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Intensive 3D Structure Modeling and Seamless Data Flow to 3D Printers Using Voxel-Based Data Format FAV (Fabricatable Voxel)

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Abstract

We released a specification of a new voxel-based data format "FAV" (fabricatable voxel) in July, 2016. 3D model data of FAV format is comprised of a voxel which is a three dimensional picture cell. This representation differs from a mesh-based data format like an AMF, 3MF which are recently proposed or STL which has been used as the 'de facto' standard so far. In addition, we are proposing to more effectively utilize abilities of current 3D printers using a fabricatable voxel which is retaining optimized information to be used for fabrication. Utilizing a FAV format, we can realize modeling a 3D model data not only surface but also internal structure and various attributes such as materials to use, full-color information, connection intensity for each voxel, and so on. Furthermore, it can utilize several processes such as design (CAD) and simulation (CAE) mutually and seamlessly without data conversion from FAV format.

In this paper, we introduce a framework of FAV format and structures that FAV can represent. You can design as you like, in detail, regardless of the inside or outside, intensively and minutely using a FAV format. Moreover, FAV format can concurrently maintain three dimensional complicated information of shape and attributes. Accordingly, it is available to be applied to various image processing like a three dimensional half-toning, and to enhance expressiveness of 3D printers.

Introduction

Additive manufacturing, so-called 3D printing, has been attracting much attention in recent years. 3D printing has many advantages over traditional subtractive manufacturing methods. For example, manufacturing abilities with not only mixing various materials but also complex tangled structures and internal structures are listed as above mentioned advantages. By maximizing the potential of 3D printers, it is expected to explore a new method for creating something only by 3D printers with ease, high accuracy and high productivity.

Discussion about 3D data format is one of the activities for managing a 3D printer effectively. Stereolithography (STL) has been used as the 'de facto' standard data format to output on a 3D printer for a long time. However, an STL file can keep data of a surface figure only, but can't hold any information of colors, materials or internal structures which can be reproduced by recent 3D printers. And it has been recognized as a major problem of STL files. New 3D data formats, AMF and 3MF, have been proposed in order to improve this problem [1][2].

AMF and 3MF can dispense color or material in various specified methods using a predetermined ratio on each mesh or part, gradation pattern astride plural meshes, linear or cyclic pattern in conformity with formula. Besides, these formats can assign complex and bright color information on surface using texture mapping. However, these methods still has concerns because they are assigning only surface. It is limited to an internal structure and attributes are complemented or estimated from surface definition. It is difficult to utilize the formats, for example, for separation by color for internal multi-layered structure, or modeling to vary material distributions on each position.

These formats also have specified methods for modeling internal structure into solid, for instance, using a formula or specifying shape of infill pattern. (Fig.1) However, any method cannot design internal structure freely because it infills all of inside the surface model with the same pattern. It is difficult to represent minutely or complicatedly a three-dimensional structure, such as variations of internal structure on each position, designs even with microstructure.

As mentioned above, several definition methods to represent three dimensional structures to effectively utilize 3D printers, however it cannot completely utilize all abilities of current 3D printers. This results from an AMF, 3MF recently proposed are ever mesh-based data format just like with STL.

In this paper, we propose a new voxel-based data format "FAV" (fabricatable voxels) which can design complex internal structures freely and control attributes of 3D model. The new format "FAV" represents 3D model by buildup of three-dimensional volume cells (voxels) in a similar way to images consisting of arranging 2-dimensional picture cells (pixels). In this manner, representing 3D model by voxels makes modeling or simulating much easier. [3]

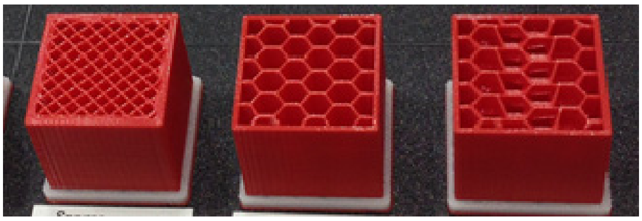


Fig.1 Various internal structures with repeated same patterns. The conventional method infills all of inside the surface model with the same pattern.

