Fluxable: A Tool for Making 3D Printable Sensors and Actuators

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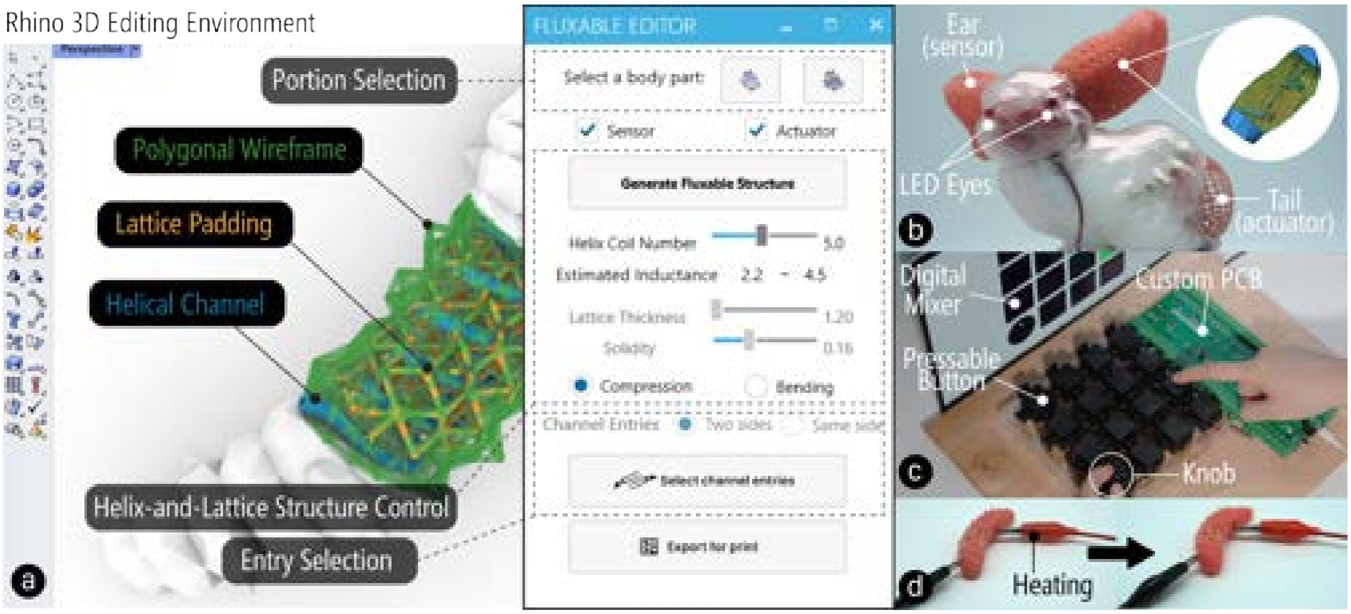

Figure 1: 3D printable sensors and actuators are created with (a) *Fluxable* design tool, such as (b) a Pomodoro bunny timer, (c) a DJ BeatPad, and (d) a caterpillar robot.

ABSTRACT

We present *Fluxable*, a tool for making custom sensors and actuators 3D printable with customer-grade Stereolithography (SLA) 3D printers. With this tool, the user converts an arbitrary 3D model into a deformable body with integrated helix-and-lattice structures, which comprise a hollow helical channel in the center, lattice paddings, and a wireframe structure on the surface. The tool allows for the parameterization of the helix for sensing performance and customization of the lattice for actuation. By inserting a conductive shape-memory alloy (SMA) into a printed object through the helical channel, the converted shape becomes a sensor to detect various shape-changing behaviors using inductive sensing or an actuator to trigger movements through temperature control. We demonstrated our tool with a series of example sensors and actuators, including an interactive timer, a DJ station, and a caterpillar robot.

CCS CONCEPTS

• **Human-centered computing → User interface toolkits**.

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KEYWORDS

3D printing, SLA, Actuator, Sensor, Helix, Lattice, Design Tool

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1 INTRODUCTION

3D printing has rapidly evolved into an accessible technique to create versatile physical prototypes. Beyond creating arbitrary physical shapes, making 3D-printed devices interactive has been extensively explored [2]. Researchers have also explored creating 3D printable and customizable sensors [1, 3, 6] and actuators [4, 7]. However, these previous approaches often rely on specialized structures and materials that support only one-directional interaction, lacking a unified design for both sensing and actuation. To address this, we extended the integrated parameterizable helix-and-lattice structures in [5] to not only support deformation recognition but also achieve controllable actuating behaviors within one unified physical design.

