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Complex Moiré Patterns Generated by Helical 3D Printing with Three Waves

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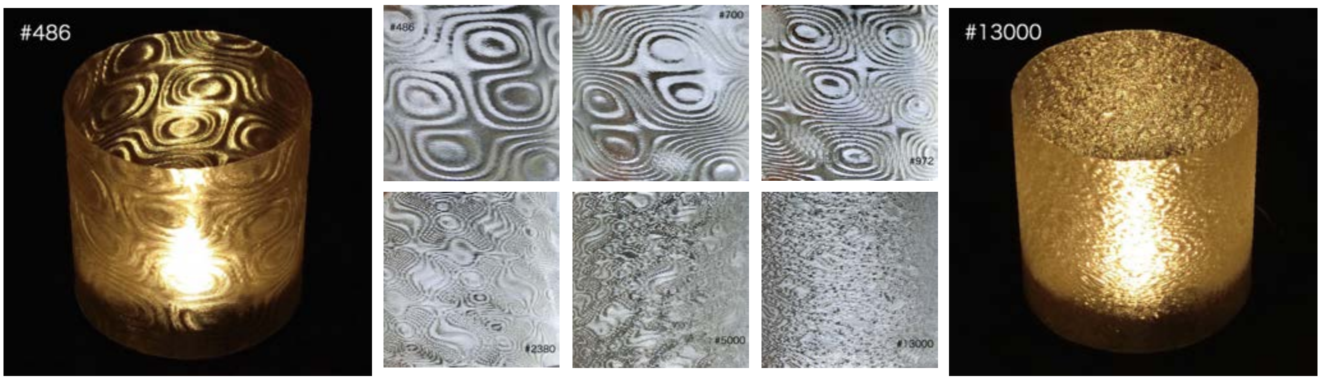


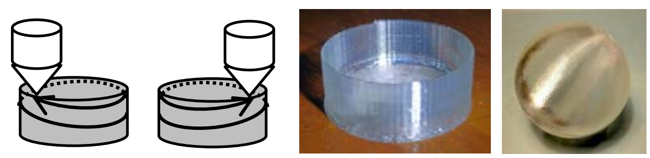
1. Introduction

Conventionally, 3D objects are designed as *undirected* models by using CAD software and are sliced and printed layer by layer by 3D printers. The directions of filaments in 3D productions are regarded just as *noises* and are not utilized for expressions, and seams between layers are not easily avoided. Some of the problems caused by slicing can be solved by using the direction-specified 3D-printing method [Kanada 2014]. A type of direction-specified 3D-printing method called "helical 3D-printing" and a generative design method without using conventional CAD tools and slicers were proposed [Kanada 2016]. This method can be used for designing and printing thin, light, transparent, and brilliant 3D productions. Seam-less exact shaping and support-less overhang are enabled by printing helically (instead of layering). 3D shapes are created by assembling simple-shaped parts and by *deformation* that generates various shapes.

This poster proposes a method for generating fine asperity by helical 3D printing using three types of waves, especially for generating complex Moiré patterns. The printing process can be modulated by three types of sine waves while printing, as described in Section 2. A generative design tool for this method and the application programming interfaces (APIs) used by this tool are described in Section 3. A combination of three waves, i.e., a fine deformation wave and two crossing in-plane waves, which are called *vibrato* waves, generates complex Moiré patterns as described in Section 4. The resulting 3D object with transparent filaments can refract and reflect light in a complex manner.

2. Helical 3D Printing and Three Types of Waves

Figure 1(a) illustrates the helical 3D printing method. A horizontally closed surface model such as an empty cylinder or both horizontally and vertically closed surface such as a sphere can be generated (see Figure 1(b)) by using a 3D printer of fused-filament fabrication type (FFF type or FDM type).



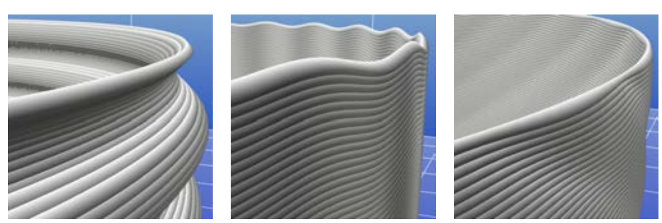
(a) Process (b) Results

Figure 1. *Helical 3D printing*

Arbitrary number of the following three types of waves can be superposed to surfaces to be generated by the helical 3D printing.

- **Deformation**: A surface is rippled by deformation. The direction of deformation is vertical to the original surface.
- **Vibrato**: Filaments are rippled toward in-plane direction by a vibrato. Vibratos mostly do not change the 3D shape.
- **Modulation**: The cross sections of filaments are rippled by modulation. Modulations mostly do not change the 3D shape either.

Directions of these types of waves can be any in-plane directions. Three wave examples are shown in **Figure 2**.



(a) Deformation (vertical wave) (b) Vibrato (horizontal wave) (c) Modulation (skewed wave)

Figure 2. *Examples of three types of waves*

3. Generative Design Tool and APIs

A web-based design interface was developed for the waved helical 3D printing (**Figure 3**). Simple base shapes, such as cylinders or spheres, can be created and the three types of waves can be superposed on the base shapes by using this generative design tool. Each wave is specified by a combination of a wave type (sine or rectangular), an amplitude, horizontal number of waves, vertical number of waves (wave pitch), and an amount of phase shift. The designer (user) can generate G-code data by pushing a button on the web page, and visualize the data and send them to a 3D printer by using a software tool such as Repetier Host (**Figure 4**).

