
Plain2Fun: Augmenting Ordinary Objects with Surface Painted Circuits

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Abstract

The growing makers' community demands better supports for designing and fabricating interactive functional objects. Most of the current approaches focus on embedding desired functions within new objects. Instead, we advocate re-purposing existing objects and authoring interactive functions onto them. We present Plain2Fun, a design and fabrication pipeline enabling users to quickly transform ordinary objects into interactive and functional ones. Plain2Fun allows users to directly design the circuit layouts onto the surfaces of the scanned 3D model of existing objects. Our design tool automatically generates as short as possible circuit paths between any two points while avoiding intersections. Further, we build a digital machine to construct the conductive paths accurately. With a specially designed housing base, users can simply snap the electronic components onto the surfaces and obtain working physical prototypes. Moreover, we evaluate the usability of our system with multiple use cases.

Author Keywords

DIY; Computational Fabrication; Creativity Support Tool

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: User Interfaces Interaction Styles

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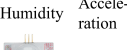
	Input	Output
2 Pins	 Switch  Button  Force	 Buzzer  LED
3 Pins	 Temperature  Humidity  PIR Sensor  Moisture	 Light  Acceleration  Speaker  Motor
4 Pins	 Compass  RGB Sensor	 Screen

Figure 2: Electronic components library

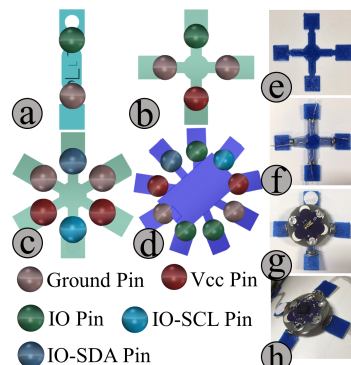


Figure 3: Housing base design. (a-d) Layouts for components with different pins. (e-h) Soft housing base fabrication

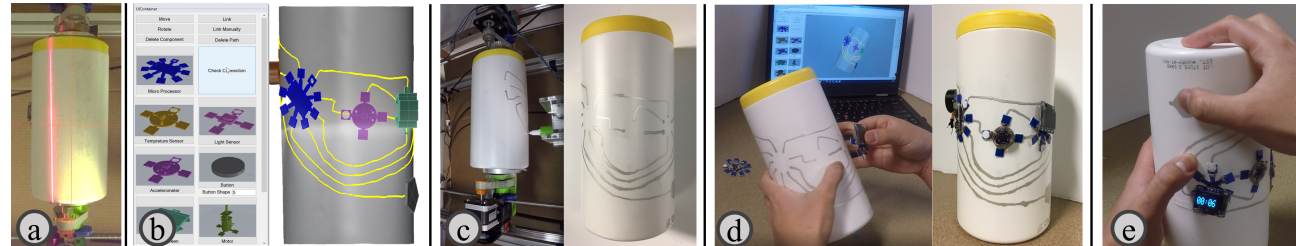


Figure 1: Workflow of Plain2Fun: users first scan a chosen object on the machine (a); we provide a design tool for users to place the components on the obtained 3D model and generate the conductive paths (b); a digital machine is used to draw the paths on the object with a conductive pen (c); then the users simply align and attach the soft housing bases onto the object (d); finally, a physical prototype on the existing object with customized interactive functions is finished (e).

Introduction

The DIY makers' community is well supported on the physical realization of mechanical functions by both hardware such as 3D printer, laser cutter, and CNC machines and computer-aid-design (CAD) softwares. Nevertheless, the makers have a growing demand for embedding interactive functions including sensing, lights, displays and sound into fabricated objects. One way to cater to this demand is the integrated fabrication of electronics and objects [10, 13], which only works for new designs. On the other hand, a post-assembly approach provides more flexibility in terms of incorporating off-the-shelf electronic components on existing plain objects. Yet, current design and fabrication tools do not support electronics design on the artifact directly, and are not user-friendly to create interactive functions.

