A SURFACE ROUGHNESS BASED VISUAL AND ANALYSIS SYSTEM FOR SURFACE QUALITY IMPROVEMENT IN FUSED DEPOSITION MODELING RAPID PROTOTYPE MACHINE

By

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Nomenclature

t	Slice or layer thickness
θ	Build orientation
$Ra(\mu m)$	Surface roughness (centerline average)
$Ra_{70°}, Ra_{90°}$	Surface roughness for 70° and 90° build orientation, respectively
Ra_{av}	Average surface roughness of the part
Ra_i	Surface roughness of i^{th} trapezium an estimation of build time of FDM part (dimensionless)
A_i	Area of i^{th} trapezium
$Ra_{(n)}$	Average value of surface roughness for layer n (dimensionless).
$Ra_{(n)Left}$	Value of surface roughness at the left side of layer n (dimensionless).
$Ra_{(n)Right}$	Value of surface roughness at the right side of layer n (dimensionless).
Adaptive $Ra_{(n)Right}$	The average value of surface roughness in the right side of adaptive layer n (dimensionless).
$Ra_{(n)Right}$	Value of surface roughness at the right side of layer n (dimensionless).
$Ra_{(n+1)Right}$	Value of surface roughness at the right side of layer (n+1) (dimensionless).
Adaptive $Ra_{(n)Left}$	Average value of surface roughness in the left side of adaptive layer n (dimensionless).

$Ra_{(n)Left}$	Value of surface roughness at the left side of layer n (dimensionless).
$Ra_{(n+1)Left}$	Value of surface roughness at the left side of layer (n+1) (dimensionless).
$z_{(n+1)}$	Height position for $z_{(n+1)}$ level from origin reference.
$z_{(n)}$	Height position for $z_{(n)}$ level from origin reference.
R	Layer thickness ratio
m	Uniform slicing layer thickness
n	New adaptive slicing layer thickness
$Adaptive\ z'_{(n)}$	Position for adaptive layer n.
$z''_{(n+1)}$	Position for $z''_{(n+1)}$ level (data information from .STL file)
$z''_{(n)}$	Position for $z''_{(n)}$ level (data information from .STL file)
Ra	Surface roughness (µm)
Ra_{Max}	Maximum value of surface roughness (dimensionless)
Ra(x)	Allowed maximum limitation value (dimensionless)

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Abstrak

Sistem SRVA yang telah dimajukan telah berjaya memperbaiki permukaan lengkap serta meminimumkan masa pembentukan model prototaip di dalam FDM. Keputusan menunjukkan bahawa peningkatan bahagian orientasi pembentukan lapisan mengurangkan nilai kekasaran permukaan. Bagi orientasi 0^0 dan 90^0 bahagian pembentukan lapisan, nilai kekasaran permukaan adalah menghampiri nilai keluaran daripada “fuzzy logic” di mana perbezaan peratusannya adalah 1.78% dan 1.52%. Maka nilai yang dikira di dalam SRVA sistem boleh diterima pada orientasi ini.Walaupun begitu, bagi orientasi 45^0 bahagian pembentukan lapisan, ia adalah 2.26% lebih tinggi daripada nilai keluaran “fuzzy logic” kerana semasa proses pembentukkan, penyokong model sekeliling memberi kesan kepada permukaan lengkap model prototaip. Bagaimanapun, nilai ini boleh di terima kerana penyokong model sekeliling tidak diberi penekanan di dalam penyelidikkan ini. Keputusan juga menunjukkan bahawa kaedah pemadanan penghirisan memperbaiki kekasaran permukaan model prototaip. Kekasaran permukaan yang telah diukur dengan kaedah ini menunjukkan 1.22% lebih rendah berbanding tanpa kaedah pemadanan penghirisan, tetapi 0.56% lebih tinggi daripada yang diperolehi oleh “fuzzy logic”. Keputusan ini diperolehi tanpa perlu mengulangi pembinaan model atau bahan kerja di dalam FDM untuk penghasilan kualiti kekasaran permukaan yang baik memandangkan kaedah yang dicadangkan di dalam tesis ini berjaya memoptimakan kitaran RP, maka masa pembinaan di dalam RP dapat dikurangkan.

