A Programming Cutting System to Enhance Productivity with Individualities

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Abstract. As an alternative to traditional laser cutting, we present LaserLeast, a fabrication-oriented design system that produce 3D objects using a laser cutter to bridge the gaps in prototyping from software to hardware and further evoke energy- and resource-saving consciousness in rapid manufacturing context. The key idea behind our system is that it employs a line-based strategy to improve the original workflow at the 2D output arrangement stage by using two shapes sharing one cutting line, and create a line-based workflow without a 3D modeling stage using three customizable components (line shape, 2.5D technique, and assemble plug). We compare LaserLeast with the traditional strategy with two use cases to address the advantages and limitations and show that LaserLeast has the potential to stimulate the creativity of product designers and the human computer interaction community to enhance productivity in both design and laser cutting through the Internet.

Keywords: Laser cutting · Programming · 3D prototype · Individual design

1 Introduction

"The soul never thinks without an image." As Aristotle noted, image-oriented thinking has been used in science, philosophy, folk art, craft, visual communication, digital art, and other creative fields. Line is the most important element used to divide a plane into two mutually spaces, referred to as figure/ground principle in design discipline. Maggie Macnab [1] argued that the most effective use of this principle is when the figure and ground are represented as equal elements of meaning when both negative and positive space can be used toward a productive end. Inspired by figure/ground art works (e.g. Escher' tessellation work [2]), we explored how to apply the design principle to digital design and manufacturing of entity objects, and achieve its new value in fostering media literacy through good design which may be beneficial to the field of human computer interaction (HCI) research.

Cutting as a digital fabrication technique facilitates the generation of prototype in a range of HCI projects (e.g. chairs (SketchChair [3]), dresses (Dress-up [4]), custom capacitive touch sensors [5], and computational textiles [6]). From a fabrication

N. Streitz and P. Markopoulos (Eds.): DAPI 2017, LNCS 10291, pp. 561–571, 2017.
DOI: 10.1007/978-3-319-58697-7_42

standpoint, digital cutting tools, such as milling machines and laser cutters, achieve much higher speeds by assembling the object from 2D plates rather than by additive fabrication methods such as 3D printing. However, this requires other manual labor in designing and cutting the joints for the assembly of 3D objects, and the actual fabrication costs decrease utilization and increase waste of material compared to additive fabrication. LaserOrigami [7] was designed to produce 3D objects using a laser cutter by folding and stretching the workpiece, rather than by placing joints, thereby eliminating the need for manual assembly. Similarly, LaserStacker [8] was proposed to use the laser cutter not only cut but also to weld to enable the building of non-planar objects by eliminating the assembly step. Because the assembly aspects have been well reviewed in the literature, here we focus on the potential and challenges of cutting prototypes from the standpoint of green design.

Here, we propose LaserLeast, a cutting fabrication-oriented design method built on the figure/ground design principle, aimed to evoke energy- and resource- saving consciousness in a rapid prototype context. The key idea behind our system is that it employs a line-based strategy to improve the original workflow at the 2D output arrangement stage. It does this by gathering two shapes sharing one cutting line and creates a line-based workflow without a 3D modeling stage using three customizable components to create at least two functional results. We conclude that the improvements of LaserLeast method to the development of a rapid prototype are as follows:

- Lowest waste and the meticulous arrangement of cut lines to minimize loss;
- Double productivity, cutting a single line to produce two useful pieces;
- Multiple results, cutting one piece for different purposes, as components for assembling one object or for assembly of several independent objects.

Based on the work, our main contributions include:

- Introducing a customizable high-design fabrication method named LaserLeast aimed to make 3D objects by laser cutting for the HCI community without gaps in prototyping from software to hardware.
- Integrating programming techniques, social Internet of things with a digital design system to cutting 3D shapes compared with previous methods, which has potential to create a global community for product innovation and exchange.
- Eliminating much of the waste produced during production by rearranging cutting patterns.
- Testing the usability of LaserLeast method through different cases and providing application examples to further explore the feasibility and expansibility of our method.

2 Theoretical Background

In design, gestalt, derived from a German word meaning “shape, form, figure, configuration, or appearance”, refers to the physical parts and their arrangements that compose meaning through their relationship with other parts. More of an existential reality than a principle, the figure/ground relationship is the most elemental of gestalt principles [1].

