Review Article *ISSN: 2319-507X*
Ashish Wankhade, *IJPRET, 2013; Volume 1(8): 66-76* *IJPRET*

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

A PATH FOR HORIZING YOUR INNOVATIVE WORK

BUILD ORIENTATION ANALYSIS IN FUSED DEPOSITION MODELING: A REVIEW

ASHISH WANKHADE[1], DILIP INGOLE[2]

1. Faculty in Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, India.
2. Faculty in Professor Ram Meghe Institute of Technology and Research, Badnera-Amravati, India.

Accepted Date:
27/02/2013
Publish Date:
01/04/2013

Keywords
Layered manufacturing,
FDM,
Build orientation,
Optimization

Corresponding Author
Mr. Ashish Wankhade

Abstract

The fused deposition modeling (FDM) process is one of several layered manufacturing (LM) techniques used to produce three-dimensional solid objects directly from a CAD model. The ability to select the optimal orientation of build up is one of the critical factors since it affects the part surface quality, accuracy, build time and part cost. Determination of proper orientation of the part during the building process has therefore been an important issue to be resolved by the RP user. Several studies have been made on determination of proper orientation of the part during the building process in a FDM system The main idea behind this paper is to highlight efforts made by the researchers in giving a concrete solution for determining the optimal build orientation in FDM process.

1. INTRODUCTION:

The use of rapid prototyping (RP) is appreciated worldwide, owing to zero tool costs, reduced lead times, and considerable gains in terms of freedom in product design and production schedules. The RP parts can be built with various possible build orientations. The specific part orientation influences the prototype build time, material, and accuracy. Parts formed using fused deposition modeling (FDM) can vary significantly in quality depending on the manufacturing process plan. Altering the plan profoundly affects the character of the resulting part. Recent years have seen a substantial amount of research in the area of layered manufacturing process planning. These works has included consideration of part orientation or build direction, support structures, layer thickness, and layer path planning, in optimizing build time, surface finish, dimensional accuracy, or part strength. Much of this work has considered various process variables towards the optimization of a single objective, but far less research has considered the multi-objective optimization of several objectives with respect to numerous process variables. Much research has considered the part orientation problem within LM applications, focusing mainly on: i) Optimizing the process input parameters and slicing algorithms ii) Optimizing the output parameters and post process requirements iii) Minimizing the support structures required iv) the establishment of feasible orientations; determination of recommended or optimal orientations.

Geometric and algorithmic methods have been implemented in the effort to optimize the build orientation with respect to build time, surface quality, or part strength. Some studies have applied an expert systems approach to determine an optimal build orientation. Another issue affecting the quality of the fabricated part is the path plan used for each layer. Various methods of filling the interior of each layer have been researched in order to produce parts quickly, that are strong, or that have a good surface finish. The majority of this research has focused on the optimization of one specific build goal, or several build goals with respect to only one process variable. The multi-objective optimization problem has been addressed in some detail, however, with respect to the stereo lithography apparatus (SLA). Such work has examined the effects of two or more process variables on the quality of the SLA parts.

2. BUILD ORIENTATION STUDIES SO FAR:

In rapid prototyping, such as SLA and FDM, the orientation of the part during fabrication is critical as it can affect part accuracy, reduce the production time, and minimize the requirement for supports and, thus, the cost of building the model.[1] Similar to traditional process planning in manufacturing, the quality of the result depends heavily on the knowledge (which is a combination of skill and experience) of the process planner. It is a strongly subjective skill, and has yet to be organized into a precise and objective methodology. [2] In rapid prototyping, the various stages in the process are automatic, except for the selection of the part orientation and the creation of support structures.[3]

Seth and Dutta in 1994 presented a method of deriving the optimal orientation by minimizing the area of contact with support structures, which can reduce the time, improve the surface finish and ensure better stability of the object.[4] Their method for the determination of the best orientation consisted of determining candidate orientations, computing the support structure requirement for each candidate and finally the best orientation is selected from the candidate list which requires minimum support structure and gives better stability of the object. In 1995, Bablani and Bagchi quantified process planning errors and process errors.[5] They developed an algorithm to calculate the process planning error, process error and number of layers in different orientations by rotating a given part about user-selected axis/axes at different intervals of rotation. The algorithm can provide suggestions to the user, such as the preferred orientation of the parts, support structure and trapped volume.

