slicing.

Slicing of tessellated CAD models is developed by slicing defacto standard STL files as shown in Figure-3. Adaptive slicing of tessellated CAD models is an improved solution to handle the contradiction of surface finish of the part and build time. Adaptive slicing is derived from the concept of limited cusp height (Figure-4) for polyhedral parts. Based on the individual importance and use with respect to the geometry of the part, many versions of the same concept are developed such as stepwise uniform refinement, local adaptive slicing and non-uniform cusp height at different faces of a solid. These procedures assume the rectangular build edge profile for the deposited layers. Proper material deposition strategy is required to develop fast interior and accurate exterior slicing method.

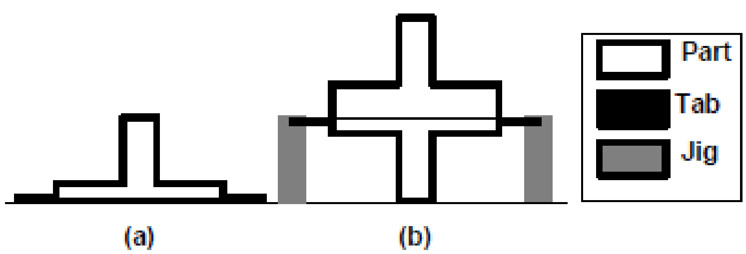

Figure-2. Process of double-sided building.

VOL. 10, NO. 11, JUNE 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

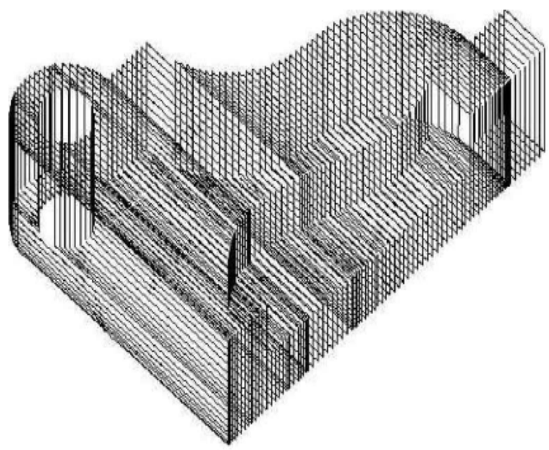

Figure-3.

Rectangular build edges are assumed only for the slicing of exterior region. For FDM, parabola build edges are assumed which is quite closer to real time situation. In Region based adaptive slicing, flexibility of imposing different cusp heights on the different surfaces of the model was implemented.

Direct slicing is useful when the CAD model is designed as the analytical surface or combination of surface patches. In the procedure of cusp height concept, the build edges are assumed as rectangular. Sloping build edges can lead to better results in terms of accuracy and reduction of build time, but its application is limited to larger objects only.

Parabolic build edges are more realistic and are implemented for axisymmetric components. It can be expected to reduce build time as the surface is approximated by realistic edge. In direct adaptive slicing, layer thickness is decided by considering maximum allowable deviation in area, but, it does not take surface geometry in consideration [10].

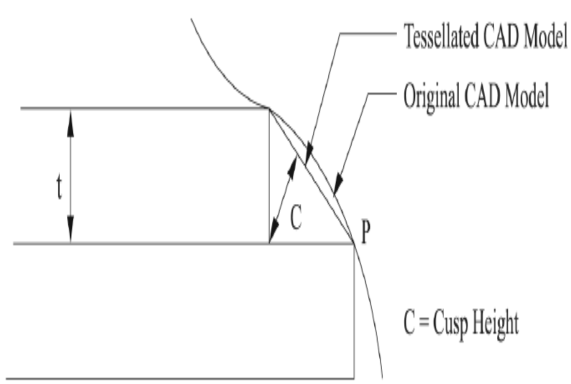

Figure-4. Cusp height.

d) Tool-path generation

Tool-path is the path of movement of the nozzle or print head to build each sliced layer. It is used to determine the various build parameters such as strength, stiffness and quality of a model to be built. The various approaches in tool path generation are discussed below:

Recursive Hilbert's curve is mainly employed for special geometric models and some regular boundaries. The build time will be longer than that of other conventional tool-path generation methods. For some special fractal models, Fractal curve can be used.