Abstract

In rapid prototyping (RP), part deposition orientation and surface finish are two significant concerns, but they are contradicting with each other. In model building in RP, a concession is commonly made between these two features to get good quality surface roughness at a short build time. A concession among these two contradicting concerns can be achieved via an adaptive slicing method; on the other hand, selection of an appropriate part deposition orientation will further provide an improved solution. In this thesis, an effort towards determining an optimum part deposition orientation and adaptive slicing method for Fused Deposition Modeling (FDM) process for enhancing part surface finish, and hence, reducing build time (repeating process in RP cycle) is proposed. The quality of the surface roughness is determined by using visual and analysis. This Surface Roughness Based Visual and Analysis (SRVA) system is obtained based on the calculation of surface roughness (Ra). In this present work, the Region Based Adaptive Slicing method is applied in building the model in FDM. The proposed methodology allows the RP user to observe and analyze the prototype model before fabricating the prototype model in the FDM. A program based on fuzzy logic is also used to verify the input and output parameters obtained from the proposed method.

The developed SRVA system has successfully improved the surface finish and minimized the build time in fabricating the prototype model in FDM. The result showed that increasing part deposition orientation would decrease the Ra value of the model. For 0^0 and 90^0 part deposition orientation, the Ra from measurement are closed to the Ra output from fuzzy logic with percentage differences 1.78% and 1.52% respectively. Therefore, the Ra values calculated from the SRVA system are acceptable for these orientations. However, for 45^0 part deposition orientation, it is 2.26% higher than the Ra output from fuzzy logic because during fabrication process, the surrounding support model affects the surface finish of the prototype model. However, this value is also acceptable because the effect of surrounding support model to the surface finish has not been the focus of the present work. The result also shows that the adaptive slicing method has improved the surface roughness of the prototype model. The inspected Ra obtained by this method is 1.22% lower than that obtained without adaptive slicing method, but 0.56% higher than that obtained by fuzzy logic. This result is obtained without the necessity to repeatedly fabricate the model or piecework in FDM for good quality surface roughness as the proposed method in this thesis successfully managed to optimize RP cycle; hence the build time in RP is reduced.

Chapter 1

Introduction

1.0 Background

Rapid prototyping (RP) is an itinerary of action in which a part is manufactured using layer-by-layer deposition of material. It is an imperative technology as it has prospective to lessen up 30% to 50% of the manufacturing lead-time of the product even the relative part complexity is very high [1,2].

RP is the most common name given to a host of related technologies that are used to construct physical objects directly from CAD data sources. Based on the principle of layer manufacturing, the RP technique begins with the intersection of the 3D model from CAD (typically an .STL file) with layers of 2D horizontal planes. As a result, a stack of 2D geometry contours is attained, each signifying a cross-section of the 3D model.

Next, the raw material is placed on the bench. The computer takes the bottom slice of the 3D model and transmits different levels of energy to the raw material to the location as designated by the geometric contour. The raw material is filled in one slice after another from the bottom-up, and the process is repeated until a complete 3D part is produced.

Nowadays additive technologies in RP process offer advantages in many applications compared to classical subtractive fabrication methods such as milling or turning. However, Fused Deposition Modeling (FDM) is one of commonly used RP processes.

FDM is an extrusion-based RP process, although it works on the same layer-by-layer principle as other RP systems. FDM is capable of using multiple build materials in a build/support relationship and it was developed by Stratasys, Inc. of Eden Prairie, MN, USA in the early 1990s as a concept modeling device that is now used more for creating masters and direct-use prototyping.

1.1 Rapid Prototyping (RP) Cycle

The RP cycle begins with the CAD design, and may be repeated inexpensively several times until a model of the desired characteristics is produced as shown in Figure 1.1. The final file or files must be in solid model format to allow for a successful prototype build. From the CAD file, an export format called the .STL file must be created.

The .STL file, so named by 3D Systems for **ST**ereo**L**ithography, is currently the standard file format for all U.S. RP systems. STL files are triangulated representations of solid models. The individual triangles are represented by simple coordinates in a text file format. STL files are usually stored in binary format to conserve disk space.

After the .STL file is created, it must be prepared differently for various types of RP systems. Some systems can accept the .STL file directly, whereas others require preprocessing. Preprocesses include verifying the .STL file, slicing, and setting up parameters for machines control. Preprocessing is usually done at a computer separate from the RP system to save time and to avoid tying up valuable machine time.