Wodziak *et al*. proposed a methodology using genetic algorithms (GAs) to obtain a near-optimal placement of parts by considering their bounding boxes so as to utilize the maximum available space and minimize the time required to build the parts. [6] Frank and Fadel in 1995 proposed an expert system that considers surface finish, build time, and support generation.[7] Only the quality of surface finish is considered as the rules determining a preferred orientation. Among many geometric features, the user chooses two important geometric features of a part. The appropriate orientation is then selected from the surface finish and the support structure of these two features.

Build style optimization research has also been done with regards to build time and surface finish of curved surfaces. Sabourin et.al presented a technique, called adaptive slicing, which involved slicing the ·part thinner in areas of high curvature and thicker throughout flat areas. [8] The main idea was to estimate the surface finish for a particular curved surface by determining how much stair stepping is present. A method has been developed by Hur and Lee, in 1996, to automatically generate support structures in SLA build styles. Not only does their method generate support structures, but it determines the best build orientation to minimize the amount of support structures required.[9] Hur and Lee determine which facets of the STL file need to be supported based on the following criteria: orientation of the facet, area of the facet, part instability, and base support. This work was done in the context of a SLA system.

In 2006, Byun et. al. explored optimal build directions using genetic algorithm for different rapid prototyping processes.[10] Two goals, average weighted surface roughness (AWSR) and build times are combined to form a single objective function, considered for minimization. In 2007, single objective genetic algorithm was employed to determine optimal fabrication directions for LM processes by Ahn et. al., so as to minimize the required post-machining region (RPMR) in LM (as post-machining is often required to improve the surface quality).[11] Here, the authors developed an expression of the distribution of surface roughness and relation between the RPMR and fabrication direction.

Pandhey ET. el. in 2009, described a systematic multi-objective problem solving approach, simultaneously minimizing two conflicting goals - average surface roughness '*Ra*' and build time '*T*', for object manufacturing in FDM process by usage of evolutionary algorithms. [12] Chen et. al., in 2008 analyzed factors affecting the selection of build orientation in layer-based machining. [13] They are: base plane size, skewness of CG, height of CG, inaccessible volume, support needed area, number of stock layers, and volume of removed material. A methodology employing fuzzy set theory to select the preferred build orientation in layer-based machining system has been developed.

It was first proposed by Dolenc and Makela in 1994 to slice a model with a variable thickness, instead of a constant thickness applied in uniform slicing.[14] Based on the surface geometry of the model, this approach decreases the thickness where high accuracy is required, and vice versa to reduce the staircase effect. Hur developed an algorithm to calculate the staircase area, quantifying the process errors by the volume supposed to be removed or added to the part. [15] Zaho et. al. in 2008 established optimizing model based on the considerations of staircase effect, support area and production time.[16] The best part-building orientation is obtained by solving the general satisfactory degree function employing genetic algorithm and the optimal scanning direction is also solved by genetic algorithm.

Byun et. al. developed the average weighted surface roughness (AWSR) that is generated from the stair stepping effect, the build time, and the part cost using the variable layer thickness.[17] They used the multi-attribute decision making method, and chose the best orientation among the orientation candidates from the convex hull of a model. After some years, Byun et al. also used the simple additive weighting method for the decision making considering the surface roughness, build time and part cost. [18] And then Thrimurthulu et al. used one genetic algorithm to obtain an optimum part deposition orientation for FDM process for enhancing part surface finish and reducing build time. [19]