A typical example in the last century is M. C. Escher's tessellation work [2] that shows multiple rotating images that fit seamlessly over a plane. In form creation by craft, Greg Payce [9] is recognized internationally for his unique ceramic works combining vase forms with precisely articulated profiles. When properly aligned, illusionary images, most often of human figures, appear in the negative spaces between the vases. In a starkly different approach to Western culture, Eastern philosophy approaches life as a both/and paradox, embodied by the rotational yin yang symbol. Opposites are seen as intrinsic parts of the whole or as essential and equal experiences. Above all, the basic tenet can be understood as a whole of interacting parts that harmonize, influence, and expand upon one other, meaning that "the whole is greater than the sum of its parts".

Based on this theoretical basis, we address the issue of sustainability from design to cutting fabrication. As Peek and Coleman [10] suggested, hardware and software are disjoint in their representations, their production methods, and their validation. There historically has been a gap between the capabilities of design in software and fabrication by hardware, because machine tools are not yet well-integrated systems, a requirement for automation or fabrication. An increasing number of researchers are looking into speeding up design-prototype iteration to allow creation of novel input and output methods (e.g. tabletop-based tangible editor [11] or low-fidelity fabrication [12–15]). To extend the use of digital cut machines in the field of HCI, we introduce a customizable high-design cutting platform applicable to a variety of low-cost materials in plane state able to build 3D objects.

3 System Description

LaserLeast system contains a fabrication-aware software platform aimed to bridge the gaps from software to hardware that exist in current strategies for the generation of prototypes using a laser cutter. The software platform is built on top of an open source algorithmic modeling platform, Grasshopper [16], which enables both graphic programming and a visual user interface. Currently, we have the basic toolsets to handle 2D structures and 3D simulation; more customized variations can be easily developed on top of the current platform.

3.1 Workflow

LaserLeast is designed with two goals in workflow (see Fig. 1): (1) improve original workflow at the 2D output arrangement stage; (2) create a programming 2D line workflow to replace the original 3D design and output arrangement stage.

Improving original workflow

Since different shapes require cutting space on a plane which can cause chaotic and failure surface position, we suggest a generation process to gather two shapes that share a single cutting line to achieve optimization of space and cut efficiency.

Creating line-based workflow

Based on the figure/ground principle, LaserLeast provides a designed line shape library with double 3D functions to increase controllability over the additional customizable components (e.g. line shape, 2.5D technique, and assemble plug).

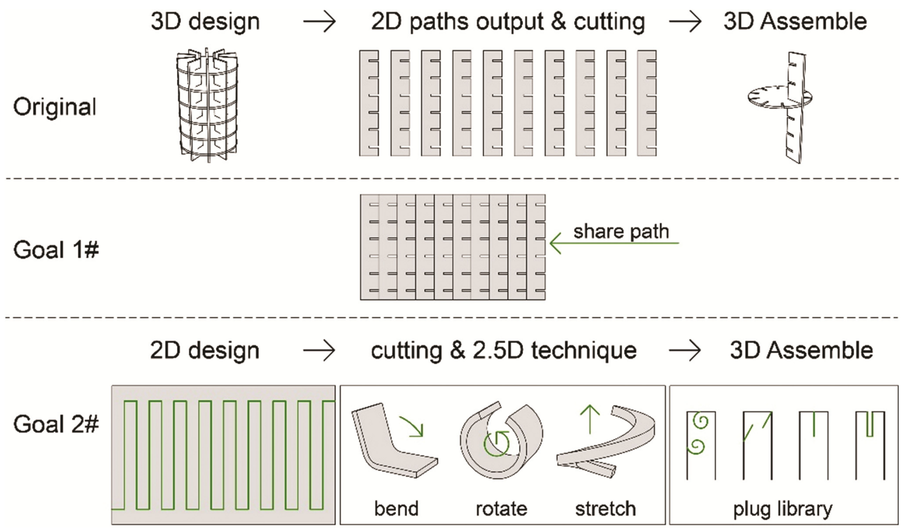


Fig. 1. Workflow and design goals of LaserLeast.

3.2 Software

Pattern sharing

To achieve optimization of fabrication efficiency, we propose a software function by automatically arranging the cutting paths to make them sharing the same cutting path. This will help to solve the problem of low material utilization when prototyping or making using cutting method.

Customizable components

The system offer tools to customize the parameters of line shape, 2.5D technique, and assemble plug.