Voxel-Based Data Format FAV

We released a specification of a new voxel-based data format "FAV" in July, 2016. It realizes that 3D model is sterically buildup of voxels which have optimized information to be used for fabrication (fabricatable voxels) and external / internal structures and attributes are represented freely and in detail.

Optimized information to be used for fabrication refers to the following things.

- All three-dimensional positions have a definition of necessary information for fabrication such as a shape, materials, colors, connection intensities, and so on regardless of the inside or outside of 3D model.
- Some processes like a design (CAD), simulation (CAE) are carried out seamlessly and interactively without wasting data by data conversion.

FAV format is 3D model data which has these conditions.

FAV format are described in XML. Tree structure of each element and attribute of XML are shown in figure 2. Each node in the tree or each code < > in the explanatory text indicates ‘Element’, and each bracket in the ‘Element’ or bracket ( ) means a given ‘attribute’ to the ‘Element’.

FAV format defines 3D model data by the following steps.

1. Register basic information to <palette>.
2. Define <voxel> using some basic information on <palette>.
3. Carry out modeling of a three-dimensional structure and attributes by buildup of <voxel> on a three-dimensional grid.

We will explain each element in the tree structure below.

<metadata>

It can store some metadata such as <author>, <license>, <title>, etc. These metadata required for data distribution or data utilization are useful to guarantee the reliability, appropriate license management, and so on.

<palette>

It registers basic information like geometries and materials for preprocessing to comprise 3D model data by FAV format.

<geometry (ID, Name)>

On this element it defines a voxel <shape> used by FAV file, and <scale> for grid cell which arranges voxels. It can define an arbitrary shape by referring to an external file. A geometry (ID) is referred by <voxel>.

<material (ID, Name)>

On this element it defines material information used by FAV file. In the case of commercialized products used, uniquely determined information like a product name, product code, or URL of material information can be drawn, as well as material kinds like an ABS, PLA, or ISO standard. A material (ID) is referred by <voxel>.

<voxel (ID, Name)>

On this element it defines a voxel unit used by FAV file. A voxel refers to an (ID) prescribed at <geometry> and <material>. In case of hybrid materials used, plural <material> defines with <ratio>. Moreover, a voxel can hold arbitrary properties. Both three-dimensional structure and attributes can be represented simultaneously by buildup of voxel unit which is defined here.

<object (ID, Name)>

On this element it defines an actual 3D model data in FAV format. The 1st step defines a grid which is the space to buildup of voxels and the 2nd step defines a structure in this grid. (Fig.4) Structures are divided to define <voxel_map> which expresses shapes and attributes, <color_map> which expresses full-color information, and <link_map> which expresses connection intensities. Additionally each map is defined separately by layer.

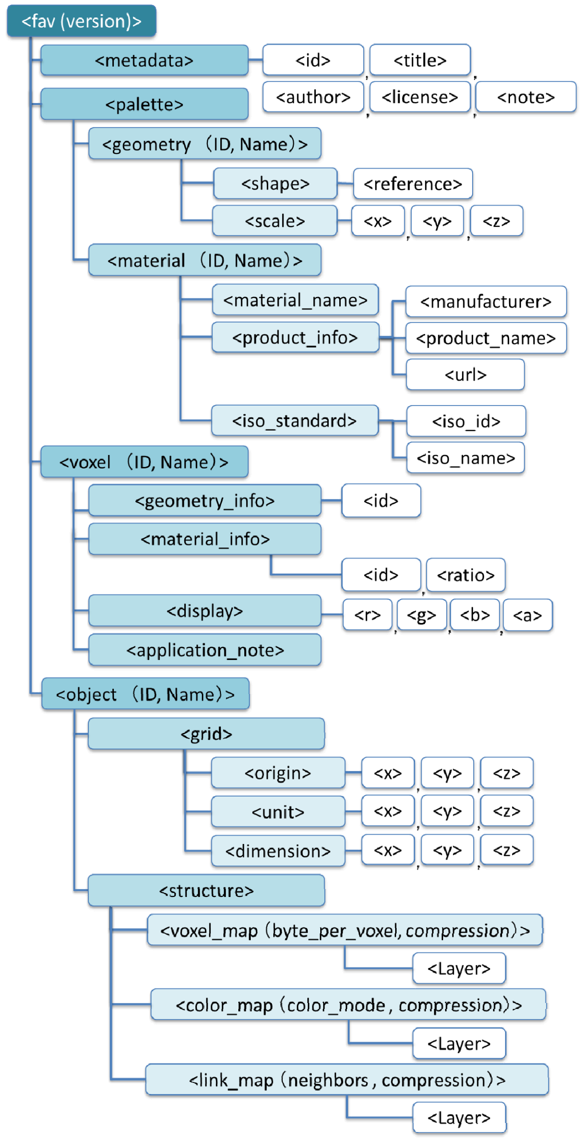
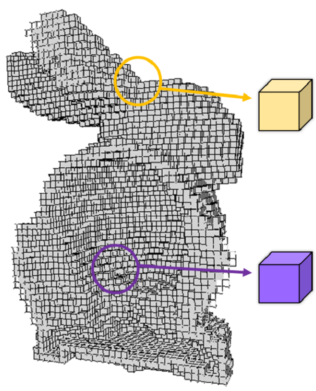