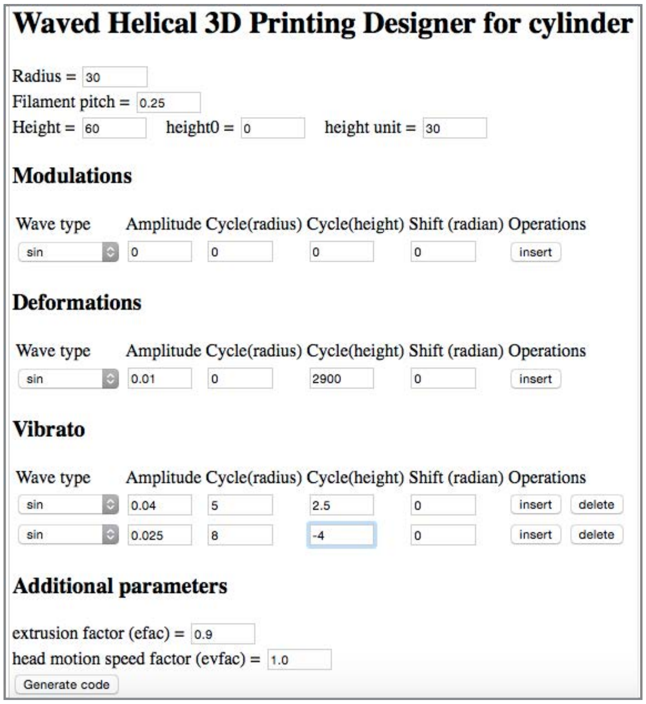


Figure 3. *Web-based generative design interface for waved helical 3D printing*

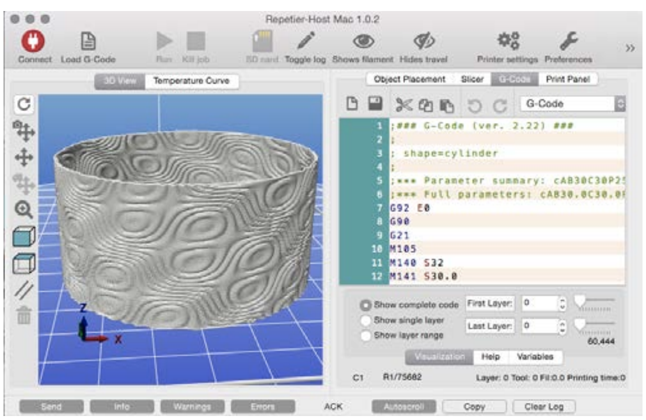


Figure 4. *Example of visualization and printing tool (Repetier Host)*

The design interface was implemented using common gateway interface (CGI). It is programmed in Python and a set of APIs for helical 3D printing, which is called draw3dp [Kanada 2015] (available at https://bit.ly/2wb6DGQ), is used. By using these APIs, a 3D model can be constructed by assembling predefined parts and by deforming them (**Figure 5**). A directed 3D model is represented by sequences of strings (straight lines). Each string Si is represented by $Si = (Pi_{start}, Pi_{end}, ci, vi)$ where Pi_{start} and Pi_{end} means the start point and the end point of the string, ci means the cross section of the string, and vi means the printing speed. vi is conceptually unnecessary, but it is useful in implementing (printing) the string.

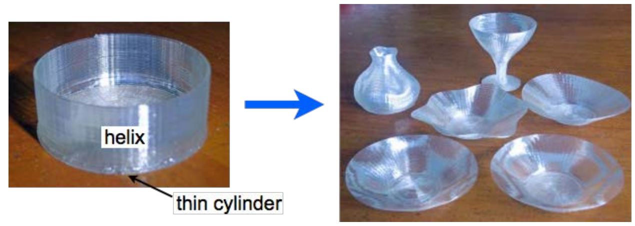


Figure 5. *Example of parts assembly and deformation*

Currently, only simple shapes, such as cylinders or spheres, can be specified as base shapes by the design tool. However, other types of shapes can be specified and deformed by using the APIs directly and multiple shapes can be combined (assembled) to create more complicated shapes.

4. Generation of Complex Moiré Patterns

By using certain additional means, fine filament structures, i.e., fine asperity with varying light reflection and refraction, can be created by the helical 3D printing method. Highly transparent polylactic acid (PLA), which is used in all the photos in this paper, is a suitable filament material for this printing method. Texture mapping can be used for generating fine structures; that is, a pattern, such as a map, can be mapped to the surface by a program using the APIs. However, a method more suited for investigating possibility of this printing method is to generate complex patterns by using the generative design tool. A type of complex Moiré patterns can be generated by superposing three waves.

Typical moiré patterns, such as shown in **Figure 6** can be generated by superposing a fine vertical deformation wave to a helix (empty cylinder). The vertical wave generates horizontal parallel lines and the filament makes mostly horizontal but slightly skewed parallel lines. These two types of lines generate fringes. In figure 5, which is a photo of a 3D-printed object, the fringes are parallel lines that go from upper left to lower right. However, it is not easy to generate complex moiré patterns by superposing waves.

Figure 6. *Simple moiré pattern by helical 3D printing*

Complex moiré patterns can be generated by adding vibratos. A single vibrato does not generate interesting patterns. However, by superposing two crossing vibrato waves, complex patterns such as shown below the poster title can be created. Figure 3 shows an example set of parameters, which generates a complex pattern. Simpler patterns are generated by a relatively coarser deformation wave, and more complex patterns are generated by a relatively finer one.

References

Kanada, Y., "Method of Designing, Partitioning, and Printing 3D Objects with Specified Printing Direction", *2014 International Symposium on Flexible Automation* (*ISFA*), July 2014.

Kanada, Y., "3D Printing of Generative Art using the Assembly and Deformation of Direction-specified Parts", *Rapid Prototyping Journal*, Vol. 22, No. 4, pp. 636–644, 2016.