In this poster, we propose *Fluxable*—a design tool that aims to lower the barrier for makers to imbue sensing and actuating capabilities into custom shapes that are 3D printable with commercial 3D printers for versatile physical prototypes. With this tool, the

Figure 2: Lattice with higher density can be added to the lattice padding as *'anchors'* to achieve desired lateral bending behaviors: the Finite Element Analysis (FEA) showcases four directional bending examples.

maker can convert a custom 3D model into a sensor, an actuator, or both by embedding a helix-and-lattice structure [5]. For the sensor, the maker can parameterize the integrated helix and lattice designs, such as the number of coils in the helix and lattice solidity, for sensing performance in the tool. For the actuator, the maker can control the output deformation movements by adding denser lattices, *a.k.a,* 'anchors', in selective regions. The converted model is printed on a consumer-grade Stereolithography (SLA) 3D printer with elastic resin to provide robust deformation for sensing and actuation purposes. While conductive materials, such as steel wire, can be inserted into the helical channel after the object is printed for inductive sensing [5], a shape-memory alloy (SMA) wire needs to be inserted for actuation controlled by heating and cooling.

2 SENSOR AND ACTUATOR DESIGN

To extend the helix-and-lattice structure, which consists of a hollow helical channel in the center, lattice padding around the helical channel, and a wireframe structure on the surface, in [5] to support controllable output deformation behaviors for actuating, we insert a conductive Nitinol memory coil spring[1], which is pre-programmed to contract and exert force when heated to 45°, into the helical channel during the post-printing process to activate compression when the SMA is heated. A uniform compression is yielded if the lattice structures are evenly distributed around the helical channel. However, it is possible to increase the lattice density in selected areas within the lattice padding as *'anchors'* to achieve desired lateral bending behaviors (Figure 2). The anchors direct the deformation of the structure by strengthening a section rather than allowing uniform force across the entire structure.

Built upon [5], our tool supports the control of helix length (L), helix diameter (d), and the number of coil turns (N) for distinct inductance profiles, which are fed into a pre-trained machine learning model for classifying four deformation behaviors—bending, twisting, compression, and extension [5]. In addition, the solidity of the lattice padding can also be controlled by the user in the tool to regulate the overall stiffness of the object for actuating outputs.

3 INTERACTIVE DESIGN TOOL

To enable makers to convert arbitrary 3D models into sensors and actuators, we developed an interactive design tool, a *Rhino3D* plugin implemented with *Grasshopper* and *Human UI* in C#, which consists of three key components (Figure 1a): portion selection, helix-and-lattice structure control, and entry selection. First, the user selects the model and then specifies the portion to be converted by dragging two planes in the 3D editing environment. Once the middle part between the two slicing planes is selected, the user decides the conversion type (*i.e.,* sensor, actuator, or both) by ticking the checkboxes. For sensors, the tool allows the user to parameterize the helical channel design to preview the resulting inductance change caused by deformation and the lattice design to control the body solidity. The estimated inductance is calculated based on the helix parameters. The helix diameter is decided by the selected part's volume, and the helix length is based on the selected part's length and the max displacement for compression. The user inputs the coil number of the helix through a slider. Lattice beam thickness and the overall solidity of the lattice padding can be controlled by the user for various levels of model rigidity through sliders in the interface. Compression is supported by default when creating actuators. Upon the selection of lateral bending, the tool takes in the direction specified by the user (Figure 2) and auto-generates internal lattice-based anchors to accomplish the desired bending behavior. Additionally, the user can select the helical channel entry positions as either being on the same side or on the opposite two sides of the selected portion. All the changes are updated in read time, and finally, the converted model is exported for printing, followed by the same post-printing process described in [5].

4 EXAMPLE APPLICATIONS

We showcase three interactive physical prototypes created with the tool: a Caterpillar robot (actuator), a multi-key DJ BeatPad (multi-sensor), and a bunny timer (sensor but also actuator). First, we created a **caterpillar robot** with the tool to mimic the crawling movements of a caterpillar by heating and cooling the inserted SMA wire (Figure 1d). Then, we built a **multi-key DJ BeatPad** to create a personalized beat composition experience. The DJ beat pad comprises a 4×4 matrix of pad units, each converted by our tool for sensing, and is connected to a digital mixer (Figure 1c). Pressing different button-like pads generates distinct beats. The pad at the bottom-left corner is attached with a 3D-printed knob, which allows for volume adjustment by twisting. Furthermore, we created a custom printed circuit board (PCB) to enable the simultaneous processing of multiple sensors, which extends our approach to support large-scale applications. Finally, we created a **bunny-look timer** to support the customization of the Pomodoro timer, a time management tool designed to improve productivity by segmenting work into manageable work and break intervals, converting the ears into two separate sensors and the tail into an actuator. The user can also use the timer as an ambient display by connecting the ears and tail to external circuitry and installing two LED lights as the bunny's eyes (Figure 1b). To use it, the user twists the ears separately to control corresponding timers and light up the LED eyes. The tail actuator will start moving when work interval ends.

5 FUTURE WORK AND CONCLUSION

We presented a tool that converts 3D models into 3D printable sensors and actuators using the embedded parameterizable helix-and-lattice structures. The next steps include examining the tool's usability through user evaluations, experimenting with other SMA types for stronger actuation, and exploring different placements of lattice-based anchors to produce more expressive behaviors.

[1]Nexmetal Nitinol 1-WAY Memory Coil Spring (W0.75/D6.5/C16; AF 45)

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