Fig.2 *Tree structure of XML elements managed by FAV data format. <object> refers to <voxel>, and <voxel> refers to <palette>.*



<voxel>

(id)	01
(name)	soft_cube
<geometry>	normal_cube
<material>	soft_material01

<voxel>

(id)	02	
(name)	hybrid_cube	
<geometry>	normal_cube	
<material>	(name)	hard_mat01
	(ratio)	0.8
<material>	(name)	elastic_mat
	(ratio)	0.2

Fig.3 *3D model data in FAV format is represented by buildup of voxels. It can design internal structures, materials, colors concurrently as well as the shape of a 3D model. Hybrid materials are available by defining plural materials with ratio.*

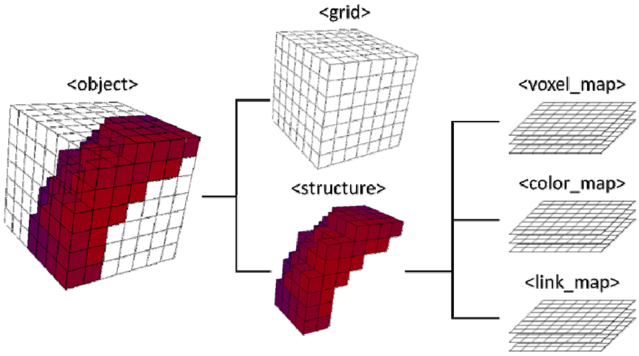


Fig.4 *An object which is defined as a structure in a grid. 3D model data is defined by being divided into <voxel_map>, which shows the shape, <color_map>, which shows color information, and <link_map>.*

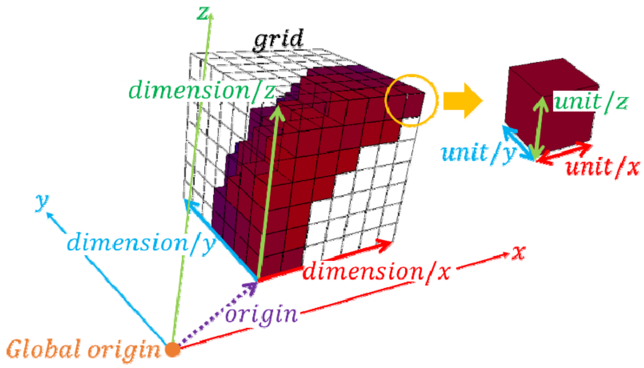
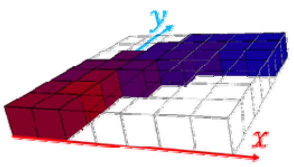