Masood et al. presented another generic mathematical algorithm, in their research, the algorithm worked on the principle of computing the volumetric error (VE) in a part at different orientations and chose the best orientation based on the minimum VE in the part.[20] And according to Rattanawong, they determined the optimal orientation on the basis of the least amount of VE, too. In their technique, it involved a primitive volume approach, which considers a part to be made from a combination of basic primitive volume.[21] Alexander et al. developed an accuracy calculation model and a methodology for creating the cost model.[22] Cusp height is used to measure the accuracy of a part. The accuracy is calculated using the weighted cusp height that considers the area of each facet in the Stereolithography (STL) data. The best orientation is chosen in terms of the user from the results calculated. The algorithm was applied to fused deposition modeling (FDM) and stereo lithography apparatus (SLA). Xu et al. selected the suitable orientation by considering the three criteria, build cost, build inaccuracy, and build time, for several RP processes.[23] This research is similar to that of Chen et al. [1] The build cost is chosen as the main optimization objective. The secondary objectives include build time and build inaccuracies. When minimizing the build cost for a given model and process, if the part orientations with the same build cost occurs, the secondary objectives are calculated to resolve tie-breaks.

Danjou et al. in their paper presented a generic system that performs a computer-aided optimization of part orientation in consideration of the mentioned factors of influence as well as related effects.[24] The whole optimization is mainly based upon iterative modification of spatial part position and the calculation of all orientation-dependent parameters. The consideration of part quality is expressed by calculating the volume deviation with the help of the cusp height of each facet. Jibin established optimizing model based on the considerations of staircase effect, support area and production time. [25] The general satisfactory degree function is constructed employing the multi-objective optimization theory based on the general satisfactory degree principle.

Lin et al. developed an optimization algorithm to define the fabricating orientation based on the minimum process error and proposed a mathematical model to predict the layered process error. [26] Byun et al. presented a decision support system to help the user or the designer choose the optimal build-up direction of a part as well as the best RP process on the given weight for different RP systems. [27] The revised average weighted surface roughness, which considers stair stepping effect, build time calculated by nozzle travel, and part cost calculated by build cost rate, labor cost rate, material cost, etc., are considered. Ziemian and Crawn produced evidence of a significant amount of research carried out in the area of laminated manufacturing process planning and part build optimization. They presented a multi-objective optimization problem associated with the fused deposition modeling (FDM) process and suggested future research by including several additional process variables. [28]

Ingole et al. carried out build orientation analyses for prismatic, curved boundary, and complex-shaped parts.[29] The effects of build orientations on cost and other significant parameters were analyzed. A mathematical model is formulated as a unique solution to estimate the total cost of part preparation in FDM. The major objective of the study is to identify the optimal part build orientation and parameters determining minimum cost of part preparation in the FDM process. Massod et al. presented a generic approach in which tessellated CAD models are used in place of basic primitives which forms a part. [30] Best part deposition orientation for tessellated CAD model is obtained by minimizing the volumetric error. [20,21] Pandey et al. developed a system for determining the optimal part deposition orientation for FDM parts considering the average part surface roughness and build time as objective functions. [31] Genetic algorithms are used for the multi-objective optimization. The optimal orientations are selected among all possible orientations instead of a list of pre-selected orientations in these works [19, 31].

3. DISCUSSION:

Many attempts [1, 7, 20, 21, 22, 23, and 30] have been made to decide a suitable part deposition orientation using different criteria like part accuracy, surface quality, build time, volume of support structure and cost. An approach based on the minimization of volumetric difference of CAD model and LM part (volumetric error) has also been used to determine better part deposition orientation [20, 21, and 30]. Minimum of average weighted cusp height among few pre-selected orientations is also used as a criterion for better surface quality [22].In most of these attempts [1, 4, 7, 20, 21, 22, 23, 30] suitable or the best part deposition orientation is selected among the few preselected orientations although part can be deposited in infinite possible orientations. Pre-selection of the candidate base planes for depositing part is impossible for a completely freeform part like bones, horse saddle etc. Pandey et al. [31] and Thrimurtullu et al. [19] made an attempt for finding out optimal part deposition orientation for FDM parts in which actual surface roughness models based on measured surface profiles has been taken as a basis. Minimum support structure requirement is also considered as the criterion for optimum build orientation [4, 9, and 16]. Process planning and process errors are also used to suggest the preferred orientation [5, 15, and 26]. Various investigations are being made in the slicing algorithms and adaptive slicing in the regions with critical geometrical features [8, 14]. Genetic algorithms and various other multi-objective decision making tools are also used to present the best possible compromise solution [12, 17, 25, 27, and 28]. Post fabrication processing requirement is also considered as a base for optimal build orientation [11].