Zigzag approach helps to facilitate easier execution of the approach but produces poor geometrical quality. It fills a layer along the X, Y or a specific direction. Contour approach establishes good geometrical quality but consumes more build time compared with the zigzag tool-path generation. The layers are built along its contour and offset curves are built by following the boundary of the model. Due to advanced computation, Spiral approach is applicable for some special geometrical models

A new tool-path generation approach was developed to improve the tool-path generation and nozzle or print head speed control to be adaptive to the various geometrical properties of complex biomedical models. Figure-5 shows the approach which includes the following algorithms: [11]

1) A slicing algorithm was developed a Non-Uniform Rational B-Spline (NURBS) curve to represent the contour of each sliced layer instead of STL based representation and increases the accuracy of a model.

2) A hybrid tool-path generation algorithm, also, uses NURBS-based representation to improve the quality and generate internal offset tool-paths and series of contour for each layer. zigzag tool-paths are used for the model's the internal area to make easier computing and building processes.

3) An adaptive speed algorithm, was designed for the different geometries of the model to optimize the speed of the nozzle or print head adaptively so as to boost up the efficiency of contour tool-paths and the build time is reducing with the most suitable slope degree of zigzag tool-paths.

e) Part deposition orientation

Keeping the part at optimum orientation, can increase part accuracy and surface finish and reduce the build time. It also reduces the volume of support structures needed for producing the part [12]. Automation of the part orientation will eliminate operator's involvement and hence possible errors are reduced. Many part orientation studies were done by Pandey *et al*. [13] and tried to establish a relationship between the manufacturing time and other build parameters such as support structure, dimensional accuracy, surface quality and manufacturing cost.

Most of the studies have done on SL process. Part deposition orientation was determined by FDM in very few attempts in which the surface finish is a primary factor due to stair stepping effect.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

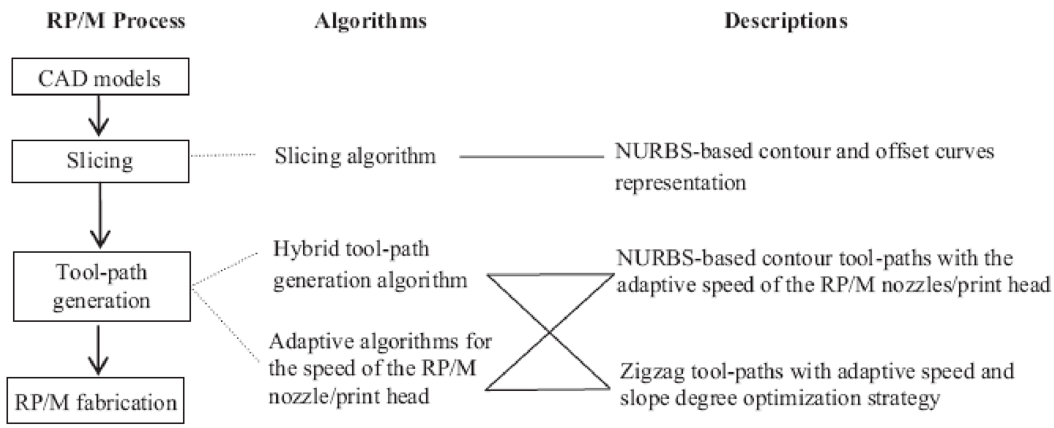

Figure-5. Process of algorithms for Tool-path generations.

From a list of preselected orientations, the best part deposition orientation was selected in most of the attempts. For depositing part of a completely freeform part, it is impossible to pre-select the candidate base planes.

Volumetric error approach or average weighted cusp height method has assumed rectangular build edge profiles, however, parabolic slice edge profiles are found in FDM. Also, build time for FDM can be determined approximately by computation of slice areas, material deposition paths, number of slices and support structure etc., however it may be mathematically cumbersome, but efficient.