Fig.5 *The meaning of each element in <grid>. <origin> defines a distance from the origin of the global coordinate system of <grid>. <unit> is used for specifying the size of a cell for <grid>. <dimension> defines the entire size of a grid. The size is specified by determining the maximum number of voxels that can be arranged in a grid. This means that the size of an actual grid in the global coordinate system can be calculated by multiplying the cell size defined in <unit> by the number of cells defined in <dimension>.*



y_7	00	00	00	02	02	02	02
y_6	00	00	01	02	02	02	02
y_5	00	01	01	01	00	00	00
y_4	01	01	01	00	00	00	00
y_3	01	01	00	00	00	00	00
y_2	01	01	00	00	00	00	00
y_1	01	01	00	00	00	00	00
	x_1	x_2	x_3	x_4	x_5	x_6	x_7

Fig.6 *Samples of one layer's structure data part of the object which is defined by three kinds of maps.*

<voxel_map (bit_per_voxel=8)>

0101000000000001010000...020200000002020202

Whether a voxel exists at each position of x axis (<dimension.x>) in a grid is to be specified by specifying the values of (id) of <voxel>. These two hexadecimal characters express one voxel.

<color_map (color_mode="RGB")>

830025810027760032910017...1f00891c008c1300960c009c

Color information for each voxel listed in <voxel_map> is to be specified in accordance with the format specified by (color_mode). These six hexadecimal characters express colors of one voxel in RGB format.

<link_map (neighbors=6)>

000000c864ff006400c800ff...0064c80064ff0064c80000ff

Link information is defined by <link_map> in the format specified by (neighbors) for each voxel listed in <voxel_map>. These 12 hexadecimal characters express one voxel link information of 6 neighbors.

<grid>

On this element it defines a grid which is the space to buildup of voxels. Meaning of each element that defined on <grid> are described on Fig.5.

<structure (Compression)>

On this element it defines structures of 3D model data to be mapped on each layer in a defined grid space. Fig.6 is sample data of one layer part of 3D model data represented by two kinds of voxels.

- ***<voxel_map (bit_per_voxel)>***

  On this element it defines structures of object themselves by mapping voxels which store some attributes. When indicating that data exists, the (id) of <voxel> is to be specified, in a similar way when indicating that data doesn't exist, 0 is to be specified. A voxel map data of one layer is comprised of connected voxel lines for number of dimension.y which arranged for number of dimension.x.

- ***<color_map (color_mode)>***

  On this element it defines full-color information that object should be held not only for display but also for materialization by 3D printing. Specifying (color_mode) from object uses color mode about Grayscale, RGB, CYMK, for instance.

  When specifying the 0 that represents voxel doesn't exist on voxel map, it is omitted to specify color information on color map. A color map data of one layer is comprised of connected color value lines for number of dimension.y which is arranged for number of dimension.x.

- ***<link_map (neighbors)>***

  On this element it defines link information of each voxel which comprises this object. Link information is a value of expression about strength of relationship like a connection intensity of each voxel. It is possible to make more highly accurate structural analysis, or generate an optimized tool path for 3D printing. Any neighbors of 6, 18 or 26 by a (neighbors) attribute are specified based on how many neighbors one voxel can hold link information.

  When the 0 that represents voxel doesn't exist on voxel map is specified, it is omitted to specify link information on link map. A link map data of one layer is comprised of connected link value lines for number of dimension.y which is arranged for number of dimension.x.

These mapped data may select a compression method by a (compression) attribute when saved in FAV files. For example, there are uncompressing: none, and compressing method: Base64, ZLIB.

Up to this point we explained briefly a data structure of FAV. The detailed FAV format specifications are released now.

Effects of FAV

We describe effects to be obtained from representing 3D model data using FAV format that we proposed.

First, Fig.10 (a) is a 3D model represented by the conventional mesh-based method. This data stores only surface information, and definition of attributes is limited to surface only.

Fig.10 (b) is a 3D model converted to FAV from (a). In this case the model is converted so that the inside becomes solid, also it can convert to become only surface, or enable infilling with repeated same patterns.

