Voxel Based Material Distribution with Probability for 3D Printing

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Abstract

This study searches for a compositional design method for digital fabrication in modeling environments. In this paper, we propose a method of voxel based compositional design for modeling with 3D printers. This method designs composites by allocating voxel patterns with different fill levels in relation to polygon model input. Compared to surface modeling, this method allows for the simple design of modeled composites. Furthermore, as it supports the input and output of STL data, there is no need for particular hardware that is compatible with this method, and it can use modeling environments with typical 3D printers. It is expected that through the application of this method, that this can be applied to designs with material characteristics, such as softness and a center of gravity, by controlling localized composites within the model.

Introduction

In recent years, there have been significant advancements in the technical development of computer-controlled machine tools, such as 3D printers. In particular, 3D printer modeling technologies such as stereolithography, fused deposition modeling, and selective laser sintering have simplified the modeling of complex forms that were difficult to achieve using previous methods of machining. For example, it is difficult to model a multiporous form that looks like a composite of bamboo and bone using machining and casting, but this can be modeled using 3D printer modeling technology.

However, whereas we have seen progress in the development of modeling technology, it is thought that there is still room for research and development into the design methods and design environment for modeled items in the rapid prototyping field. Currently, in typical rapid prototyping systems, STL (stereolithography) is used as the standard format for input data[1]. STL is a system for approximating 3D shapes using multiple-angled shapes, and expresses the object as a collection of the facets of multiple-angled polygons defined according to the peak coordinates and normal vectors (Fig.1).

STL is a widely used as a method of drawing 3D models for computer graphics, due to the simplicity of its data structure and low processing cost. However, with the STL system, it is not possible to define elements other than standard surfaces. For this reason, based on modeling using a 3D printer, when designing a model that has complex composites such as bamboo or bone, it is necessary to use a complex 3D model, and this increases the design cost.

In this paper, we propose a voxel based design method, with the aim of supporting the compositional design of modeled objects in modeling environments using 3D printers.

Figure 1*. STL (stereolithography)*

Related Work

The following related studies cover design methods and design environments based on digital fabrication modeling environments.

Jonathan Hiller and Hod Lipson study a voxel based freeform fabrication and simulation of the properties of materials, assuming micro-scale assembler[2][3]. The method allows a large variety of materials to be combined and to create new materials with unique properties.

Bernd Bickel, Moritz Bacher, Miguel Otaduy, Hyunho Richard Lee, Hanspeter Pfister, Markus Gross, Wojciech Matusik present a data-driven process to design and fabricate materials with arbitrary deformation behavior[4]. The process finds the best combination of stacked layers of base materials.

Compared with related studies, this research differs in following points. our system can adapt to a general 3D printing system, thus high performance requirement for hardware is not necessary. Also, material property can be generated by single material printing as well as multi-material printing in this system.

Method

This method involves the compositional design of modeled objects through the process shown in Fig. 2.

First, STL data is input into this system (Fig. 3). As the 3D polygon model expressed using STL data approximates the surface form using a polygon mesh, it does not possess information about the form concerning composites for the total modeled object, including the interior.

For this reason, with this system, the input polygon model is converted to the voxel model (Fig. 4). Whereas the polygon model can only express surface forms, as the voxel model can express collections of solids as 3D forms, in addition to the surface form, and it is also possible to design a composite of the internal area based on solids. The algorithm of cellular automaton region extracting is used to extract the inner area of the model[5].

In this paper, we refer to the solid area generated through the process of converting to the voxel model as the voxel area.