4. CONCLUSION :

The work published by various researchers for optimal part build direction is presented. Majority of the work seems to have focused on part accuracy, build time, support requirement and fabrication cost as the main criteria for optimization. Few researchers determined part deposition orientation along with adaptive slicing and used cusp height as limiting parameter assuming build edge profiles as rectangular. Actual build edge consideration and its use in adaptive slicing and part deposition orientation has been done in which the optimal part deposition is investigated among all possible orientations.

The research so far revels that there is still a need to develop optimal part deposition orientation systems by considering various objectives simultaneously (multiple criterion) in which all possible orientations must be investigated unlike few preselected orientations.

The author proposes to attempt to develop a universal solution to determine optimum build orientation by using multi-objective optimization which will be suitable for any of the RP technique. The final aim will be to provide the best possible trade-off between the build objectives.

5. REFERENCES :

1. W.Cheng, J.Y.H.Fuh, A.Y.C.Nee, Y.S.Wong, H.T.Loh, and T.Miyazawa, Multi-objective optimization of part building orientation in stereolithography, Rapid Prototyping Journal, 1995; 1(4),12–23

2. Wang, H.P. and Li, J.K., Computer-aided Process Planning, Elsevier Science, Amsterdam, 1991; 205-206.

3. Kruth, J.P., Material in cress manufacturing by rapid prototyping techniques, Annals of the CIRP, 1991; 4(2), 603-14.

4. Seth, A. and Dutta, D., On the computation of part orientation using support structures in layered manufacture, Technical Report UM-MEAM-TR-94-15, The University of Michigan, Ann Arbor, MI, July 1994.

5. Bablani, M. and Bagchi, A., Quantification of errors in rapid prototyping processes, and determination of preferred orientation of parts, Transactions of the NAMRI of SME, 1995; XXIII, 319-24.

6. Wodziak, J., Fadel, G. and Kirschman, C., A genetic algorithm for optimising multiple part placement to reduce build time, Proceedings of the Fifth International Conference on Rapid Prototyping, University of Dayton, Dayton, OH, June 1994.

7. D. Frank and G. Fadel, Expert system-based selection of the preferred direction of build for rapid prototyping processes, Journal of Intelligent Manufacturing, 1995; 6(5), 339–345.

8. Sabourin, E, Houser, S A, BS(jhn, J H, Adaptive Slicing using Stepwise Uniform Refinement, Rapid Prototyping Journal,1996; 2(4):20-26.

9. Hur, J and Lee, K, Efficient Algorithms for Automatic Support Structure Generation in Layered Manufacturing, Proceedings ASME Computers in Engineering Conference, paper #96-DETC/CIE-1324, 1996.

10. Hong-Seok Byun and Kwan H. Lee., Determination of the optimal build direction for different rapid prototyping processes using multi-criterion decision, Robotics and Computer-Integrated Manufacturing, 2006; 22(1):69 – 80.

11. Daekeon Ahn, Hochan Kim, and Seokhee Lee, Fabrication direction optimization to minimize post machining in layered manufacturing, International Journal of Machine Tools and Manufacture, 2007; 47(3-4):593 – 606.

