Visualization tools for design support in SFF

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Abstract

When considering the use of SFF, there are many questions a designer might ask. What model orientation should be used, will the model have adequate aesthetic and functional properties, is the STL file suitable for transfer to the SFF machine? These questions could be answered by a comprehensive design support system for SFF. This paper addresses a number of components for such a system that can be met through the use of visualization tools. These include:

1. Visualization of surface roughness
2. Visualization of characteristic features (e.g. surface macro-texture)
3. Visual simulation of fabrication

Example applications of these tools are presented together with a status review of their implementation to date. It is envisaged that these tools will be incorporated into an already existing network-based preprocessor used for visualization, repair and slicing of STL files. The direction of future work is also discussed which will include the visual representation of functionally graded materials (connected with FEM results).

1. Introduction

Design visualization has become an important part of the computer aided design process. It enables designers to produce realistic images of the final product that can be used as commnuication aids to other personnel, customers and suppliers. Visualization also has a role to play in design analysis where the results of a finite element analysis can be shown as shaded stress contours on the computer screen. Solid freeform fabrication (SFF) has also proved itself as a valuable design tool. SFF models can be used to verify design concepts, to create working prototypes and to provide a link into prototype or production tooling. There are several aspects of SFF that set it apart from other prototyping and manufacturing processes:

(a) it is a material addition process,
(b) all commercial SFF techniques are layer-based,
(c) the additon of material is usually in the form of discrete volumes e.g. roads in FDM, droplets in ink-jet techniques.

These aspects combine to give SFF models some distinctive characteristics. These include the so-called “staircase” effect, requirement for supports, build imperfections (e.g. air gaps, warping), poor definition of small features and a wide variation in surface roughness. All of these will have some effect on the appearance and functionality of the SFF model.

This paper endeavours to show that by giving designers the ability to visualize some of the characteristics before the SFF model is built, it is possible to make their use of SFF more effective. This capability would form a key element of a design support system for SFF that would enable designers to answer such questions as what model orientation should be used, will the model have adequate aesthetic and functional properties, is the STL file suitable for transfer to the SFF machine? The authors envisage that such a system could be used over the Internet and the preliminary development of this aspect is described also. Finally conclusions about the significance of the work are drawn and future research plans are outlined.

2. Visualization of design intent

Visualization, in general, is a method of extracting meaningful information from complex data sets through the use of interactive graphics and imaging. It provides processes for seeing and understanding what is normally unseen, thereby enriching existing scientific methods. Volume visualization as a subfield of visualization, for example, is a method of interpreting complex volumetric data. On the other hand, several geometric modeling algorithms have also been used for interaction between a virtual and the real world. Called virtual manufacturing, these algorithms have become an important part of intelligent machining systems by allowing for the precise modeling of existing technologies.

2.1 Visualization of surface roughness

One approach for visualizing the physical model frequently used by SFF community has been approximating the surface of the object by a collection of surface patches, which results in the display of a smooth, shaded object of the physical model (Salton and Meek, 1995). When being fabricated by SFF apparatus, however, an object is built by laying down material layers in a gradual, controlled way, which results in the staircase (or laddering) effect on what should actually be smooth surfaces. Traditional geometry-based modelers which display a smooth, shaded object of the physical model hence provide the designer with no information on the actual surface finish of the object. For example, a sphere fabricated by SFF apparatus will look like a stack of discrete, differently-sized circular disks rather than a simple smoothly skinned crystal-like ball. Chandru et al (1995) have thus suggested voxel-based modeling for evaluating the geometrical effect on the surface of a physical part made by SFF techniques.

Alternatively, a visualization algorithm of surface roughness based on the slanted angle of STL facets is proposed in this paper. The normal vector for each facet in the STL file is analyzed in respect to the horizontal (x-y) plane. The angle between the vector and the plane is used to determine the local surface roughness value. This is achieved by accessing a database of empirically measured surface roughness values for several SFF processes (Campbell and Martorelli, 2000). The surface roughness value is displayed as a particular color shading on the computer image. This gives the designer a visual image of the overall surface roughness and any problem areas in the model. An example of an SFF model visualized in this way is shown in figure 1. The original orientation (on the left) shows an area of poor surface roughness on the lid of the teapot. If this was deemed unacceptable, the designer would re-orientate the model and re-calculate the surface roughness values. In this case, the teapot on the right has much better surface roughness values on its lid. An added benefit of the software is that it also shows poor facetting within an STL file through “speckled” shading. This is caused by neighbouring facets having significantly different normal vector angles. This is clearly seen around the main body of the teapot in figure 1.