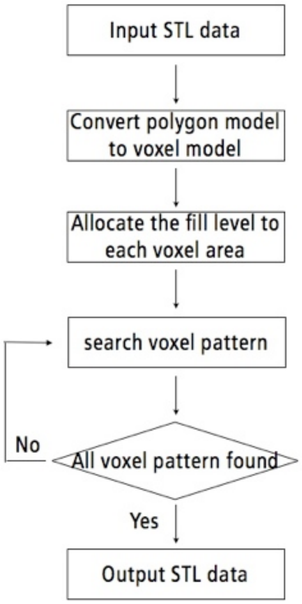

***Figure 2**. Flow chart of this method*

***Figure 3**. Input STL data*

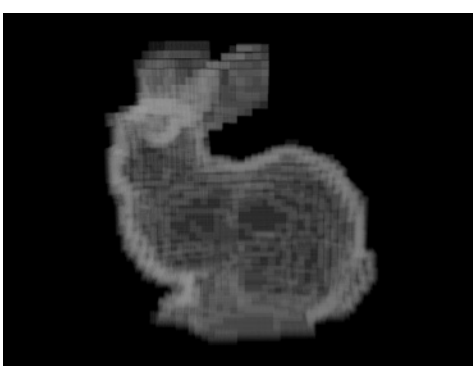

***Figure 4**. Convert polygon model to voxel model*

Next, we partition the voxel area generated through the conversion to the voxel model into 2 x 2 x 2 areas in the xyz direction (Fig. 5). One voxel area is composed of eight small solids, and the shape within the area is determined by this combination of small solids. In this paper, we refer to the shape composed of the combination of eight small solid fills as a voxel pattern.

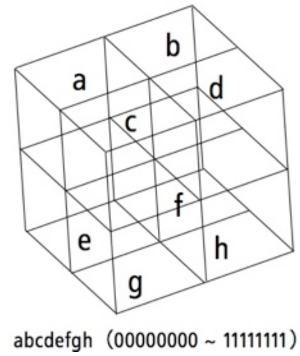

***Figure 5**. Divide voxel area*

There are 256 types of voxel patterns and they are classified respectively into nine levels of fill from 0/8 to 8/8 (Fig. 6). Voxel patterns are expressed using a bit string and are allocated respectively into bit strings from 00000000 to 11111111. The bit strings into which each voxel pattern is allocated correspond to the areas in which the respective small solids exist, with 0 representing a hollow space and 1 referring to a small solid. In the design process, after conversion to the voxel model, by referring to the bit strings allocated to each voxel pattern, it is possible to judge the relationship of connection between neighboring voxel areas and draw the voxel pattern that is finally determined.

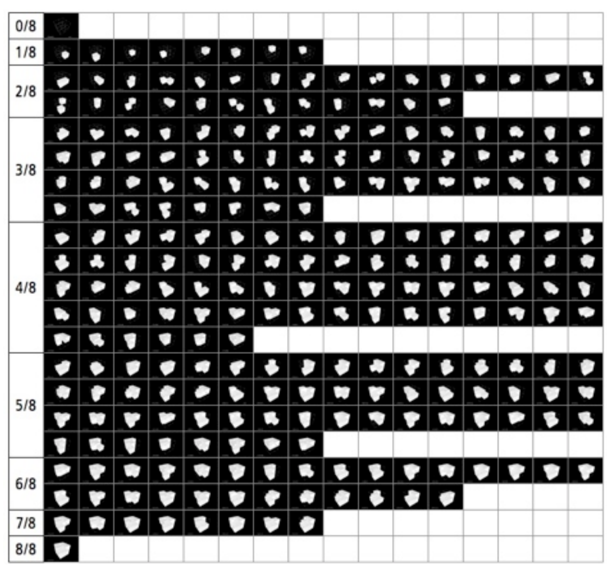

***Figure 6**. Voxel patterns*

Next, the fill level is allocated within the range from 0/8 to 8/8 in relation to each voxel area (Fig. 7). When modeling using a 3D printer, there is no relationship of connection with the periphery, and where there are voxel patterns floating in the area, it cannot be formed as an integrated shape. For this reason, for each voxel area, a shape that connects with the surface of a voxel pattern within any of the neighboring areas from among six neighbors in front, back, right, left, top, or bottom must be selected from the voxel patterns that satisfy the allocated fill.