Specifically, in line shape design, we adopt array design to customize a basic shape, usually a long strip which can be linked in one line by consecutive double-square or central rotatable method, thus ensure each pattern separated by one line can get similar function. The system also provide the assemble element library which can be pinned in the designed line shape to provide different connection method and match different thickness materials.

To ensure all 2D features are properly executed in actual 3D work, we implement one tool to simulate the transformation, one tool to set the 2.5D direction and location by bending, rotating or stretching.

3.3 Hardware and Material

The hardware system includes a cut machine tool and common flat materials. In our case, we use a laser cutter that will help efficiently convert the digital patterns into flat prototypes. Otherwise, die-cutter, milling cutter, or hand cutter can be used.

This method is suitable for easy-to-cut material with flat and flexible properties which can be easily and cheaply purchased. The candidate materials include everything from natural materials to synthetic materials, such as pp films, paperboard, wood or bamboo board.

4 Experiment

LaserLeast assembles all designs from three basic customizable components that are included in a model library and able to be extended by users. The line shape in one plane can be designed to separate two functional parts with several pieces, which can be bent, rotated or stretched into 2.5D and assembled into 3D with different plug approaches. We conducted two test cases using the line-based workflow and compared with one case using the original process used to prototype a similar 3D shape.

4.1 Test 1: Wavy Line

We employed a wavy line to separate one board into two same pieces with a plug line in every strip top. This case was fabricated using a rotating and bending technique to become 2.5D and final self-plugging with each strip to complete two matching 3D objects (see Fig. 2).

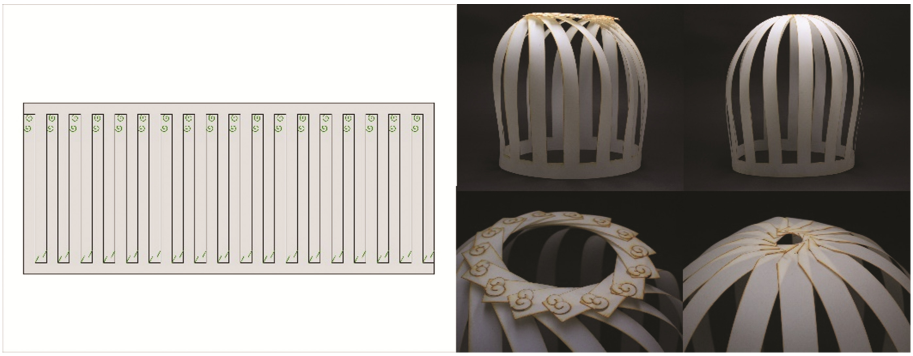


Fig. 2. 3D shape was tested by programmable wavy line design.

4.2 Test 2: Revolving Line

We employed a revolving line to separate one board into two differently shaped pieces with a plug line in every strip top and two connections. This case was fabricated using stretching technique to become 2.5D and used final plugging with connections to complete two different 3D objects (see Fig. 3).

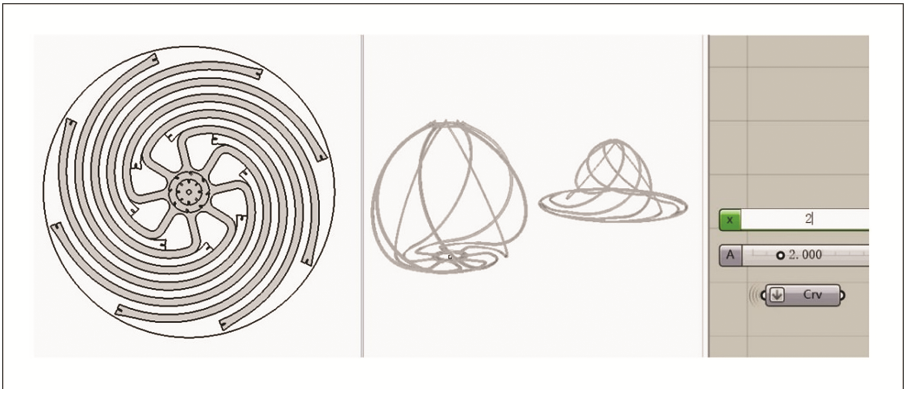


Fig. 3. 3D shape was tested by programmable revolving line design.