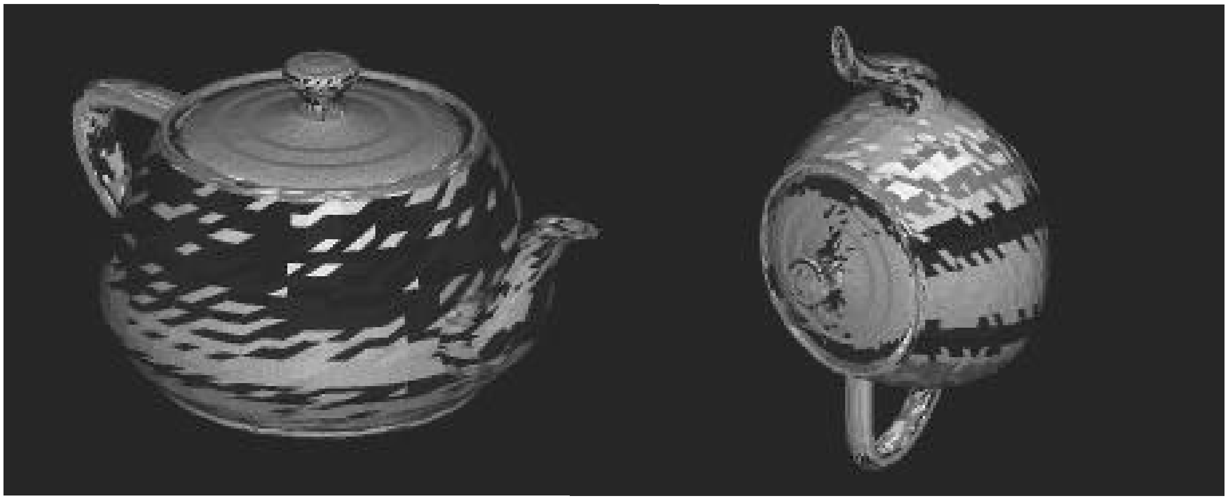


Figure 1. Example of surface roughness visualization images

2.2 Visualization of surface texture

Surface macro-texture design is an example of an SFF characteristic feature that can be greatly aided by the visualization technique. Surface macro-texture denotes a set of tiny repetitive geometric features on an object's surface. The use of porous macro-texture on the surface of an orthopedic implant to promote bone ingrowth, for example, offers a valuable alternative to acrylic bone cements as a means of fixation. Fabrication of surface textures using existing technologies, however, is confined to a simple surface texture with little room for varying surface parameters (Bobyn et al., 1980). Designing millimeter or sub-millimeter surface textures for SFF, e.g. for 3D Printing (Jee, 1996), is difficult due to the complex macro-structure of the tiny texture geometry. It needs to be both compatible with the non-traditional manufacturing method of SFF and representable in an efficiet CAD model structure. A previous research project proposed a visual simulation technique for facilitating surface texture designs as shown in figure 2 (Jee and Sachs, 2000).