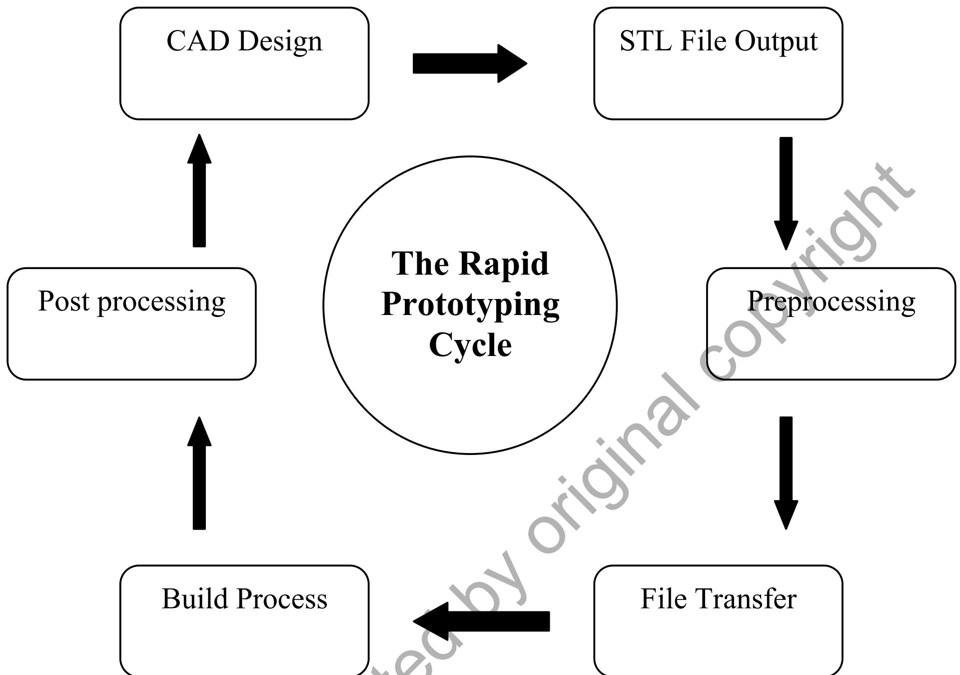

Figure 1.1 *The Rapid Prototyping cycle*

After the .STL has been preprocessed and saved into a new slice format, the new file can then be transferred to the RP system. File transfer can be done several ways, from manually transferring by disk or tape to network transfer. Since more complicated files are usually very large, a local area network or Internet connection is now almost essential for easy file transfer. Once the final file formats are transferred to the RP device, the build process occurs. Most RP machines build parts within a few hours, but can run unattended for several days for large parts.

Upon completion of the build process, post processing of the part must occur. This includes removal of the part from the machine, as well as any necessary support removal and sanding or finishing. If the finished part meets the necessary requirements, the cycle is complete. Otherwise, iterations can be implemented in the CAD file and the cycle is repeated.

1.2 Statement of the problem

In general, all RP technologies use layer-by-layer slicing method and stack one slice after another from the bottom-up to fabricate the model. Basically, there are two important issues here. Firstly, what is the thickness of the layer?, and secondly, how to reduce the gaps between layers which contribute to the staircase effect, and hence, the surface roughness of the prototype model.

The first issue deals with the slicing method of the model. The layer thickness is proportional with surface roughness. If the layer thickness is increased, the staircase effect is increased, and hence, the surface roughness is also increased.

The second issue deals with part deposition orientation. As mentioned earlier, the raw material is filled in one slice after another from the bottom up. If the layers during the fabrication processes are stacked in different orientation, then there would have some gaps between these layers. In theory, the increment of part orientation would reduce the gap, and hence, improved the surface roughness.

Consequently, to conclude the above statements, it becomes:

$$\frac{LayerThickness}{Part\ Orientation} \propto Surface\ Roughness\ (Ra)$$

Earlier researchers [3,4] have studied this relationships, however, in this present work, the relationship is used to visualize and analyze the surface roughness and then proposed new implementation of RP cycle in FDM.

1.3 Research objectives

The primary objective of the research is to develop a Surface Roughness Based Visual and Analysis (SRVA) system for rapid prototyping (RP) in FDM (as shown in Figure 1.2) to improve surface finish and minimize the build time in RP process. The SRVA system would analyse the .STL file data before transferring it to the FDM machine. Using the SRVA, the RP user can directly attain the optimum part deposition orientation for fabrication of prototyping model in the FDM. The RP user can also analyze the portion which would give high effect of surface roughness and then apply the adaptive slicing method to improve further the surface finish of the model. Therefore, repeating RP cycle which was mentioned earlier in Figure 1.1 would be minimized.