Voxel-based 3D Processing for 3D Printing

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Abstract

In this paper we discuss about an efficiency of voxel model data in 3D printing system. Particularly, we propose a voxel-based data structure that is called "FAV" (Fabable Voxel) file format, where information about connection between each voxel can be stored, for designing, analyzing and fabricating 3D object seamlessly. This kind of data structure based on networked voxel model has significant advantages: storing network information for fabrication or simulation. We propose some methods for generating tool path from voxel model data directly and show that dynamic simulation with this networked voxel model has more accuracy than non-networked voxel model.

Introduction

An additive manufacturing, especially 3D printing technology is becoming very popular recently. By these technologies, making a thing with a complex surface, a complex internal structure or a complex multi-material distribution, is becoming easier. In order to take advantage of these technologies, an integrated design system which include computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM) is required (Figure 1). Using such integrated design system and coming and going between these function seamlessly, these 3D printing technology can be used more efficiently. There are many research about design system integrating CAD and CAE[10][7][5][9], however, there is few integrated design system including CAM function. Hence more research about such system is required.

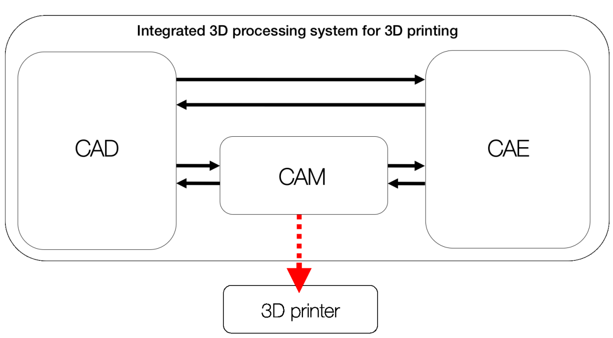
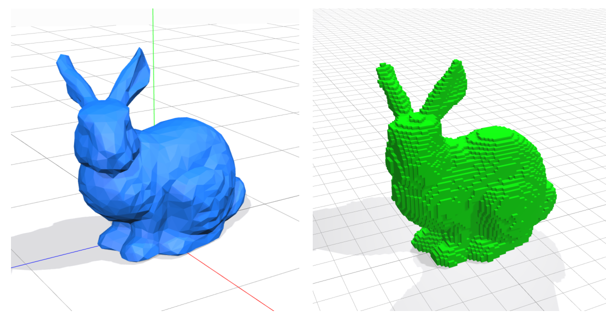


Figure 1: Conceptual diagram of integrated 3D processing system for 3D printing.

A standard file format which can be used seamlessly in such integrated design system is also required. In such additive manufacturing field, stereolithography (STL) file is often used as a standard file format(Figure (a)). However, this data format is not suited to the latest 3D printing technologies, because information about material, color or other information without geometry can not be described in the file. Other file formats based on a surface mesh model: AMF[2] and 3MF[1], where these information can be described, have been presented. However, it is difficult that such data format based on surface mesh model have information about complex internal structure and more information for fabrication, for example, tool path of 3D printer.



(a) (b)

Figure 2: (a) Example of mesh model. (b) Example of voxel model.

There is a voxel model (Figure 2) as other 3D model format, where each voxel is distributed in a reticular pattern. This model often use in computer graphics, CAD and CAE. The relationship between mesh model and voxel model in 3D is similar to the relationship between vector model and pixel model in 2D. However, there are significant differences between them. For example, in 3D case, there must be a internal structure and the physical property become more important than 2D case. Considering it, voxel model is more suited for 3D printing than surface mesh model in some cases.

In this paper we propose a voxel-based data format which is called "*FAV*" (Fabable Voxel) file format for designing, analyzing and fabricating 3D object seamlessly. Voxel file formats previously used: .binvox [8], .vxc [4], has almost no information for fabrication. The voxel model based data structure proposed here is able to have information about connection between voxels. Data of connections can be used as tool path or represent a three dimensional electric circuit diagram on 3D printed object. We also propose some methods for generating network of voxel as the tool path and show that information about the connections can be led to dynamic simulation of 3D printed object with more accuracy.

