-1D Fabrication: Investigating Decoupling Dimensions of Fabrication Output and Fabrication Machine Size

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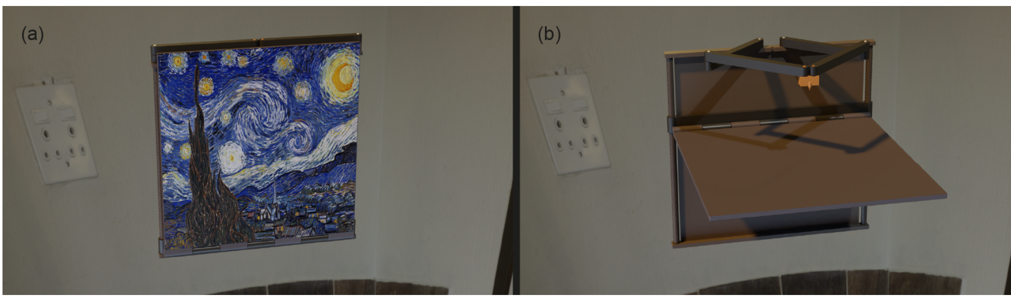

Fig. 1. Fabrication in the living room: (a) the printer acts as decoration while out of use; (b) it unfolds to become a fully functional 3D printer.

Fabrication devices often appear as "large, clunky cubes", and the more capable a machine is, the larger it usually is as well. Minus 1D Fabrication investigates decoupling the output dimensions of fabrication machines from the form factor of the machines themselves. We propose designs for pen-shaped laser cutters and book-sized 3D printers, including designs that can increase the build volume without increasing the size of the machine. The resulting form factors assist the integration of fabrication into daily life.

Additional Key Words and Phrases: Personal fabrication; 3D printing; laser cutting

1 INTRODUCTION

Current fabrication devices are bulky and although the fabrication process may be interesting to watch, the machine itself is typically not very decorative. We employ the idea of reducing the dimensions of the device frame to investigate solutions with unique and interesting form factors. Such fabrication machines could blend seamlessly into living spaces, for example by taking the place of a painting. Since the form factors approach those of tablet PC's with a stylus, it might even be possible to combine mobile computing and mobile fabrication in a single device.

2 BACKGROUND AND RELATED WORK

Extending the output capabilities of 3D printers has been investigated before, and machines that for example offer output of arbitrary size in one dimension by making use of conveyor belts are already commercially available [12]. This paper instead proposes reducing the dimensionality of the machine itself while maintaining baseline fabrication capabilities. Fabrication machines capable of locomotion [5, 9] can also produce outputs that span further than the size of the machine itself, but still often maintain a cube-like appearance. Combining the methods presented in this paper with

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such locomotion platforms could result in mobile fabrication machines with the market-proven disc-like form factor of autonomous robotic vacuum cleaners.

Prior work presents designs for laser cutters intended to reduce overall machine size [4, 11]. Mobile Fabrication [8] also uses fabrication machines of reduced size, as well as manual fabrication alternatives, to explore fabrication on the go. The designs presented here aim to overcome output size limitations inherent to devices of reduced size, but the considerations for mobile modeling on the go in prior work are still highly relevant. Kerf-Canceling Mechanisms [7] introduces modelling techniques for laser cut joints that ensure a serviceable fit irrespective of the specific laser cutter that was used for fabrication. These techniques can also compensate for inconsistencies in cut quality. Since fabrication outside of a fully controlled environment may be less consistent, such techniques are relevant for the mobile laser cutter design presented in this paper.

Everyday Making [10] placed mock-up 3D printers in the homes of participants to study how they would be used in this environment. Although the duration of the study was limited to five weeks, some participants still took the effort to decorate their mock-up printers. Based on these findings, this paper aims to approach unobtrusive or decorative designs.

3 DIMENSIONALITY REDUCTION TECHNIQUES

This paper investigates one design and implementation for a pen-shaped laser cutter, as well as several different designs for book-shaped 3D printers.

3.1 Pen-shaped laser cutter with variable beam output angle

The output angle of a laser can be adjusted by changing the alignment of a mirror that intersects the lasers path. Laser projectors use arrays of moving mirrors to achieve a full 2D output plane this way. Restricting this approach to a single rotating mirror allows positioning all required components along a straight line. This alignment achieves a form factor that approaches a single dimension. A prototype of such a device is rendered in Figure 2 (a). Since pens are ubiquitous today, bags, clothing and accessories already would accommodate devices of such a form factor easily.

