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Detailed Terms
Surface Skeleton Generation Based on 360-degree Profile Scan

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Abstract

A rapid prototyping method is invented, which works on a specific data structure produced by an optical metrology technique: 360-degree surface profile scanning. A computer algorithm takes an object profile data, restructure the format, generate horizontal and vertical ribs, lay out the ribs on a 2D canvas and output the geometries to a file format compatible with laser cutters. A laser cutting machine is subsequently used to cut all the ribs from sheet materials. Then, the ribs are manually assembled based on computer-generated assembly codes. Through this process, the original object’s 3D surface can be prototyped rapidly at an arbitrary scale, which may well exceed the working dimension of the laser cutter.

1. Introduction

Rapid prototyping technologies, such as 3D printing and laser cutting, have been rapidly developed for years. New applications and cross-disciplinary research ideas emerge along with the maturity of the technology [1]. In this trend, the interaction between engineering and architecture plays a distinctively important role. Such interactions are especially nurtured and cherished at Singapore University of Technology and Design (SUTD), a recently established government institution in collaboration with Massachusetts Institute of Technology (MIT).

The conventional notion of rapid prototyping is a non-scalable method of physical design production. Designers are limited to model manufacturing as small, desktop artifacts reduced in sized by factors. A typical maximum model size when using common rapid prototyping machines is less than 25 centimeters square. This is due to the physical limitation of the machine’s building method. Software generates data assuming that production is of a single model limited to the build volume of the machine. Research exploration in the field has yet to produce a reliable, cost effective method of prototyping or mass manufacturing of very large objects.

In this paper, we introduce a project funded by the International Design Center (IDC) of SUTD. Our objective is to explore a “very large scale prototyping” technique to extend the physical limit of a laser cutter. This technique takes the optically measured surface profile of an object as the input and automatically generates a very large scale surface skeleton structure as the output. The structure is composed of many “ribs” that can be manufactured by a commercial laser cutter. Each rib has a number of slots to enable assembly with adjacent ribs by simple interlocking mechanism. At the end of the processing pipeline, a reverse engineered prototype of the original object can be produced efficiently.

2. Reconstruction of surface profile

An optical metrology method is applied to obtain an object 360-degree surface profile. The experimental setup is shown in Figure 1. The projector projects a black-and-white light field with a sharp edge. The light
edge falls on the object and deforms due to the surface profile variation, as shown in several recorded images in Figure 2.

![Figure 1. Experimental setup of the optical scanning technique.](image1)

![Figure 2. Recorded images of a duck model.](image2)

From each image, a profile line can be extracted. By combining all the profile lines, the 3D surface of the model is reconstructed, as shown in Figure 3.

![Figure 3. Reconstructed surface of the duck model.](image3)

### 3. Rib structure generation

The scanning method, by default, is applicable to objects with a single radial axis. We explore this special condition and develop an algorithm that generates surface skeleton (ribs) around the radial axis, as shown in Figure 4. Ribs of two orthogonal directions are generated, serving two primary functions. The vertical ribs, in the same direction as the axis, provide the standing structure of the scaled prototype; the horizontal ribs,
orthogonal to the axis, provide the linkage to fix the relative position of the vertical ribs. In a broader view, the supporting and linking functionalities are shared by ribs of both directions. The fore-mentioned interlocking mechanism relies on the so-called cross-plane slots – those between horizontal and vertical ribs. In order to prototype an object at a large scale, the algorithm also creates in-plane slots – those joining one horizontal or one vertical rib alone. Ribs exceeding the physical limit of a laser cutter cannot be cut as a whole; hence, the in-plane slots break a rib into several sections to enable production.

Figure 4. Generated rib structure.

Each rib, by itself, is a 2D structure; so they can be laid out on a sheet, as shown in Figure 5. The geometrical data are output to a common file format, such as EPS and DXF, which can be recognized by a laser cutter. The cutting process is done automatically without any human intervention.

Figure 5. Several ribs laid out a sheet.

4. Manufacturing and assembly
After laser cutting, depending on the size of the prototype, hundreds of ribs may be produced, as shown in the Figure 6. They have to be manually assembled based on computer generated assembly code. For the duck model, it took two days to cut and two days to assemble. In conclusion, we have developed a rib generation
algorithm applicable to a specific surface geometry format, this approach can be extended to a number of surface structures.

Figure 6. Ribs produced by a laser cutter. The prototype has to be manually assembled.

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