12. Nikhil Padhye, Subodh Kalia and Kalyanmoy Deb, Multi-Objective Optimization and Multi-Criteria Decision Making For FDM Using Evolutionary Approaches, KanGAL Report, December 24, 2009

13. Y.H. Chen, Z.Y. Yang and R.H. Ye, A Fuzzy Decision Making Approach to Determine Build Orientation in Automated Layer-Based Machining, Proceedings of the IEEE

International Conference on Automation and Logistics Qingdao, China September 2008.

14. Dolenc, A. and Makela, Slicing procedures for layered manufacturing techniques, Computer-Aided Design, 1994; 6(2), 119-26.

15. Hur J, and Lee K., The development of a CAD environment to determine the preferred build-up detection for layered manufacturing, International Journal of Advanced Manufacturing Technology, 1998; 14(4), 247-254.

16. Jibin Zhao, Renbo Xia, Weijun Liu, Jinting Xu, Application of Genetic Algorithm in Rapid Prototyping, Proceedings of 3rd International Conference on Intelligent System and Knowledge Engineering, 2008.

17. Byun H. S.; Lee K. H., Design of a new test part for benchmarking the accuracy and surface finish of rapid prototyping processes, L.N.C.S., 2669(2003), 2003, 731-740.

18. Byun Hong S.; Lee Kwan H., Determination of optimal build direction in rapid prototyping with variable slicing, International Journal of Advanced Manufactory Technology, 2006; 28(3-4), 307- 313.

19. Thrimurthulu K., Pandey Pulak M., Reddy N. Venkata, Optimum part deposition orientation in fused deposition modeling, International Journal of Machine Tools and Manufactory, 2004; 44(6), 585-594.

20. Masood S. H.; Rattannawong W.; Iovenitti P., Parts build orientations based on volumetric error in fused deposition modeling, International Journal of Advanced Manufacturing Technology, 2000; 19(3-4), 162-168.

21. Rattannawong W.; Masood S.H.; Iovenitti P., A volumetric approach to part-build orientations in rapid prototyping, Journal of

Materials Processing Technology, 2001; 119(1-3), 348-353.

22. Alexander P.; Allen S.; Dutta D., Part orientation and build cost determination in layered

manufacturing, Computer-Aided Design, 1998; 30(5), 343-356.

23. Xu, F.; Loh, H. T.; Wong, Y. S., Considerations and Selection of Optimal Orientation for Different Rapid Prototyping Systems, Rapid Prototyping Journal, 1999, 5 (2), 54-60.

24. S. Danjou, P. Koehler, Determination of Optimal Build Direction for Different Rapid Prototyping Applications, 14èmes Assises Européennes du Prototypage & Fabrication Rapide, Paris, 2009.

25. Zhao Jibin , Determination of Optimal Build Orientation Based on Satisfactory Degree Theory for RPT, Ninth International Conference on Computer Aided Design and Computer Graphics (CAD/CG 2005) 0-7695-2473-7/05

26. Lin F, Sun W, Yan Y., Optimization with minimum process error for layered manufacturing fabrication, Rapid Prototyping Journal, 2001;7(2),73–81.

27. Hong-Seok Byun, Kwan H. Lee, Determination of the optimal build direction for different rapid prototyping processes using multi-criterion decision making, Robotics and Computer-Integrated Manufacturing, 2006; 22, 69–80.

28. Ziemian, C. W. and Crawn, P. M., Computer aided decision support for fused deposition modeling, Rapid Prototyping Journal, 2001; 7(3), 138–147.

29 D S Ingole1, T R Deshmukh, A M Kuthe, and K M Ashtankar, Build orientation analysis for minimum cost determination in FDM, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, October 2011; 225, 1925-1938

30. S.H. Massod, W. Rattanawong, P. Iovenitti, A generic algorithm for part orientation system for complex parts in rapid prototyping, Journal of Material Processing Technology, 2003; 139 (1–3), 110–116.

31. P.M. Pandey, K. Thrimurtullu, N.V. Reddy, Optimal part deposition orientation in FDM using a multi-criterion genetic algorithm, International Journal of Production Research, 2004; 42(19), 4069-4089