We propose Plain2Fun, a pipeline that allows novice users to design and construct an interactive prototype on an existing object's surface, as shown in Figure 1, while including (i) An interactive design tool that facilitates users to customize the circuitlayout, generating conductive paths on

surface of an object while avoiding intersections and misconnections. (ii) A digital machine for drawing conductive paths automatically, and (iii) A library of components with soft housing bases that can be simply stuck onto object surfaces to construct prototypes.

Related Work

3D Interactive Object Fabrication. Numerous works have been proposed for designing and fabricating 3D interactive objects. The functional components have been embedded within the empty chamber inside the 3D prints [4, 10]. Previous works also showed integrated fabrication approaches by combining conductive materials with 3D printing [5, 11]. Roquet et al. [3] integrated flexible paper circuits and 3D printing. However, these approaches focused on designing and fabricating new objects from scratch. Here, Plain2Fun supports users to re-purpose the existing objects.

Augmentations on Existing Objects. Recent works have studied augmenting existing objects by attaching new physical parts onto or directly 3D printing around the objects [2]. Moreover, RetroFab extended the idea of mechan-

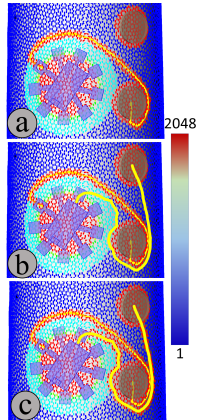


Figure 4: Weight distribution of a mesh while adding a conductive path. (a) The weight map before adding the path. (b) A new path (yellow line) is generated using weighted geodesic algorithm and avoid touching the existing components and paths. (c) Weight distribution of this mesh is updated after adding a path.

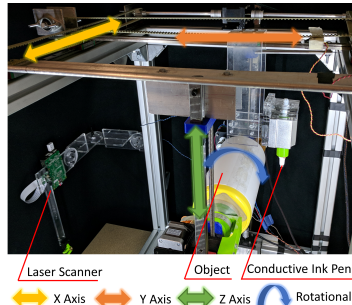


Figure 5: Our digital fabrication tool with 3 translational and 1 rotational DOF.

ical hijacking and automated the physical control interfaces [9]. Apart from mechanical augmentations, RFID [7], and capacitive [15] were used to detect users' interactions. Due to good conformability, stretchable soft sensors/displays have been introduced as an extra layer on the 3D objects [13, 14]. Inspired by the idea of a soft layer, we propose to house the off-the-shelf breakout boards on flexible bases and attach them on the surfaces of the object, to utilize the simple attachment of flexible material and wide choices of off-the-shelf components.

Designing and Constructing Circuits on Surface. Despite the existence of general-purpose PCB design tools, more novice-friendly systems have been developed. Anderson et al., proposed a system to generate layout design for breadboards based on users' high-level inputs [1]. To pursue more flexibility, copper tape has been used as conductive paths on flat surfaces [3]. Moreover, conductive ink based circuits¹ can be constructed with drawing pens and ink-jet printer [8]. As for 3D objects, Voxel8² prints conductive inks together with plastic filament. In SurfCuit [12], copper tapes were manually placed in the channels on the 3D prints and connections were crafted by soldering on the stripes. In Plain2Fun, we develop a customized 4 DOF CNC like machine with a capacitive silver ink pen to draw traces directly on surfaces of objects.

Plain2Fun

Here we explain the pipeline together with a typical use case of Plain2Fun as illustrated in Figure 1. A creative maker has a plain wet tissue can and would like to transform the can to a digital sand timer like device and preserve the can's original shape and function. To deliver the function of a digital timer, a quick formulation could include a

micro-controller, a display, a speaker, an accelerometer and a capacitive button. The traditional way usually involves hooking up them together on a breadboard with wires, while Plain2Fun links the components together with conductive paths and uses the surface of the object as a PCB board.

With Plain2Fun, users first scan the plain object on the machine (Figure 1 (a)), then import the scanned 3D model into our design tool (Figure 1 (b)). The users select the components from the library and place them onto the surface of the object in a drag-and-drop manner. Then the users can either connect the pins with manually routed paths or auto-generated ones. Further, the digital machine constructs the conductive paths with a silver ink pen (Figure 1 (c)). Lastly, the users align the physical housing bases with the drawn paths and then attach the bases onto the surfaces to finish the physical prototype (Figure 1 (d)).