A single rotating mirror can be used to increase the output dimension of a laser cutter by aligning the mirror at a 45° angle relative to the laser's path. When the laser is directed at a flat plane, such as a sheet of plywood, any change in the angle of the laser also results in a change of the distance between the diode and the target. This changes the size of the focus spot on the target plane, limiting the cutting capabilities of the laser. To investigate the feasibility of the idea despite this effect, we performed empirical tests with a commercially available 6W laser diode with integrated focusing lens. Such a laser is capable of cutting paper, cardboard and plywood up to about a 3 mm thickness. For this diode, rotating the lens changes the focal distance of the laser. Empirical tests found that cutting performance was ideal within a 5 cm wide focal band. Cutting outside of this band had a noticeable impact on cutting performance due to the laser being unfocused too severely. Figure 2 (b) demonstrates how the focal point F defines the effective cutting area. Using this design, the cutting area can be increased by increasing the distance between the laser and the material to be cut, as well as by adjusting the focal point of the lens during operation.

3.2 Book-sized 3D printers: Printing "outside the box"

We propose a variety of designs for 3D printers that approach a 2-dimensional form factor.

3.2.1 Foldable pantograph. A straightforward approach to reduce the dimensionality of 3D printers is to make the cartesian gantry foldable. In such a design, the 3D printer remains its cubic shape while in use, but can be folded into a much more compact form factor while out of use. An example of such a design and how it could blend into living spaces can be seen in Figure 1. This design uses

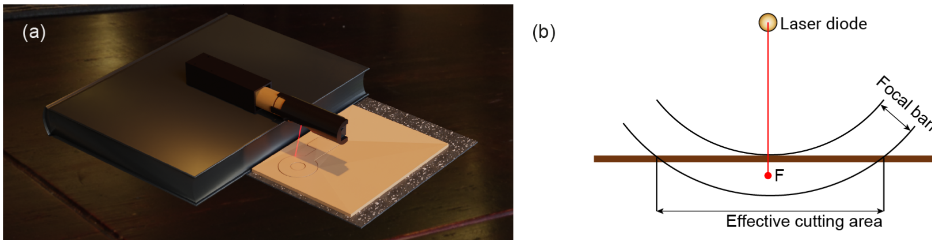

Fig. 2. A pen-shaped laser cutter design: (a) the device can be operated in the living room. (b) Operational limits based on focus requirements for laser cutting.

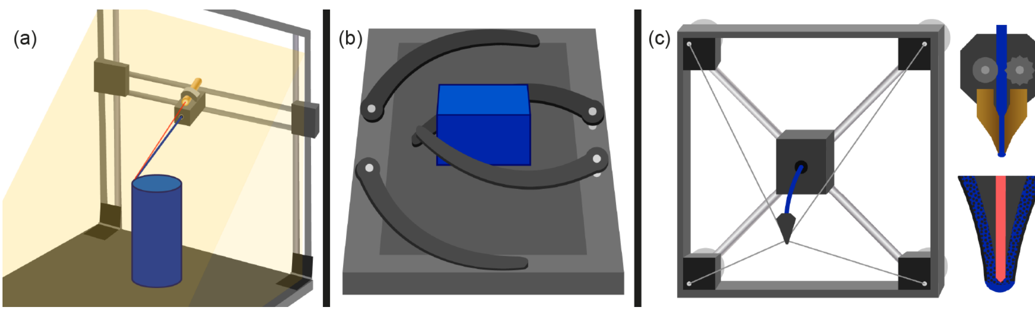

Fig. 3. Three design alternatives for book-shaped 3D printers: (a) remote heating with angled extrusion; (b) lifting the model; (c) a wire-driven delta printer.

actuators that form a pantograph similar to a Morgan printer [3] to span the X/Y plane, which fold flat while out of use. The build plate is attached to a 90° hinge and the underside of the build plate can be used as a decorative surface similar to a painting, or as a touch display while out of use.

3.2.2 Remote heating with angled extrusion. An alternative way to reduce the dimensionality of a fabrication machine is to provide a method of reaching beyond the confines of its frame. One method to do so is to enable remote heating capabilities using a laser rather than using a heated nozzle. The 3D printer shown in Figure 3 (a) extrudes straight or straightened filament at an angle relative to the 2D frame of the machine. Unheated filament sticks for handheld 3D printing pens, such as the 3Doodler [1], could be used for this purpose. A laser that is attached to the extruder at a slightly different angle then heats the tip of the filament stick as it reaches the desired position. Such a machine achieves a half cuboid build volume from within a book-sized frame.