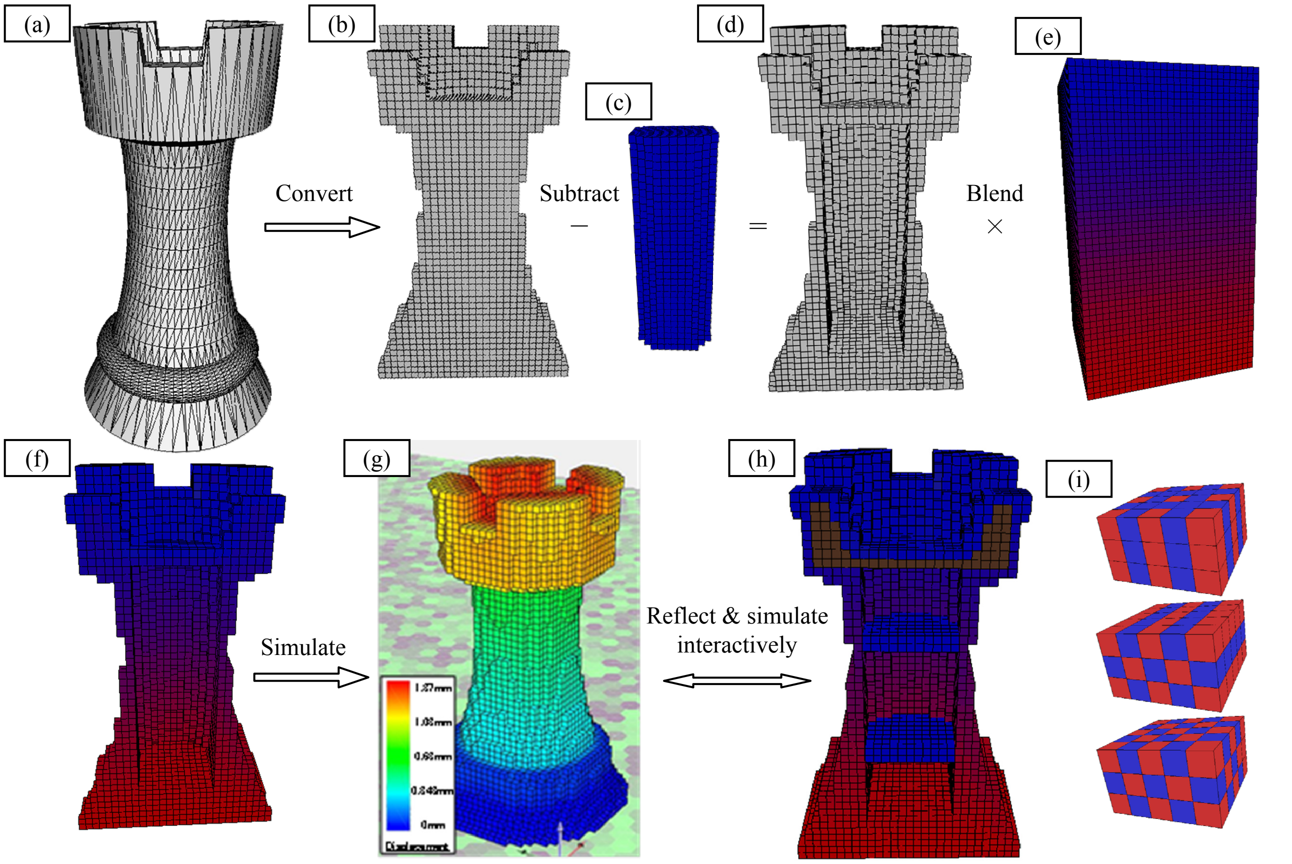


***Fig.7** Intensive 3D structure modeling and seamless data flow to 3D printers using FAV format. **(a)** An existing mesh-based data. **(b)** A cross section of a solid 3D model data which is converted to FAV. **(c)** An arbitrary 3D model by FAV equivalent of (b). **(d)** The result of design by subtracting (c) from (b). **(e)** Definition of distribution for hybrid material. **(f)** The result of design by blending material distribution (e) to three-dimensional configuration (d) after designed separately. **(g)** An image of physical simulation using (f). **(h)** A seamless and interactive process that provides both physical resimulation using a modified model and redesign to reflect the result of the simulation. **(i)** Samples of microstructures represented by composing plural kinds of voxels or composing the state of existence.*

Fig.10 (c) is an arbitrary 3D model defined by FAV format. We get a free design of internal structure like Fig.10 (d) using Boolean operation among these plural model (b) and (c) for instance.