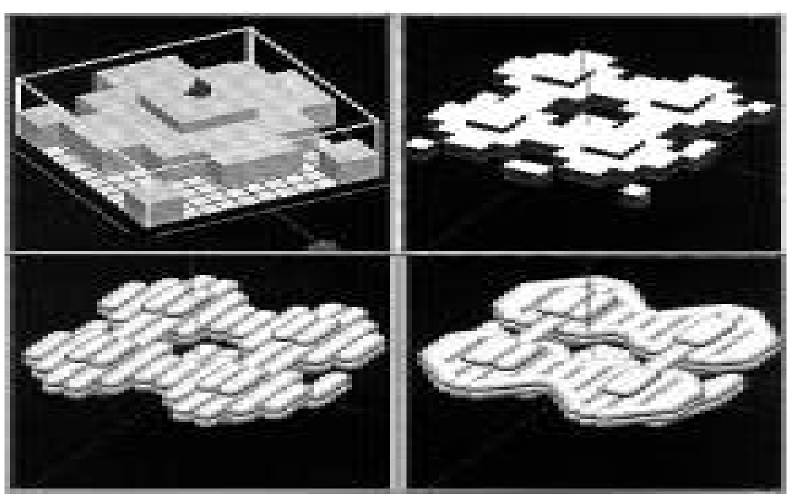


Figure 2. Visualization images for macro-surface texture

2.3 Visual build simulation of SFF

In order to develop a visual simulation tool according to the SFF process rules, manufacturing parameters must be incorporated to properly describe the geometry of the visually simulated model. In essence, a virtual model can be built purely based on the SFF build file as shown in figure 3. The implemented technique takes into account necessary geometric attributes of physical phenomena of the 3D Printing process and hence provides designers with the ability for verifying unseen fabrication capability of the existing prototyping machine in the embodiment of their design. The visualization capability of the proposed method can be demonstrated by comparing the virtual model of a design with the physical model as shown in figure 4. Depending on the application area, the staircase effect can have a significant effect on part fabrications (Jee, 1996). Careful examination of the visually simulated model before the actual fabrication can hence help minimize unwanted design iterations.

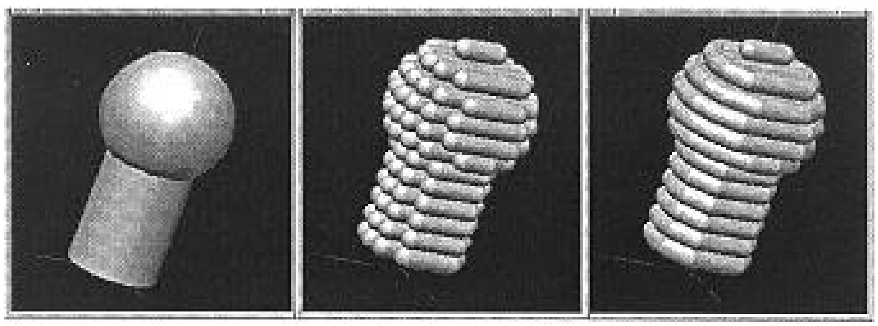
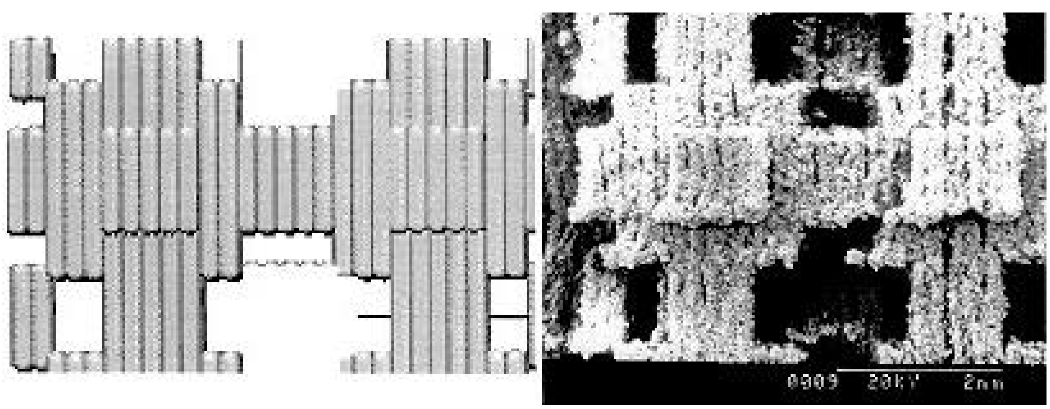


Figure 3. Simulated build for SFF process (3D Printing).



a. CAD model b. physically fabriacted part

Figure 4. Comparison of build simulation and actual SFF model.

In fact, the simulation paradigm can not yet cover all known issues in the SFF community such as material, surface property, and dimensional tolerance. Instead, it is currently limited to the lowest common denominator for the process capability of all available SFF techniques, i.e. part geometry. However, it can still make an important contribution to effective use of SFF by the designer. Although the processeses all differ significantly in their process parameters such as part support, layer thickness, and auxiliary process (post process) steps such as curing or sintering, the underlying theme is the same: all of these processes build a fabricated part one layer at a time. A common manufacturing capability such as minimum feature size relative to the dimension of one material layer can hence be captured and submitted to a designer so that it will lead only to manufacturable designs.

3. Network-based SFF preprocessor

Navigating the World Wide Web (WWW) using Internet software has become a highly successful utilization of communicative networks. At the same time, rapid advances in computing and communication technologies are creating a new approach for product design and manufacturing. It is thought that the lessons learned from the Internet can be applied to SFF technologies as well, and a group of researchers and developers has already moved toward creating an environment for automated SFF capability on the Internet (Bailey, 1995; Luo et al., 1999). It is also important to devise ways to generate physical prototypes through a cheaper and better-amortized process using the Internet.

