A NEW CAD MODEL FORMAT FOR SFF MACHINES?

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I. Abstract

This paper addresses the issue of a standard input data format for Solid Freeform Fabrication (SFF) machines. Currently implemented approaches do not address the different aspects of Solid Freeform Fabrication. This paper will state the requirements from the perspective of the SFF machine designer and make recommendations based on these requirements.

II. Introduction

Current SFF techniques successfully produce parts for visualization. SFF machines also have produced parts for prototyping in some very limited applications. In the future, these machines will generate models, prototypes, production parts, and replacement parts. When identifying input data requirements, the future applications of SFF technologies must be considered.

III. The Selective Laser Sintering (SLS) Process

The SLS process lays down thin (typically 0.005 inch) layers of powdered materials. After adding a powder layer, a laser beam sinters the cross section of the part that intersects with the current layer [DECK88]. Each layer is parallel to the plane determined by the X Y axes. The process builds up layers in the positive Z direction. DTM Corporation of Austin, Texas is commercializing this process.

A. Input Data

DTM now uses a standard proposed by 3D Systems of Valencia, California [3DSY88]. Refer to section IV.A of this paper for a brief description.

B. Translation and Rotation

To simultaneously build as many parts as possible, we must move the parts from their original positions. This will allow parts to be built side by side. In the SLS process, minimizing the part's Z axis distance will decrease the amount of time required to build a part.

C. Sorting, Slicing and Fill Generation

The first sort of the facets is by their low Z value. Facets intersecting with the current Z define the part boundaries. The part boundaries produced from slicing and the surface normals determine the part cross section. A raster fill generates the laser path.

D. SLS Process Irregularities

Certain shapes or features of the part exaggerate process irregularities. We will address minimization and the quantification of irregularities during refinement of the process. Retaining three dimensional surface information would allow different implementers to adjust for irregularities.

IV. Currently Used Data Formats

This section describes the two formats currently used for data input.

A. 3D Systems

The format specified by 3D Systems [3DSY88] has been very successful. It is readily available, supported by some CAD vendors, and implemented by several SFF designers. This format specifies solids made up of a triangular mesh surface with unit normals for each facet. Using a single entity type to describe the solid increases the ease of implementation on SFF machines. Unfortunately, the data representing a vertex repeats on each occurrence of that vertex. Nonlinear surfaces may require many facets for adequate description.

B. HP-GL

HP-GL is a widely supported two dimensional graphics language commonly used as input to pen plotters [HEWL89]. Although HP-GL can represent curved surfaces, it lacks the flexibility required for SFF machine input. HP-GL requires the CAD system to generate and transfer hundreds of cross sections for each inch of a model in the Z axis. Determining the cross sectional thickness at the CAD system level restricts the application of process knowledge on the SFF machines.

V. Requirements

The following section is a list of items that a SFF standard should address.

A. Precise Geometry

The anticipated use of solid freeform fabrication processes for prototype parts requires a shift from faceted models to precise geometry models. Our understanding of precise geometry relates to a focus on the model as an ideal structure. The goal is the set of data points specified by the designer. Any approximating surface must achieve that goal within the resolution required by the part and as defined by its intended use.

The issue is the distinction between the part as designed (however it is done) and the representation of that part, which serves as the basis for freeform fabrication. Often, the representation consists of a series of interpolated curves that approximate the original object. Mathematical descriptions of fairness seem to focus on the characteristics of the interpolated curve [SU89]. Original data points that violate the definition of fairness are discarded or adjusted. This treatment seems to regard the original data points as the approximations. Parts that include textured surfaces (such as knurls) or threads require maintaining the defined geometry with a high degree of resolution that cannot be casually discarded. The desire to avoid physical postprocessing of the part to improve resolution may further complicate the issue.

The tendency to regard these surface approximations as de facto precise geometry is not without precedent [SDRC88]. However, we see the construction of precise geometry as a process of refinement, bringing the approximating surface as close as possible to the desired "true" surface. As the theoretical surface evolves, the technique provides some method of evaluating the difference between the two surfaces, the true surface and the so-called precise geometry, to determine when to terminate the process. The precise geometry is an acceptable approximation of the true surface when the residual between the surfaces is minimized. Such techniques using rational B-splines have been described [PAPA87].

B. Single Entity

There are several reasons for using a solid model format based on a single entity (i.e., surface patch). It 1) simplifies SFF machine implementation, 2) streamlines the optimization process since only one entity type intersects with the current build plane, and 3) contributes to the possibility of hardware implementation of commonly used operations.

C. Surface Normals

Surface normals are very useful during the generation of the fill. Although winding conventions may be used, surface normals add a degree of certainty. If an error occurs that causes a solid to be invalid [REQU80], surface normals can minimize this error. An example of this would be two surface patches with small gaps between their seams or overlapping seams.

D. Standard Algorithms

Algorithms for common operations are an important part of a model standard. These algorithms should address the CAD and SFF designers' needs, such as the generation and decomposition of the specified entity. This will make the standard easier to implement and improve chances for acceptance. A standard algorithm also will provide a measure for new algorithms. Different algorithms can update the standard if they are functionally equivalent to their predecessors. The requirement for these algorithms may provide an early proving ground for the feasibility of a standard.

The algorithm that would satisfy most SFF machine designers would determine the intersection of the entity(s) with a plane or a raster line in that plane.

E. Variational Data

Tolerance, surface finish, and other allowable variations from the input data are what Requicha [REQU86] refers to as variational data. Tolerance data is an important part of the SFF future. The process may speed up during cross sections of high tolerance. Tolerance data can be used in postprocessing of parts. The evaluation of a part's dimensions and conformance to the tolerance data provides feedback to the control software.

F. Size

Redundant information is unacceptable. A data standard should make extensive use of vertex and feature tables.

G. Ease of Use

If the standard employs the single entity and publishes algorithms for common operations, the standard will be easier to use. If the standard addresses most of the SFF industry's concerns and is easy to implement, it should gain wide acceptance.

VI. Recommendations

We recommend the formation of a committee to develop a standard for solid freeform fabrication data. This committee should include experts in the fields of CAD, CAE, mechanical design, SFF design, geometry of solids, and part tolerances. It would examine current standards and make recommendations for the following:

1. a mathematical technique to describe precise surface geometry that would provide a uniform system of transferring data to freeform modeling systems;

2. a method for including variational information such as part tolerance, surface finish, and overall part strength;

3. a process for employing the recommended technique in current graphics systems; and

4. algorithms for the generation and decomposition of the solid model.

The technique chosen for the representation of precise surface geometry should provide an improvement in the storage utilization by the solid models. Fiasconaro [FIAS87] reports a significant reduction in storage requirements when converting from a faceted model to B-spline surface patches. The B-spline typically requires ten percent of the storage space required by the faceted model. He also notes the versatility of the rational B-spline representation.

The graphics system would then refine the surface through an iterative process until it provided an acceptable model of the part geometry. The standard would include a method of evaluating the approximating surface to determine its validity.

Algorithms for the generation and decomposition of the solid model provide a standard approach to incorporating the preceding process in existing systems and using the standard in the new solid freeform fabrication systems.

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