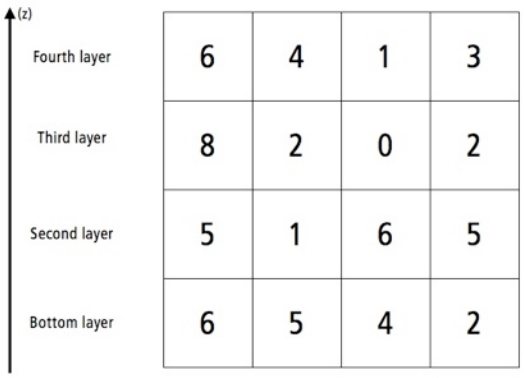

***Figure 7**. Distribute density to each voxel areas*

The search for voxel patterns that satisfy the conditions is performed through two scans. First, in the first scan, a search is conducted in relation to all of the voxel areas (Fig. 8). A voxel pattern that meets the fill level in relation to the target voxel area is allocated, and it is judged whether this voxel pattern connects with the surface of the voxel pattern in the voxel area that is the lower neighbor (z negative direction). If there is a relationship of connection, it is judged that there is a voxel pattern within that voxel area that meets the conditions and the search is completed. If there is no relationship of connection, a different voxel pattern that satisfies the fill level is allocated and judgment concerning the connection is carried out again. If there is a voxel pattern within the target voxel area that satisfies the fill level but does not connect to the surface of a voxel pattern in the lower adjacent voxel area, an 8/8 fill level voxel pattern is temporarily assigned and the search is completed. The same search is conducted in relation to all voxel areas and this completes the first scan.

In the second scan, a search is conducted in relation to the voxel areas for which the voxel patterns satisfying the conditions were not found on the first scan (Fig. 9). A voxel pattern that satisfies the fill level in relation to the target voxel area is assigned and it is judged whether it connects to the surface of the voxel patterns within any of the neighbor voxel areas, that is to say the right neighbor (x positive direction), left neighbor (x negative direction), front neighbor (y negative direction), back neighbor (y positive direction) or top neighbor (z positive direction), to which a connection was not found on the first scan. If there is a relationship of connection, it is determined that a voxel pattern that satisfies the conditions is present in that voxel space, and the search is completed. If there is no relationship of connection, a different voxel pattern that satisfies the fill level is assigned, and the connection is judged again. Once the assignment of the voxel patterns satisfying all of the voxel areas is executed, this completes the second scan.