3.1 Development of preprocessor

Jee and Lee (2000) recently proposed an SFF preprocessor with this functionality for use over the Internet. Figure 5 shows two different process configurations for SFF usage; the upper one for a traditional process configuration and the lower one for the new configuration supported by the proposed method.

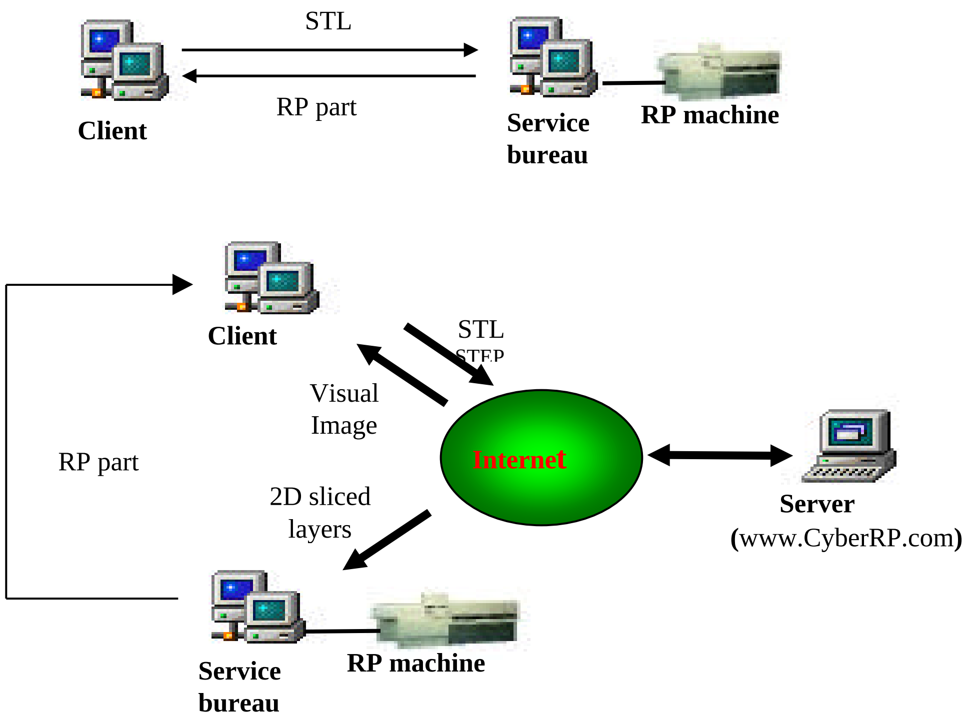


Figure 5. Traditional and proposed process configurations for SFF usage.

The proposed preprocessor can be realized by developing a client/server model on the network and directly providing users with a convenient tool, a preprocessor for SFF over the Internet, so that it can quickly fill the gap between various CAD systems and distributed SFF machines. In this client/server model the server program continuously listens on one end of the channel, and the client program periodically connects with the server to exchange data. Also, all the distributed SFF machines are connected to a server that will manage the process schedule of these machines. The server mainly manages a database for handling STL files so that a client can access the server in order to search appropriate STL files. The client can also directly upload and register its own STL files to the server for SFF processing. The server will first read and translate the imported STL file into an analytic model for visualization, and the resulting image data will be sent to the client so that it can be displayed on the client terminal. The server also provides clients with functionality of cleaning/repairing ill-defined CAD files, converting STL file into data recognized by an actual SFF machine, and visually simulating fabrication (Jee and Sachs, 2000) as desired by the SFF industry. Each client can therefore order an appropriate slice thickness for the STL file over the network, and an image generated from the slicing can be sent to the client for display on the client terminal. The client can also order a request for visual simulation functionality on the server before the real fabrication of the STL file using SFF machines. The server will then create a virtual model and send an image data to the client for display.

3.2. Example use of preprocessor

Users see the familiar browser interface at their client computers, and server computers supply simple Web-like pages or do complex data processing in response to the user input. Figure 6 shows a visualization image of an example STL file, *spider*, displayed over the network. Figure 7 shows a visually simulated SFF part image using the virtual prototyping (visual simulation of the SFF part) option over the network. If the resulting image looks acceptable, users can assign a working order for SFF fabrication to the server. The server can then search an appropriate SFF service bureau and pass the order in order to execute the fabrication. Working orders, on the other hand, could possibly be assigned directly to a specific service bureau depending on users' preferences.

Figure 6. Example of normal STL file visualization.