Electronic Components Library

To deliver interactive functions, makers usually need to create a recipe with a micro-controller unit (MCU), a power unit, and some functional components for input/output. We select a normal MCU breakout board (Adafruit Trinket M0) which retains enough pin-outs on a small footprint. Figure 2 shows the 17 functional components that we selected after searching a wide range of off-the-shelf components.

Most of the components can be categorized based on their pin configuration: (i) two-pin component (an I/O pin (IO) and a ground (G)); (ii) three-pin (a power (P), a G and an IO); (iii) Four-pins (a G , a P and two IO for I^2C bus (i.e., SDA , SCL)); (iv) MCU (a G , a P and five IO of which two pins can be used as an I^2C bus). Figure 3 (a-d) shows the layouts of the housing bases that we designed for each category. The housing bases apply a split multi-arm structure design and are able to conform to heavily curved surfaces. For easy connection, we add a ground pin to a three-pin

¹<https://www.circuitscribe.com/>

²<https://www.voxel8.com/>

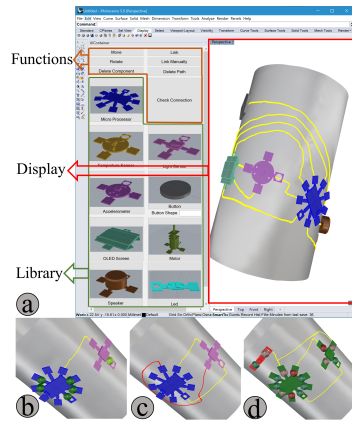


Figure 6: User interface of the design tool: UI layout (a), path generation (b), intersection warning (c), and connectivity check (d).

component, and an extra pair of ground and power to a four-pin component and a MCU.

Conductive Path Generation

To assist users to construct conductive path between two pins, we propose a weighted geodesic algorithm based on [6] to generate the shortest possible route in real time while avoiding intersections with existing paths and components. Instead of calculating the path lengths using Euclidean distances as did in [6], we assign a weight value w_{s_i} to each face s_i of the original mesh and define a weighted length for a path L_P :

$$L_P = \sum_{p_i \in P} w_{p_i} l_{p_i} \quad (\forall p_i \in s_i, w_{p_i} = w_{s_i})$$

where p_i refers to the short segments that compose path P and l_{p_i} is the Euclidean length of p_i . This way, we can assign different weights to the mesh faces thus differentiate the existing paths and the components covered areas from the empty surface areas as shown in Figure 4. Then we apply Dijkstra's algorithm to find a "shortest" path which is steered away from the occupied areas.

Implementation

Digital Fabrication Tool. As shown in Figure 5, we build a CNC machine which integrates scanning and drawing functions. The machine consists of a drawing head mounted with a conductive ink pen (CSIP-998), an open source laser scanner³, and a 4-DOF motion system. A pair of universal clamps is used to fixate the object and rotate it along the center axis. The user can fit an object between them by moving the clamps along the X axis. The Fabrication tool is controlled by an Arduino Mega 2560 and interfaces with the design tool through serial communication.

³www.freelss.org

Soft Housing Base Fabrication. The soft substrate of the housing base is built by 3D printing with Thermoplastic Urethane (TPU) filament (Figure 3 (e)). Then we wrap bare metal wires on each arm which serve as electronic contact pads (Figure 3 (f)). We solder the breakout boards onto the loose end of the metal wires (Figure 3 (g)). Strong Double sided tape pads are attached on to the square end areas of the housing base to maintain physical contact with the surfaces of objects. In the Plain2Fun pipeline, the users are provided with components which are already on housing bases and they can stick the component onto the object by simply peeling of the protect layer of the double sided tape (Figure 3 (h)).