Networked voxel data format

A data structure we propose here is mainly composed of three elements: *MetaData*, *VoxelData*, *NetworkData*, in abstract terms (Figure)) . In *MetaDataclass*, some references: material ID and mechanical property of material and voxel property: voxel size, grid size and number of edge of each voxel, are described. In *VoxelData* class, information about voxels are described as digit string each vertical layer where each value represents blank or material ID of the voxel. In *NetworkData* class, information about connections between voxels in each vertical layer are described as digit string where each value represents a material property of the connection. Practically, this abstract model is represented as XML-based file (Figure), thus the file format can be used as the expansion of AMF easily.

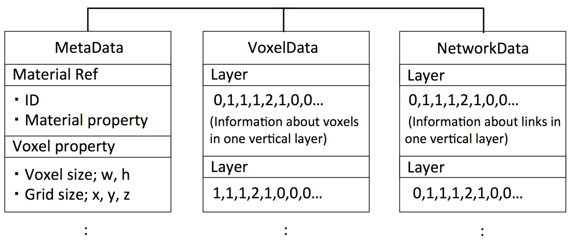
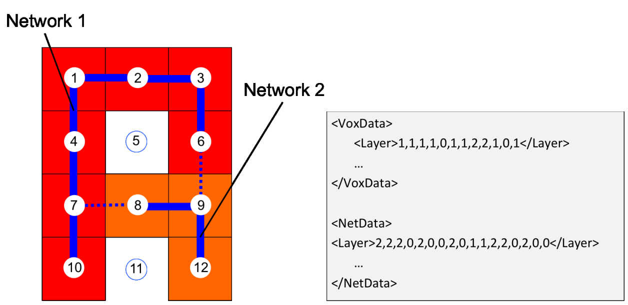


Figure 3: Data structure of .FAV file format.

This data structure based on networked voxel model has some advantages. One of the advantages is that the information about tool path for 3D printing can be stored in the data. In Figure (a), blue lines represent a stronger bond and blue dot line represents a weaker bond and for example, by regarding the strong bonds as the path, the tool path can be generated. Some methods for generating tool path from voxel data directly are proposed in following section.



(a) (b)

Figure 4: (a) Example of networked voxels. (b) Example of some part of the data format of voxel model in left figure.

One problem of this networked voxel file format is size of data. For example, considering a cube shaped voxel model composed of 8 million voxels (200 x 200 x 200) which can be corresponded to 3D printed cube shape object (60 x 60 x 60 mm) by 0.3mm printing pitch, size of data of *VoxelData* is about 8 MB, that of *NetworkData* is about 24MB and total size of data with binary format and without any compression is about 32 MB (Figure 4). Moreover, the more larger the size of the 3D model, the larger rapidly the data size becomes (Figure 4). Therefore we need to consider to apply compression algorithm.

Tool path generation

In case of fabricating a object using 3D printer, generating tool path is required. The tool path is generated using slicer which can slice the mesh data to cross-sectional layers, in many cases. The problem of this approach is that tool path and model data is separated and thus it is difficult to edit the tool path and the mesh data seamlessly. In .FAV file format, both model data and network data as part of tool path can be described and it become easier to edit tool path and model data seamlessly. Therefore, we propose a method for generating tool path from voxel data directly.

Some approach to generate tool path from voxel data can be considered. If giving priority to speed of printing, the most ideal tool path might be Hamiltonian path that visits each voxel exactly once in this case. But Hamiltonian path problem that are problem of determining whether a Hamiltonian path exist in given network is NP complete, thus searching Hamiltonian path is not realistic in large network. However, creating Hamiltonian path is possible in some cases. For example, by dividing each voxel to 4 sub voxel in each vertical layer, Hamiltonian path can be created([3]) (Figure (a)). But if this path is regarded as the tool path, the volume of 3D printed object becomes eight times larger than original voxel model. Thus using this method is limited to peculiar case. We propose mainly two realistic approach to generate tool path from voxel model.