3.2.3 Lifting the model. A printer with the capability to hold onto the current print and lift it up at least one layer height at a time could potentially print objects of essentially arbitrary height. A clamping mechanism similar to that shown in Figure 3 (b) can achieve a more secure hold by integrating a universal gripper mechanism [2] into the clamps. A 3D printer that grabs and lifts the model it is printing during fabrication would require an initial shape to grab onto in place of a build plate. This shape could be a detached part of the machine, or simply some found object, such as the cork of a bottle, or a cardboard box.

3.2.4 Wire-driven delta printer. A delta-style 3D printer that uses flexible delta arms, that is, wires instead of rods, for positioning the printing head, does not require a tower gantry to reach the desired printing height. The printer shown in Figure 3 (c) instead uses a central semi-flexible rod to push the print head away from the base. This rod could simply be a thick strand of filament as shown in the upper detail view. In this configuration, the printer would make use both of a bowden-style extruder responsible for both extruding filament and maneuvering the print head, as well as a direct extruder that is only active when extruding printing material. Alternatively, this rod could be part of the machine and contain a fibre laser and a pipe for powdered filament. In this configuration, printing material would be deposited in a process similar to laser cladding [6], as shown in the lower detail view.

4 DISCUSSION

Fabrication outside of a workshop environment requires additional considerations to ensure that it can be done safely and free of unwanted side effects. Additionally, the appearance of the machines, especially while not in use, is equally important for any technology to be widely adopted into living spaces.

4.1 Visual integration into living spaces

The alterations to the form factor of fabrication machines proposed in this paper open up new possibilities to integrate them into living spaces seamlessly.

4.1.1 Hidden in plain sight. The foldable nature of designs such as those shown in Figures 3 (a) and 1 allows them to act as a decorative surface, such as a painting, while out of use. Folding designs generally allow some exterior surface to be a canvas for personalization, which can help promote a sense of ownership and affection and can encourage displaying them publicly in living spaces. Devices such as the ones shown in Figure 3 (b) could be integrated directly into a tabletop surface or a counter space, providing shelf space while not in use.

4.1.2 Out of sight. Fabrication machines such as the one depicted in Figure 3 (c) could be placed out of sight while still being accessible to use. For example, this machine could be attached with suction cups to the bottom surface of a table or a chair. The elevation provided via this attachment opens up a build volume underneath an empty seat while keeping the fabrication device itself hidden.

4.1.3 Mobile integration. A permanent storage solution for fabrication devices at home may not be necessary at all, if these devices are already integrated into the mobile computation devices like cell phones and tablets.

4.2 Equipment and safety features

3D printing can be done safely in any room with an open window as long as materials such as ABS that may generate toxic fumes are avoided. 3D printers are generally no more dangerous than a hot stove. Some machines, for example those using a pantograph for actuation, could pose a pinching hazard and would require integrated force sensors to ensure that operation halts as soon as any obstruction is detected. Alternatively, infrared proximity sensors could halt operations ahead of time as soon as users get too close to avoid accidents entirely.

In the case of laser cutting, additional equipment and safety features are necessary. However, many living spaces today already have all the necessary equipment available. For example, the fume hood above a stove top could be used to extract the fumes generated while laser cutting. A cut-resistant surface is useful as a foundation below the material to be cut. Coasters or bread cutting boards could serve this purpose, as well as any cardboard packaging that is about to be discarded anyway. A pen-sized laser cutter should also feature a tipping sensor to ensure the beam can only ever be directed at the cutting material. Mobile computing devices are already regularly equipped with the necessary sensors, so fabrication that integrates into this mobile ecosystem can benefit from these features as well.

4.3 Fabrication duration limitations

If the proposed designs are operating outside of home, the duration of the operations is limited by battery life. A battery that fits a pen-sized device restricts the duration of fabrication to a handful of minutes. Such a short duration means that the types of objects that can be fabricated are limited to a small size, such as simple tools or a spare key. A battery that fits a tablet-sized devices increases this time scale to a few hours, increasing the fabrication options dramatically.

5 CONCLUSION

The concept of dimensionality reduction is not limited to these specific form factors, but can instead continually guide the progress of future design iterations. In future work, -2D Fab could for example feature a 3D printing pen that is able to move on its own. One might envision an advanced muscle stimulation system that steers a fabrication process by controlling a person's arm while they are at rest, such as while watching a movie. In the same vein, a marble-sized laser cutter that can roll across surfaces autonomously and cut the material it passes may seem impossible today, but might be an interesting design challenge in the future.

One way that fabrication may integrate into living spaces is that devices become part of the space itself, for example by integrating into furniture that is considered an essential part of the space, rather than a distinct object within. Fabrication devices with reduced dimensionality can help facilitate this transition.

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