User Interface. The user interface of our design tool is implemented as a plug-in for Rhino 5 (Figure 6 (a)) using C# language and RhinoCommon SDK and runs on Windows. The users are provided with three types of functions. (i) Components operations: Users can import a component from the library by drag and drop, and use "Move" and "Rotate" To adjust the position of the component on the 3D model. (ii) Paths operations: "Link" enables the user to auto-generate a path by choosing two pins on different components (Figure 6 (b)), while "Link Manually" lets users draw a path by clicking points on the surface. And a red path indicates intersection (Figure 6 (c)). (iii) Facilitating functions: By clicking "Check Connection", users can visualize the connection suggestions (Figure 6 (d)). Pins with the same color match each other. And when a component is correctly connected, it will turn green (the 4-pin one in Figure 6 (d)), otherwise, it remains red (the 2-pin one).

Example Use Cases

Our design and fabrication workflow can be potentially adapted to different contexts. Here, we selectively demonstrate four use cases including decorating existing objects

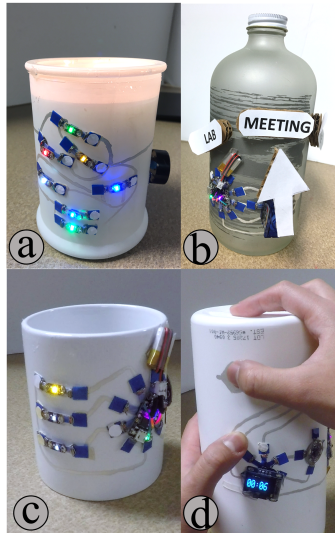


Figure 7: Example use cases: a candle holder with a surface mounted Christmas tree (a), a status indicator on a bottle (b), a temperature display for a coffee cup (c), and a digital sand timer (d).

with lights and sound (Figure 7 (a)), creating articulating components for interactions (Figure 7 (b)), sensing and reacting to the status of the objects (Figure 7 (c)), and leveraging the movements of the objects to trigger activities (Figure 7 (d)).

A Candle Holder Celebrating Holidays. In this case, we mainly add output components including a speaker and an LED array to the objects. While the speaker is playing Christmas music, the LEDs are lighted up successively from top to bottom. The electronic features and the original function of the candle are combined seamlessly to create a joyful atmosphere. Also, this example demonstrates that our design tool can generate organized conductive paths even if the components are cluttered up on the object.

A Status Pointer. Figure 7 (b) shows a status pointer which is composed of a servo motor and a capacitive button. By touching on the capacitive button, the servo motor can rotate the pointer to different labels. When the user is not in his office, he can inform other people about his status by rotate the pointer to a label. By using Plain2Fun, the user not only can use static components like speakers and screens, but also can use moving components like motors, since the housing base can provide strong mechanical support as well as stable electrical connections. Also, the user can extend the object interface easily by adding more passive markers together with the components.

A Mug with a Temperature Display. We create an interactive cup (Figure 7 (c)), which has three LEDs and a temperature sensor. The LEDs indicate the temperature of the water inside the cup, e.g., more LEDs will be lighted up with a higher temperature. Since Plain2Fun is additive and non-invasive, the original function of the cup is not spoiled.

An Electronic Sand Timer. We build an electronic sand

timer (Figure 7 (d)) on a wet tissue can with an accelerometer, an OLED screen, a speaker and a capacitive button. The user can press the capacitive button to set time and turn the tissue box up-side-down to start counting down. This electronic sand timer provides two types of input: touching and movements of the objects. In this use case, we showcase that the input and output components work together to deliver new functions.

Limitation and Future Work

In the future, we can further improve Plain2Fun in following aspects. Firstly, in the current version of the design tool, the users have to connect each pair of pins manually, so later, we can embed an auto-planning algorithm to deal with all connections at once after the user has decided the position of each component. Secondly, we can use flexible PCB instead of current soft housing base to reduce the size of the components and improve its appearance. Thirdly, we can leverage color painting to further beautify the appearance.