Recently an endeavor is made for ascertaining optimal part deposition orientation for FDM components in which genuine surface roughness models predicated on quantified surface profiles has been taken as a substructure. Additionally an investigation was done to find the optimal orientation among all possible orientations unlike culling a felicitous orientation from the list of few pre-culled orientations.

f) Curved Layer Fused Deposition Modeling (CLFDM)

CLFDM proposes an incipient building paradigm for FDM [14], the filaments would be deposited along curved paths in lieu of planar paths as shown in Figure-6. Curved layer process is used to eliminate the staircase effect and increase build speed, improve surface quality, reduce waste, and easier decubing.

An algorithm was developed and implemented for engendering 3D curved paths of the nozzle for filament deposition to achieve prosperous reproduction of felicitous inter-filament bonding and part shape.

CLFDM would be very opportune for the engenderment of functional prototypes of skull bones and other thin shell-type components. Other applications are in the building of intricate and minuscule sized turbine blades and thin cross-sectional objects, engendered for authentic use or for design, verification and testing. It is additionally anticipated that there would be ample amelioration in the mechanical properties of curved and thin shell-type components, more bonding between consecutive layers, lesser number of layers for identical part, higher continuity of filament resulting in more vigor

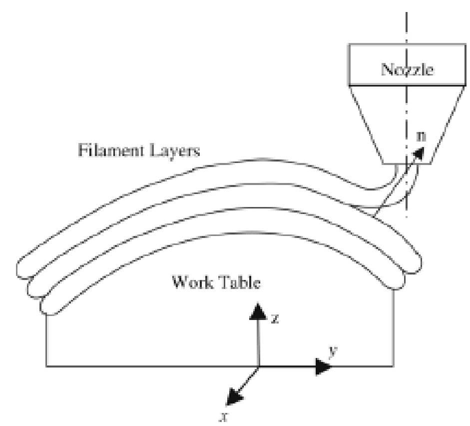

Figure-6. Prototyping of parts by CLFDM using 3-axis control (X, Y and Z).

g) Recoating and scanning

The laser scan time for each layer and the total recoating time between layers decide the total build time required for a component in SLA process. Both of them are functions of part size and geometry. For building sizably voluminous cross section area components, preserving the laser scan time can be consequential and for building long and tall components, preserving the recoating time is consequential. An orthogonal array of experiments has been developed using Taguchi experimental design techniques [15],which provide the least number of experimental runs and desired process parameter settings. Coordinate Measuring Machine (CMM) and surface profilometer are used to take a set of measurements to find out the quality of SLA parts and to find the functional relationships between the part quality and build parameters.

Two analysis tools, Analysis of Variance (ANOVA) and Response Surface Methodology have been used to validate the SLA process and to perform the product optimization.

3. DISCUSSIONS

Build time reduction studies presented above reveals that most of them are not only dealt with build time, also deals with surface quality, geometrical accuracy, strength etc.

- After analyzing the various hollowing methods for rapid prototyping technology, a two-dimension hollowing algorithm is discussed in detail with SLS, SLA and FDM. The great strength of a 2D algorithm is to work online and minimize the build time.
- The double-sided build paradigm shows improvement for prototyping mouldable parts with FDM. Re-usable jigs reducing the cost over many runs.
- Some approximation in STL file is avoided by Direct slicing, compared with STL-based slicing. An immense drawback of direct slicing is the capability among sundry CAD systems and is not applicable to any other set of CAD software and machine [16]. As a result, STL-based slicing is still the widely used method in LM processes.
- A series of optimization strategies for tool-path generation were developed in RP process to amend geometrical precision and to reduce build time for "Biomedical model fabrication", including a slicing algorithm and NURBS-predicated representation, hybrid, contour and zigzag tool-path generation, and adaptive speed control strategies.
- Most of the research works on part orientation have done on SL process. Considerably, less number of attempts have been made for FDM process. It is found that many build parameters have get affected by the part deposition orientation such as surface quality, build time, volume of support structures, shrinkage, curling, distortion, roundness/flatness, resin flow, material cost and trapped volume etc.
- The benefit of CLFDM is in building slightly curved and thin parts. Additionally, CLFDM can increase strength of parts and to reduce stair-step effect, number of layers and build time simultaneously, whereas, the flat-layered FDM failed to meet the strength requirements. Due to the requirement of higher sophistication in part and extruder manipulation, capital investments may increase.
- The suggested optimal set up can reduce the total laser scan time significantly, but it requires voluminous amount of total recoating time. When comparing with other setups, the resultant total build time may increase or decrease. It depends on the specific part's geometry and dimensions in consideration. This method suits only for SLA.

