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AR based ornament design system for 3D printing

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Abstract

In recent years, 3D printers have become popular as a means of outputting geometries designed on CAD or 3D graphics systems. However, the complex user interfaces of standard 3D software can make it difficult for ordinary consumers to design their own objects. Furthermore, models designed on 3D graphics software often have geometrical problems that make them impossible to output on a 3D printer. We propose a novel AR (augmented reality) 3D modeling system with an air-spray like interface. We also propose a new data structure (octet voxel) for representing designed models in such a way that the model is guaranteed to be a complete solid. The target shape is based on a regular polyhedron, and the octet voxel representation is suitable for designing geometrical objects having the same symmetries as the base regular polyhedron. Finally, we conducted a user test and confirmed that users can intuitively design their own ornaments in a short time with a simple user interface.

Keywords: 3DCG; Modeling; Augmented reality; 3D printing; Voxel; Octet truss

1. Introduction

In recent years, 3D printers have attracted attention as a means of outputting computer-designed 3D shape data to the real world. The price of 3D printers is in a downward trend, and some are now even within the means of ordinary consumers. When 3D printers have become commonplace household items, what will be the sort of item they used to produce most often? Household ornaments is one possibility. People find geometric three-dimensional shapes like those shown in Fig. 1 both interesting and appealing when used in items such as key holders, straps or Christmas tree decorations, or simply as ornaments in their own right. In this study, we propose a system that supports ordinary users in the design of ornaments that include symmetrical structures.

Conventional 3D graphics software is difficult for non-specialists to use as a means of creating three-dimensional shapes. Furthermore, the high cost of 3D printer materials and the long time needed to print objects mean that the feature of previewing designed object with quick trial-and-error process is important.

Barriers to using 3D software for shape modeling include the difficulty of grasping a 3D space via a planar display, and the fact that the typical mouse and keyboard user interface is not intuitive. There have already been widespread efforts aimed at making a user interface more amenable to novice users. For example, the use of AR (augmented reality) has often been proposed. AR is a technique involving the display of computer-generated images superimposed on a real-world space captured by a video camera. By synchronizing the real and virtual coordinate systems based on the use of markers called AR markers, it is possible to make computer-generated objects and characters appear just as if they were present in the real world. By using a shape modeling interface in conjunction with stereoscopic equipment such as head-mounted displays and pointing devices, it is possible to get the same visual effect as when the object really is present. Furthermore, by allowing the user to perform shape modeling actions directly by hand or with hand-held tools instead of with a mouse and keyboard, it is possible to give the user the feeling of actually creating something.

With conventional 3D graphics software, not only is it difficult to manipulate objects, but there is also a problem in

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Fig. 1. Examples of ornaments with geometric patterns and symmetric features (designed with the proposedsystem).

that the 3D shapes made in this way are often inappropriate for output to a 3D printer. For example, it is not possible to print objects that have holes or self-intersections in the surface. Such defects often have to be corrected manually. To address this problem, two possible approaches can be considered. One is to provide a means to correct the problems in data after it has been created, and the other is to provide users with a system that is only capable of producing shapes that are printable on a 3D printer. For the former approach, the automatic restoration method proposed by Bischoff et al. [1] could be applied. A number of research studies on mesh reconstruction are found in the survey papers [2,3]. However, the latter approach, i.e., provide a system that is incapable of designing shapes that cannot be printed, seems to be more appropriate for users lacking in specialist knowledge of 3D modeling.

Therefore in this study we propose a 3D modeling system with the following characteristics:

- Allows ornamental shapes having symmetrical shape characteristics to be designed via an intuitive AR-based modeling interface.
- Can only produce shapes that are printable on a 3D printer.

An advantage of this system is that there is no need to correct the data so that it can be output by a 3D printer. Further, it is possible to preview a designed 3D object superimposed on the real world in AR before it is actually output by a 3D printer.

Our AR-based 3D modeling system uses an air-spray interface. Although AR is critically flawed by the lack of force feedback, an air-spray has essentially no force feedback and therefore allows us to hide this drawback of AR.

To ensure that it can only design solid models capable of being produced by a 3D printer, the proposed system uses an octet truss structure made of octahedrons and tetrahedrons to represent the internal structure that holds the shape data. We propose a shape representation method called *octet voxels*, whereby each of these octahedrons and tetrahedrons stores a value used to distinguish between the inside and outside of the three-dimensional shape.

Related studies are discussed in Section 2 of this paper, and in Section 3 we describe the properties of octet voxels and the proposed system. The results of user tests are discussed in Section 4. Finally, our conclusions are presented in Section 5.

2. Related work

The 3DM interface developed by Butterworth et al. is strongly related to our study as an attempt at improving the 3D modeling interface [4]. This system uses a head-mounted display to perform 3D modeling in a virtual reality space. This system does away with the mouse and keyboard interface that is hard for beginners to use, and instead uses a hand-held pointer device to manipulate the menus and cursor shown in a VR space.

Surface Drawing is an early study of the combination of AR and 3D computer graphics [5]. In this system, the movements of a glove worn by the user are tracked by special sensors to generate band-shaped polygonal surfaces along its locus in a virtual reality workspace, thereby allowing the user to form three-dimensional shapes intuitively. Using various tools with built-in sensors, the user can perform operations such as deforming or deleting objects. Although this system uses expensive large-scale hardware to implement AR, Cheok et al. have proposed a modeling system with approximation functions that uses a cheaper marker system [6]. Studies where AR markers are used to make simple 3D models include a study by Sano et al., who developed a system that creates a full scale box model by generating textures from photographic information [7], and a study by Schlaug where shapes can easily be formed by modeling in the same way as with clay [8].

For the input device of our system, we referred to a study by Jung et al. [9], where an air-spray interface is used to perform rough 3D computer modeling in an AR space. This involves a 3D design process whereby a skeleton shape is first created by a pointer device, and then the air spray is used to blow particles onto this shape. Although this process is limited to shapes without pronounced roughness, it can form a variety of shapes. An air compressor is connected to the air-spray held by the user, and releases puffs of air when the user performs spray operations. The sound of these puffs and the feel of the spray actuator provide the user with sensory feedback. Our proposed system uses a similar air spray interface, but without the air compressor, and uses a simple AR marker as a mouse.

To ensure that the designed shapes can be output by a 3D printer, the shapes have to be a solid. Owada et al. proposed a voxel based approach with sketch interface [10]. On the other hand, Rivers et al. proposed a CSG based tool [11]. One heavily related to our system is the Hirose et al.'s system [12]. This is a design support system tailored specifically for geometrical toys called Sphericon. In this system, the space is partitioned into small cells based on a conical shape, and three-dimensional shapes are represented as sets of these cells. In recent years, several papers related to digital fabrication with 3D printers were published. Prévost et al. proposed a method to modify shape of objects so that they stand [13].

Symmetry is essential for attractive design, and was sometimes used as a constraint of design system [14,15]. To efficiently design the shape of ornaments with symmetry, we