Conclusion

In this paper, we presented Plain2Fun, a fast design and fabrication pipeline which allows users to add interactive functions to plain everyday objects with customized circuits layouts. To achieve this goal, we developed an interactive design software, a fully automatic digital machine for conductive path generation, and a library of components with soft housing bases for easy attachment. Through multiple example use cases we verified that the physical prototypes made with Plain2Fun delivered the desired functions. We believe that a wide range of applications can be enabled by applying Plain2Fun and other novel ideas can be derived from this workflow.

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REFERENCES

1. Fraser Anderson, Tovi Grossman, and George Fitzmaurice. 2017. Trigger-Action-Circuits: Leveraging Generative Design to Enable Novices to Design and Build Circuitry. In *UIST' 17*. ACM, 331–342.
2. Xiang'Anthony' Chen, Stelian Coros, Jennifer Mankoff, and Scott E Hudson. 2015. Encore: 3D printed augmentation of everyday objects with printed-over, affixed and interlocked attachments. In *UIST' 15*. ACM, 73–82.
3. Claudia Daudén Roquet, Jeeun Kim, and Tom Yeh. 2016. 3D Folded PrintGami: Transforming Passive 3D Printed Objects to Interactive by Inserted Paper Origami Circuits. In *DIS' 16*. ACM, 187–191.
4. Wei Gao, Yunbo Zhang, Diogo C Nazzetta, Karthik Ramani, and Raymond J Cipra. 2015. RevoMaker: Enabling multi-directional and functionally-embedded 3D printing using a rotational cuboidal platform. In *UIST' 15*. ACM, 437–446.
5. Scott E Hudson. 2014. Printing teddy bears: a technique for 3D printing of soft interactive objects. In *CHI' 14*. ACM, 459–468.
6. Mark Lanthier, Anil Maheshwari, and Jörg-Rüdiger Sack. 1997. Approximating weighted shortest paths on polyhedral surfaces. In *SoCG' 97*. ACM, 274–283.
7. Hanchuan Li, Eric Brockmeyer, Elizabeth J Carter, Josh Fromm, Scott E Hudson, Shwetak N Patel, and Alanson Sample. 2016. PaperID: A technique for drawing functional battery-free wireless interfaces on paper. In *CHI' 16*. ACM, 5885–5896.
8. Simon Olberding, Sergio Soto Ortega, Klaus Hildebrandt, and Jürgen Steimle. 2015. Foldio: Digital fabrication of interactive and shape-changing objects with foldable printed electronics. In *UIST' 15*. ACM, 223–232.
9. Raf Ramakers, Fraser Anderson, Tovi Grossman, and George Fitzmaurice. 2016. Retrofab: A design tool for retrofitting physical interfaces using actuators, sensors and 3d printing. In *CHI' 16*. ACM, 409–419.
10. Valkyrie Savage, Sean Follmer, Jingyi Li, and Björn Hartmann. 2015. Makers' Marks: Physical markup for designing and fabricating functional objects. In *UIST' 15*. ACM, 103–108.
11. Martin Schmitz, Mohammadreza Khalilbeigi, Matthias Balwierz, Roman Lissermann, Max Mühlhäuser, and Jürgen Steimle. 2015. Capricate: A fabrication pipeline to design and 3D print capacitive touch sensors for interactive objects. In *UIST' 15*. ACM, 253–258.
12. Nobuyuki Umetani and Ryan Schmidt. 2017. SurfCuit: Surface-Mounted Circuits on 3D Prints. *IEEE Computer Graphics and Applications* 38, 3 (2017), 52–60.
13. Michael Wessely, Theophanis Tsandilas, and Wendy E Mackay. 2016. Stretchis: Fabricating highly stretchable user interfaces. In *UIST' 16*. ACM, 697–704.
14. Sang Ho Yoon, Ke Huo, Yunbo Zhang, Guiming Chen, Luis Paredes, Subramanian Chidambaram, and Karthik Ramani. 2017. iSoft: A Customizable Soft Sensor with Real-time Continuous Contact and Stretching Sensing. In *UIST' 17*. ACM, 665–678.
15. Yang Zhang, Gierad Laput, and Chris Harrison. 2017. Electrick: Low-Cost Touch Sensing Using Electric Field Tomography. In *CHI' 17*. ACM, 1–14.