4. CONCLUSIONS

Various published works for build time reduction are presented. Usually one or more objectives have been considered, where build time is not treated as primary factor. It is noted that influence of build time with the characteristics like surface quality and accuracy are inevitable. There are numerous ways to reduce the build time at any instance through the three phases of build process. The manufacturing time is mostly influenced along with Z axis, i.e. height model, but also by the size and geometry of the cross sections. It is realized to develop optimal build time systems based on different characteristics for various LM processes must be investigated.

5. REFERENCES

[1] Kai C. C. and Fai L. K. 2000. “Rapid prototyping: principles and applications in manufacturing,” World Scientific, Singapore.

[2] Kochan D. 1993. “Solid freeform manufacturing: advanced rapid prototyping,” Netherlands: Elsevier.

[3] J. Giannatsis, V. Dedoussis and L. Laios. 2001. “A study of the build-time estimation problem for Stereolithography systems Robotics and Computer Integrated Manufacturing,” pp. 295-304, 17.

[4] Yu KM and Li CL. 1995. “Speeding up rapid prototyping by offset,” P I Mech En B J Eng, Vol. 209, pp. 1–8.

[5] Li CL, Yu KM and Lam TW. 1998. “Implementation and evaluation of thin-shell rapid prototype,” Comput Ind, Vol. 35, No. 2, pp. 185–193.

[6] Ganesan M., Fadel GM. 1994. “Hollowing rapid prototyping parts using offsetting techniques,” Proceedings of the 5th international conference on rapid prototyping, Dayton, OH.

[7] Chiu WK and Tan ST. 1998. “Using dexels to make hollow models for rapid prototyping,” Comput-Aided Des, Vol. 30, No. 7, pp. 539–547.

[8] Daosheng Cai, Yusheng Shi, Lichao Zhang and Shuhuai Huang. 2007. “The two-dimension hollowing algorithm for rapid prototyping technology,” Int J Adv Manuf Technol, Vol. 33, pp. 738–745, DOI 10.1007/s00170-006-0513-7.

[9] Sara McMains. 2002. “Double sided layered manufacturing,” Proceedings of JUSFA02 2002 Japan USA Symposium on Flexible Automation, July 15-17, Hiroshima, Japan.

[10] Pulak Mohan Pandey, N. Venkata Reddy and Sanjay G. Dhande. 2003. “Slicing procedures in layered

manufacturing: a review," Rapid Prototyping Journal, Vol. 9 No. 5, pp. 274–288.

[11] G. Q. Jin, W. D. Li, L. Gao and K. Popplewell. 2013. "A hybrid and adaptive tool-path generation approach of rapid prototyping and manufacturing for biomedical models," Computers in Industry, Vol. 64, pp. 336–349.

[12] D. T. Pham and S. S. Demov. 2001. "Rapid Manufacturing: The Technologies and Applications of Rapid Prototyping and Rapid Tooling," Springer-Verlag London Limited.

[13] Pandey P. M., Venkata Reddy N. and Dhande S. G. 2007. "Part deposition orientation studies in layered manufacturing," Journal of Materials Processing Technology, Vol. 185, pp. 125–131.

[14] Debapriya Chakraborty, B. Aneesh Reddy and A. Roy Choudhury. 2008. "Extruder path generation for Curved Layer Fused Deposition Modeling," Computer-Aided Design, Vol. 40, pp. 235–243.

[15] Jack Zhou, Dan Herscovici and Calvin Chen. 1999. "Parametric Process Optimization to Improve the Accuracy of Rapid Prototyped Stereolithography Parts," International Journal of Machine Tools and Manufacture, No. 40, pp. 1-17.

[16] Haipeng P. and Tianrui Z. 2007. "Generation and optimization of slice profile data in rapid prototyping and manufacturing," Journal of Materials Processing Technology, 187–188, pp. 623–626.