Fig.10 (e) is a combination ratio design of hybrid material defined by FAV format. We can get a model like Fig.10 (f) by blending material distribution to three-dimensional configuration after designed separately.

It enables modeling separately so as to be easy to understand and merge plural structures of attributes like Fig.10 (b) to (f) such as external / internal shapes, colors, materials, and so on. Of course all of attributes can be modelled together.

Fig.10 (g) is a result of physical simulation using (f). Model data which designed intensively an internal structure, material distribution, connection intensity of each voxel, can make a structural analysis that has high precision.

Fig.10 (h) is a 3D model which is a modified design to reflect the result of simulation using (g). FAV makes users possible to carry out several modelings freely and intensively such as changing a material with high amounts of distortion to harder one, making structure changes for reinforcement, removing internal cavities to release a pressure, and so on. Furthermore, the users get a seamless and interactive process that provides both physical resimulation using a modified model and redesign to reflect the result of the simulation.

Fig.10 (i) is samples of microstructures represented by composing plural kinds of voxels or composing the state of existence. These microstructures are defined for other model structures to enable to design complicated things that have never been fabricated until now, simulate performances, and fabricate actual things.

FAV format which provides both three-dimensional shape and full-color information are available to apply various three-dimensional equivalent image processing like a half-toning [5][6].

As mentioned above, you can design as you like, in detail, regardless of the inside or outside, intensively and minutely using a FAV format that we proposed. Moreover, FAV format can concurrently maintain three dimensional complicated information of shape and attributes. Because of this, users can utilize several processes such as design (CAD) and simulation (CAE) mutually and seamlessly without data conversion from FAV format.

Conclusion

The detailed FAV format specifications are released in July, 2016. Besides, Fab3D[7](Fig.8) which is a cross search engine has approximately sixty thousand 3D data whose secondary use is allowed by license among 3D data of the world makes us enable to use by FAV format.

We also intend to provide some software which can design 3D model by accumulating voxels, transfer existing mesh-based data to FAV, design and edit FAV, make a physical simulation using a FAV or create slicing data for 3D Printers.

In the future, we will examine a solution to a well-known issue about voxel data size that is becoming large. For example, a compression technology for image which is comprised of two-dimensional pixel to apply to 3D model which is comprised of three-dimensional voxels. Besides, we will study new modeling methods to design or edit complicated 3D structure and many attributes effectively. And we will work on enhancing software to utilize FAV and expanding FAV specification.

Acknowledgement

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Author Biography

Tomonari Takahashi obtained his masters in software and information science at Iwate prefectural University in 2008. His research field is human computer interaction using images or movies. He joined Fuji Xerox in 2008 and started development of application software for electronic devices. He focuses on research of 3D data handling.

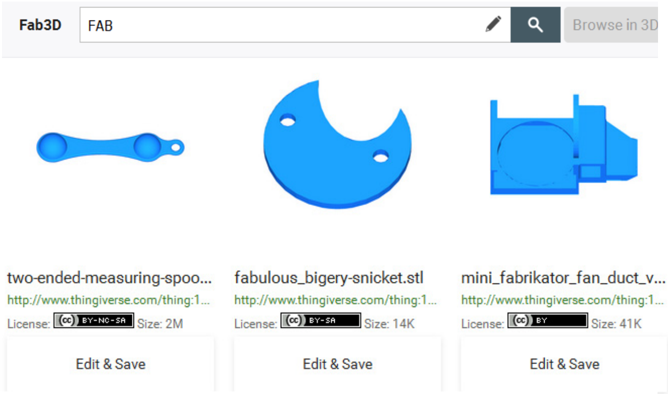

Fig.8 *Fab3D which is a cross search engine. It has approximately sixty thousand 3D data whose secondary use is allowed by license among 3D data of the world makes us enable to use by FAV format.*