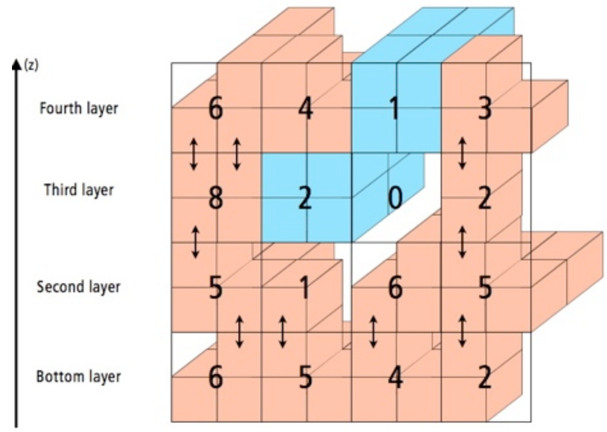

***Figure 8**. First scan*

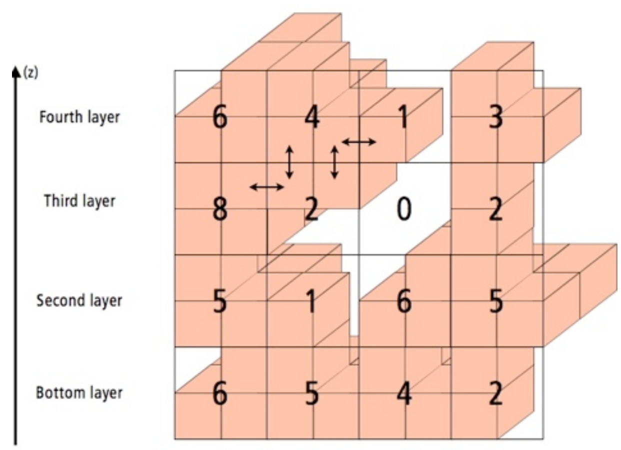

***Figure 9**. Second scan*

Through the second scan, if there are no voxel patterns that both satisfy the fill level within the target voxel area and connect to the surfaces of voxel patterns of neighboring voxel areas, it will be judged that a fill level distribution that cannot be designed with this method has been input and an error is returned. When an error is returned, the design process is performed again from the process in which the fill level is assigned to each voxel area, and a search is conducted for voxel patterns satisfying the conditions through the same scan.

All of the voxel patterns within the voxel area are drawn and when design of the modeled object composite is complete (Fig. 10), 3D form data is output. With this method, as it presumes the use of a modeling environment using a general 3D printer, this is output in STL file format. With STL output, all solids that comprise the 3D shape are saved as surface data without volume.

For this reason, when using the output STL data and modeling, in particular when modeling using the fused deposition modeling, it is necessary to configure the printer so that all of the areas internal to each solid are filled with the material and are modeled.

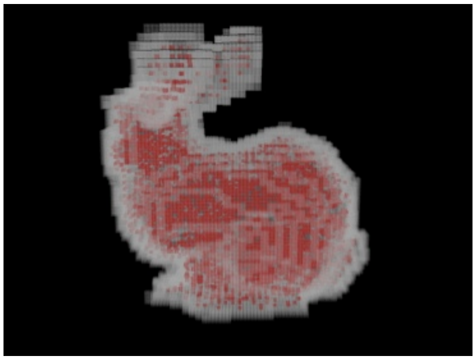

***Figure 10**. modeled object composite is complete*

Furthermore, when modeling using the 3D printer, this is formed while the hollow sections are filled with support material. For this reason, through the design of the composites, the surrounding neighbors are surrounded by small solids. The support materials that exist within the closed hollow sections cannot be removed from the outside. With this method, in consideration of the removal of the support materials, voxel patterns are drawn using small solids in which a hole that will act as a passageway for the removed materials are opened.

Result

Fig. 11 shows a 3D printed model that its composition is designed with this method. The fill level of this model is designed to be gradually decreases in z positive direction. We use stereolithography 3D printer and the model can be shaped as it is designed.

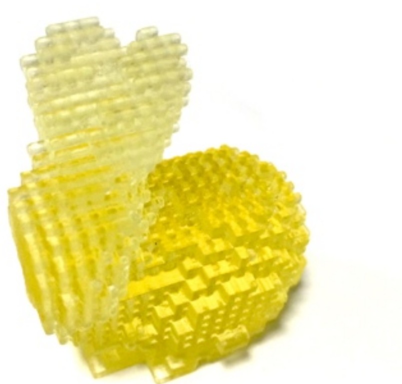

***Figure 11**. 3D printed model*

Conclusion

In this paper, we have proposed a method of voxel-based design, with the aim of supporting the compositional design of modeled objects, based on modeling environments using 3D printers.

First, with this method, it is possible to design modeled object composites in a much simpler way than with surface modeling. Furthermore, as it supports the output and input of STL data, it is possible to use modeling environments using general 3D printers without requiring any particular hardware.

On the other hand, as 3D objects are expressed as a collection of solids, it lacks the ability to reproduce surface shapes compared to the polygon model. For this reason, in order to approximate delicate surface shapes with a high degree of accuracy, it is necessary to increase the density of the voxels, which increases the data size.

Future Work

In terms of our future outlook, we plan to analyze the relationship between fill level dispersion, fill level averages, and the design error rate when performing the compositional design of modeled objects using this method.

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