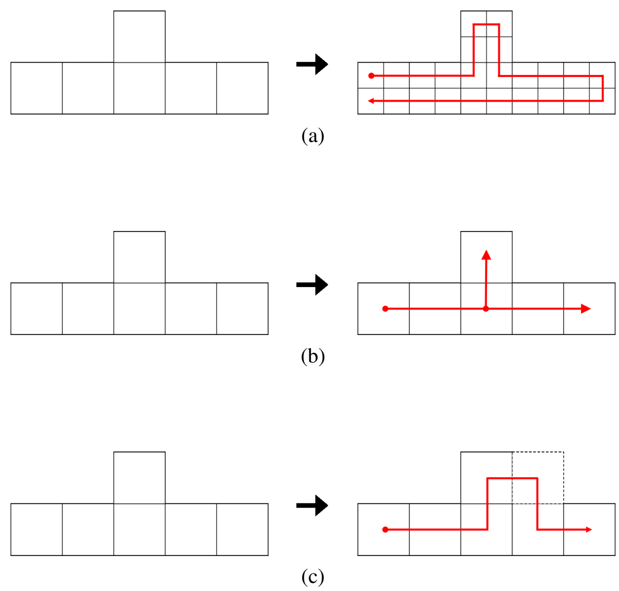


Figure 5: Three methods for generating tool path. (a) Division method. (b) Segmentation method. (c) Addition method.

One of the approaches is segmentation method where a part of model which can not be described by single path is divided to multiple path. As shown in Figure (b), such model which has no Hamiltonian path can be described by multiple path. Advantage of this method is that the tool path can be generated without deforming shape of an original model. On the other hand, disadvantage of this method is that the more increasing the number of path, the slower the speed of printing become, because it need to move extra from end point of current path to start point of next path. There are also other disadvantages, for example, about bad appearance and weaker strength of gap between paths of printed object.

The other one is addition method. As shown in Figure (c), even voxel model which can not be described by single path, by adding a bridge voxel, it would be possible to describe by single path. An advantages of this method are the relatively higher speed of printing and higher strength of printed object. However there is a disadvantage that the shape of an original voxel data is deformed somewhat.

In practical usage of these two method for 3D printing, we need to use these method according to purpose and the property of local part of voxel model. For example, if more precision of size is prior, segmentation method is efficiency and if speed of printing or strength is prior, it is better to use an addition method. We need to develop a practical tool for generating optimal tool path in accordance with purpose, integrating these approaches.

Structural Analysis

By association between CAD and CAE seamlessly, it become easier to design a more complex and functional 3D object. There are many previous research about generating 3D object optimized for a given purpose, based on the results of CAE [10][7][5][9]. Comparing to surface mesh model like STL, voxel model has some advantages on physical simulation from viewpoint of complex internal structure or cost of computation of calculating a optimal mesh. Particularly, we argue networked voxel proposed here is more suited to structural analysis and optimization of 3D printed object.

In case of FDM type 3D printer, even if using a single material, there are at least two strength properties; a weak connection between vertical or horizontal layers and a strong connection in continuously printed region (Figure). In that point, our data format which has connection property is more suited for simulation of 3D printed object. We tested this advantage of the networked voxel data format for structural analysis of 3D printed object.

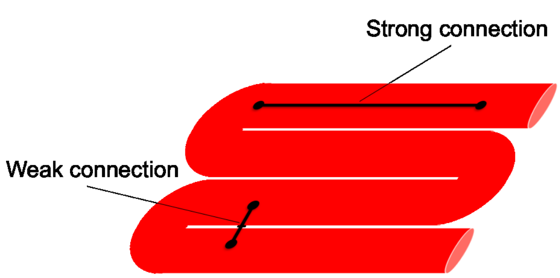
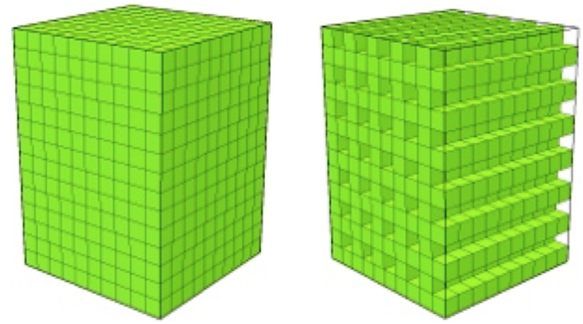


Figure 6: Example of 3D printed layer. Continuously printed region has strong connection and vertical or horizontal layers has weaker connection

For testing this advantage, we implemented a voxel-based simulator modifying VoxCAD that is voxel based dynamic simulator using mass-spiring model [6]. In original VoxCAD, a material property of a link between voxels is determined based on the material property of the voxels, thus if all voxels have same material property, strength of the links are homogeneous. In contrast, in our model, the link property is determined depending on a strength of the link described on the *NetworkData* class, thus even in the same situation, the material properties of links can be heterogeneous and it become more close to that of 3D printed object.