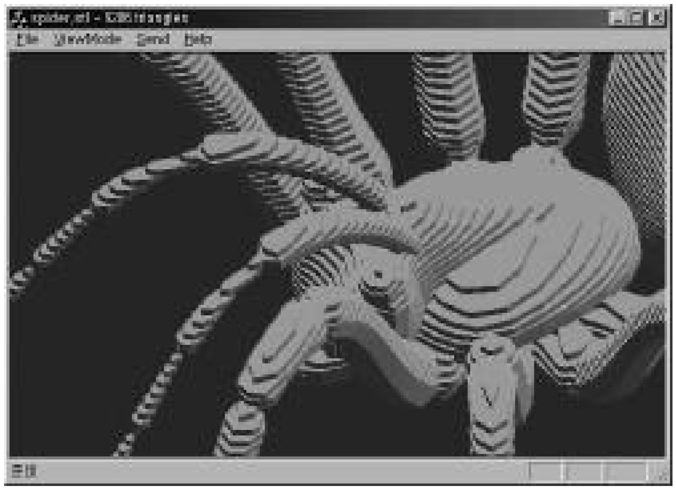


Figure 7. Example of build visualization showing layer simulation.

As part of future work, we will also add a functionality of a Remote Search and Evaluation (RSE) tool to the proposed preprocessor. Using the proposed RSE functionality on the Internet, users' attention can quickly be switched to a specific SFF process in which they might be interested. Figure 8 shows an example of an RSE browser tool which will be added to the SFF preprocessor for searching and evaluating different SFF machines distributed across the Internet. Eventually, this will enable direct tele-manufacturing using tele-control of SFF machines over the network.

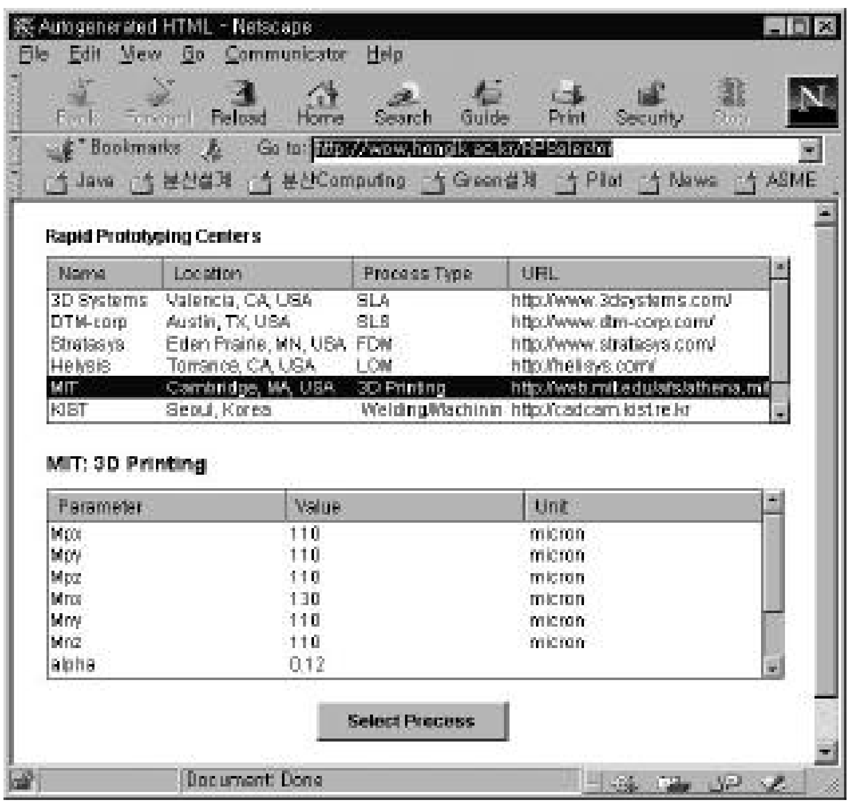


Figure 8. RSE browser tool interface.

4. Conclusions and future work

Several modules for design visualization of SFF models have been developed. They enable a designer to visualize surface roughness, surface features and build geometry. The framework for an Internet-based SFF preprocessor has also been developed to help end-users have more effective communication with SFF providers. The future aim of the research is to incorporate the visualization modules into the preprocessor to create a comprehensive design support system for SFF. Additional functionality will be added to the system including orientation optimization, improved layer simulation and visual representation of functionally graded materials (determined using FEM or similar).

Acknowledgement

The authors wish to acknowledge the financial support provided by the Royal Society for Dr Jee's study to visit to the UK.

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