4.3 Comparison Results

In order to better position the approach in practice, we further compared two case of LaserLeast with one common subtractive techniques, which have been widely used in the prototyping field of HCI research, and created a new method to solve efficiency, resource, and energy issues and meet new demands. We herein carefully compare the workflow, ease of interaction, fabrication statistics, and final prototypical results using the interlocked slices of Autodesk® 123D™ Make (Fig. 4a) and wavy line case of LaserLeast (Fig. 4b) and revolving line case of LaserLeast (Fig. 4c). The similar model shape was selected for all three methods with identical scales (30 cm x 30 cm x 25 cm) and comparable resolution.

In Autodesk® 123D™ Make, the user is allowed to quickly manipulate the total number and orientation of planar sections with slots. In the 2D pattern, we found that the Autodesk® 123D™ Make system generated regions with multiple shapes with large spare areas, which led to wasted leftover material. Overall, these methods all took less than 10 min to die-cut and less than 10 min to complete the assembly. However, the interlocked slices method achieved 18% material utilization. In the LaserLeast system, wavy line case achieved almost 100% material utilization, and revolving line case achieved 90% material utilization. LaserLeast was in the dominant position in terms of time and material consumption, provided shape composition with aesthetic principle. In addition, the users only need to design line pattern, making the design more ubiquitous use without the modeling expertise.

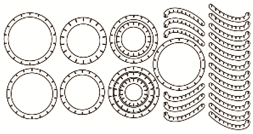
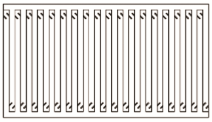
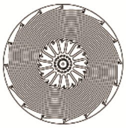
Approach	Prototype	Pattern	Pattern Area (L × W cm)	Material Utilization
(a) Interlocked Slices			175 × 75	18 %
(b) Wavy Line Case of LaserLeast			110 × 50	100 %
(c) Revolving Line Case of LaserLeast			35 × 35	90 %

Fig. 4. Similar shapes were fabricated respectively by (a) interlocked slices, (b) wavy line case of LaserLeast, and (c) revolving line case of LaserLeast.

5 Application

To demonstrate LaserLeast, we now present two application examples to reveal its abilities of optimize- and custom-fabricated objects.

5.1 Optimized Plug-in

According to the optimization problem of cutting path alignment proposed by LaserLeast method, we developed a path generation and re-arrangement plug-in suitable for laser cutting machine. The cutting paths generated by modeling software or vector software can be reassembled in this plug-in. As Fig. 5 shows, the key idea of the plug-in lies in the rearrangement of the vector path of different shapes, through the calculation of the length and curvature of lines, and like a puzzle making the similar parameters of the lines close or together, thus achieving savings in material area and improving material utilization.

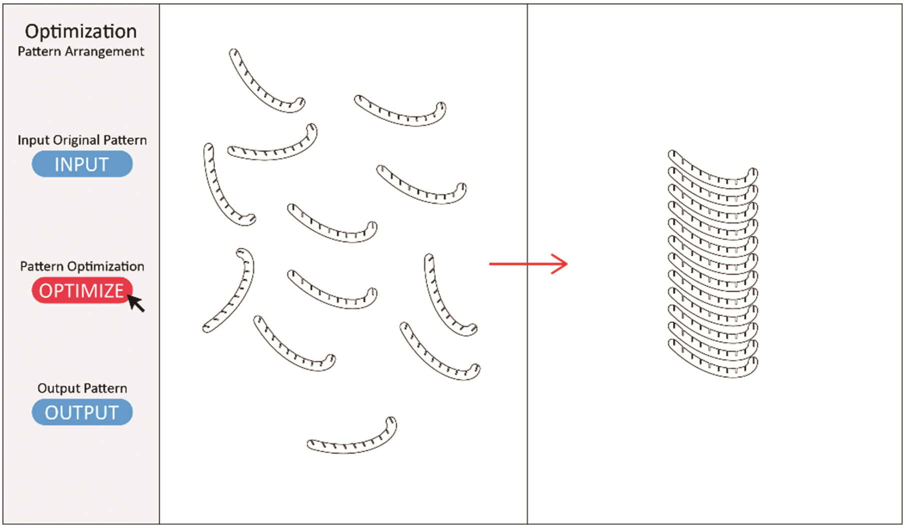


Fig. 5. Optimized plug-in interface.

5.2 Individual Customized Platform

Through this application, we intend to demonstrate that LaserLeast is a quick method of enabling users participated in individually customizing product during the design and fabrication process.