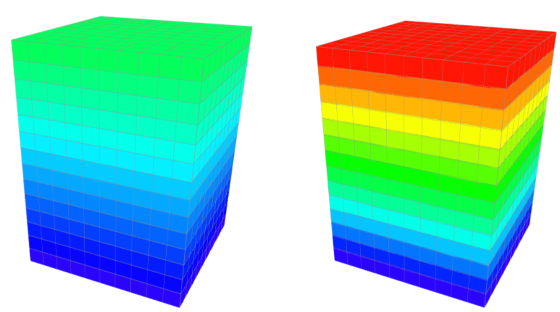


(a) (b)

Figure 7: Internal structure of voxel model. (a) High-density model. This model is composed of 1,400 voxels and its density is 1. (b) Low-density model. This model is composed of 1,050 voxels and its density is 0.75.

We conducted a compression test of a real object and simulation of compression test of two 3D voxel model: a homogeneous link model and a heterogeneous link model. A homogeneous link model means that its material property of all links are same. In contrast, a heterogeneous link model means that its distribution of link property are various and in this case, there are two link property: a strong bond and a weak bond. In that point the heterogeneous one has similar to the 3D printed object than the homogeneous one. Base shape of these three object is a vertically long rectangular shape like Figure (a) and we applied two type of internal structure: high-density model (Figure (a)) and low-density model (Figure (b)), to real object and each linked voxel model. All voxel have same material property which is resemble to real object and the material property of strong bonds are equal to it. On the other hand, that of weak bond has half of them.

In these compression tests, a force of 500N is applied on upper surface to -z direction. The result shows that the displacement of the heterogeneous link model to the load has more accuracy than that of homogeneous one in both cases (Figure , Figure 4).



(a) (b)

Figure 8: Sample of simulation results. (a) Result of homogeneous link model of high-density model. (b) Result of heterogeneous link model of high-density model.

Discussion

In this paper we discussed about an efficiency of voxel model data in 3D printing system. Particularly, we proposed voxel-based

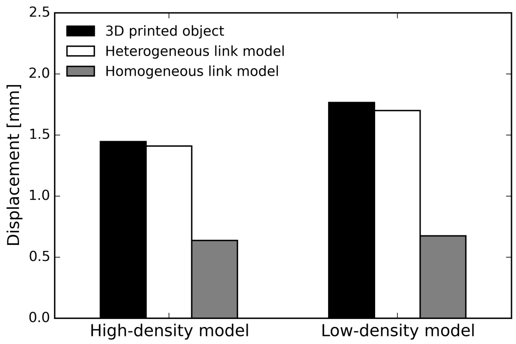


Figure 9: Comparing results of compression expreriment. Left bars represents the displacement of voxel model 1 and right bars are those of voxel model 2. These results show that the results of heterogeneous link model in both cases are more similar to real object than homogeneous link model.

new file format where not only voxel model data but network information can also be described and presented some of its advantages. As described above, voxel data is more suited to 3D printing than surface mesh model in some cases. Although we proposed some element technology of voxel-based 3D processing, we need to develop integrated design tool where we can design 3D object coming and going between CAD, CAE and CAM function seamlessly as next step.

We mainly focused on CAE and CAM function in this paper, however, CAD function is also important. As it is easier to regard a voxel model as virtual model of physical object than surface mesh model, it can be easier to design the structure using physics simulation and also by more human oriented method like a sculpture or a claying. Other remarkable advantage of the voxel model is that it is able to have internal structure. In many case of designing such internal structure, a function of the structure: strength, flexibility or some physical property of a printed object or optimal distribution of required space, is important. In these cases, designing the structure based on the results of CAE is efficient. Therefore, we also study about such designing approach as next step.

Acknowledgments

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