Based on LaserLeast method, we use the law of revolving line case to achieve a personalized lampshade product design platform, named "MagicLamp". Figure 6 shows

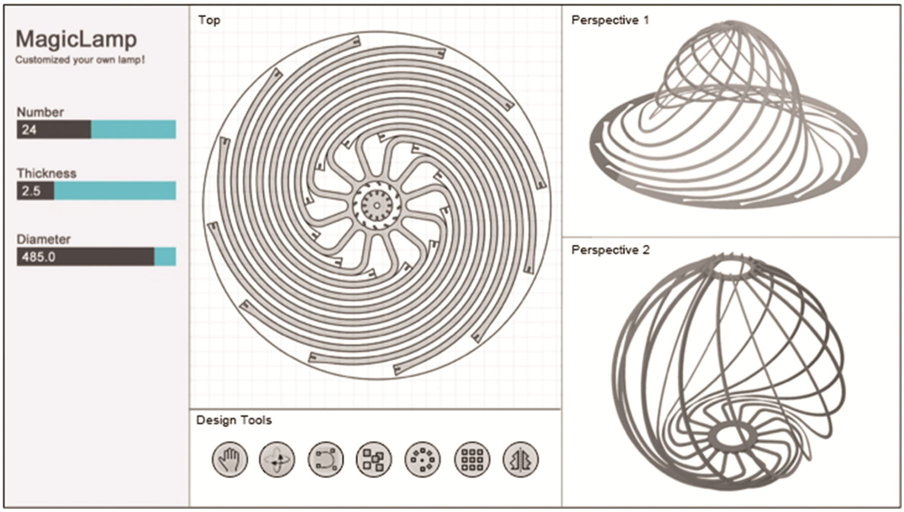


Fig. 6. User interface of MagicLamp example.

the user interface of this platform, including parametric tools, graphic design, and real-time stereoscopic effect display. Among them, parametric tools are used to support parameter definitions for different thicknesses and attribute materials quickly. Graphic design tools are used for editing line shapes. 3D real-time display interface can be used to assist users timely modification during design process. The user can adjust these tools to build aesthetically desirable units.

On this platform, users can design individual product through the online system anytime, and anywhere. General manufacturing tools, such as laser cutter, can also simplify the original manufacturing system, so that the data of product data can be conveniently connected to the local manufacturing, which achieve optimization of design and manufacturing processes.

MagicLamp was built on the provided revolving line pattern for product design. Parametric tools can be served as the basis for design productivity, enabling users to diversify product form based on the provided pattern. The user can overlap repeatedly, symmetrically or alternately line the units to construct product forms. Figure 7 shows two different designs in the basic pattern from two users.

Fig. 7. Multiple results of MagicLamp pattern.

6 Discussion

We introduce a fabrication-aware software platform with two level functions: an improved traditional workflow at the 2D output arrangement stage by gathering two shapes that share one cutting line, and a creative line-based workflow without a 3D modeling stage using three customizable components (line shape, 2.5D method, assembly plug). We then used two test cases to compare with original methods (see Fig. 4).

The figure/ground concept behind LaserLeast offers the following three advantages: (1) Automatic cutting pattern arrangement and line-based design provide a more energy- and resource- saving approach to laser cutting production; (2) Line-based workflow provides an easier and immediate way to produce 3D objects with a laser cutter; and (3) The programming line and customizable components allow increased aesthetical richness and optionality towards a similar shape.

LaserLeast is also subject to limitations: (1) The simulation cannot cover every design and fabrication element and LaserLeast is limited to uncertainty from designed 2D shapes to 3D object shapes whether they are constructed by cutting, bending, and stretching the material. (2) Works only with materials that can be folded and stretched (e.g. hard board, slight wood or Polymethyl methacrylate (PMMA). (3) Some final products may be limited in pressure capability as a single layer structure.

7 Conclusion and Future Work

Given our current results, the line-based strategy and LaserLeast method will stimulate the creativity of the HCI community to explore green consciousness in laser cutting and individual consciousness in product design. Based on the platform, LaserLeast can be served as a creative community for product innovation and exchange gathered by people from around the world through the Internet.

Future improvements to the method will include function improvement in the simulation, case explorations on line-based strategy including 2D form design, the development of double layer structure, expanded range of usable materials, and more user studies.

Acknowledgements. The authors thank all the reviewers for providing valuable insights and suggestions that have helped in substantially improving this paper, as well as all volunteers for general support. This project is supported by the State Key Program of National Natural Science of China (Grant No. 61332017), National Key Technologies R&D Program (Grant No. 2015BAF14B01).

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