

# ActMold: Rapid Prototyping of Electronic Circuits on 2.5D Objects with Interactive Vacuum Forming

Junichi Yamaoka  
Keio University  
yamajun@sfc.keio.ac.jp

Yasuaki Kakehi  
Keio University  
ykakehi@sfc.keio.ac.jp

Yoshihiro Kawahara  
The University of Tokyo  
kawahara@akg.t.u-tokyo.ac.jp

## CCS CONCEPTS

•Human-centered computing → Human computer interaction (HCI);

## KEYWORDS

Digital Fabrication, Rapid Prototyping, Vacuum Forming

### ACM Reference format:

Junichi Yamaoka, Yasuaki Kakehi, and Yoshihiro Kawahara. 2017. ActMold: Rapid Prototyping of Electronic Circuits on 2.5D Objects with Interactive Vacuum Forming. In *Proceedings of SIGGRAPH '17 Studio, Los Angeles, CA, USA, July 30 - August 03, 2017*, 3 pages. DOI: 10.1145/3084863.3084870

## 1 INTRODUCTION

Recently the availability of fabrication tools such as 3D printers have become widespread, and prototyping tools that can print solid objects, such as an electric circuit, have been developed using a conductive filament. However, digital fabrication techniques for 3D objects are still in the process of development. For instance, the printing speed of current 3D printers is still slow, and recycling is difficult because the filament material in most of today's 3D printers is for one-time use only. Moreover, it is difficult to reprint circuits because the circuits are integrated into the printed objects. Many researchers have been developing these alternative fabrication methods using current digital fabrication machines such as 3D printers and laser cutters [Beyer et al. 2015].

We move toward a solution for these issues by developing a fabrication system called ProtoMold [Yamaoka and Kakehi 1993], which is capable of molding 2.5-dimensional (2.5D) objects quickly. This system combines a dynamical shape display and a vacuum forming system that can reuse molded objects. By applying heat on the object, the molded object can be reversed to a flat surface. Therefore, the system allows users to change design repeatedly. This time, we propose a prototyping method of 2.5D-shaped objects with electronic circuits. By printing patterns of conductive ink on a plastic sheet in advance, the objects can work as electronic interfaces. In this paper, we describe the system design of this new system named ActMold and methods for prototyping functional 2.5D objects, including electric circuits.

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

SIGGRAPH '17 Studio, Los Angeles, CA, USA

© 2017 Copyright held by the owner/author(s). 978-1-4503-5009-9/17/07...\$15.00  
DOI: 10.1145/3084863.3084870

## 2 PROTOTYPING PROCESS OF ACTMOLD

### 2.1 Printing Circuits on Surfaces

Before modifying the plastic sheet, the user can print a circuit on its surface with conductive ink to add computational functions to the molded prototypes. The user can design a circuit using the design software Frizing, which automatically generates the circuit. The Rhinoceros CAD software converts the vector data of the circuit to .stl data, and the 3D printing software (Repetire-Host) converts the .stl data to Gcode, which is then sent to the 3D printer to print the circuit. Since our vacuum forming machine will expand the surface, we need a stretchable conductive material to make circuits on it. For this purpose, we utilized conductive ink (LA-3, CEMEDINE Co., Ltd.). To print a circuit on the plastic sheet, we developed a printing system which has a syringe filled with the ink on the head of the 3D printer (Ninjabot Inc., NJB-200W) (Figure 1a). The hardening time of the conductive ink is 10 min at 100°C; the ink will cure while the plastic sheet is heated before molding.

### 2.2 Shaping 2.5D Objects

For making 2.5D shapes, we use our ProtoMold system that consists of a heater, pin array display, vacuum unit, camera, and computer (Figure 2). We used a vacuum forming machine (V.former, Rayama

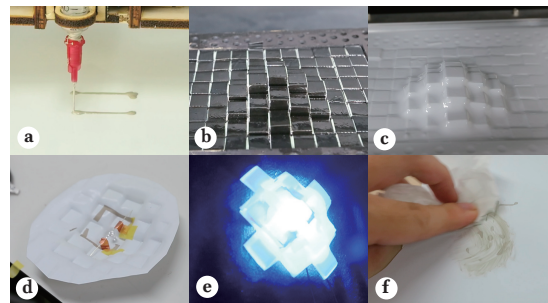


Figure 1: Prototyping Process using ActMold.

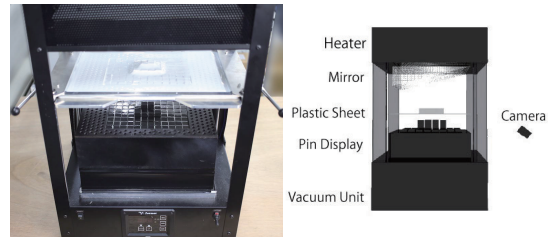


Figure 2: System of ActMold.

Pack Co., Ltd.) capable of controlling the warming temperature and duration for the plastic sheet. In the current implementation, the pin array display uses 96 (12 × 8) linear actuators (L12-1 Micro Linear Actuator, Actonix Motion Devices Inc.). The maximum stroke of each actuator is 30 mm. The size of each pin is 16 mm in width and 18 mm in length (Figure 1b). After the plastic material is heated and soft, it is vacuumed against the pin array display to form its shape (Figure 1c). We developed the software and that controls the pin display's form with Processing.

### 2.3 Attaching Electronic Components

Furthermore, each electronic component is connected to the circuit by neodymium magnets. In a simpler way, the user can attach the components on the plastic sheet using masking tape (Figure 1d, e). We surveyed a relationship between the volume resistivity of the conductive ink and the length of a pin of a shape display. We printed a line (3mm wide) using conductive ink on a plastic sheet; molded it while changing the length of the pin from 5mm to 25 mm.; and calculated the volume resistivity of the top and bottom of shape of the pin. The number of trials was 15 times for each pin. After this examination, as shown in Figure 3, the resistance values were 20.5Ω and 114.3Ω for the 5 mm and 25 mm lengths of the pin, respectively. The line was not disconnected by changing the pin length. The user need design a circuit while considering this alteration of the resistance value.

### 2.4 Remaking the objects

After the plastic material is heated and soft again, the user can remove the components, deform the plastic sheet, and reattach the components with ease. The printed circuit can be erased from the plastic sheet by rubbing the surface with acetone (Figure 1f).

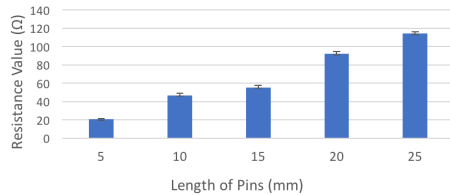


Figure 3: Volume Resistivity of Conductive Ink.

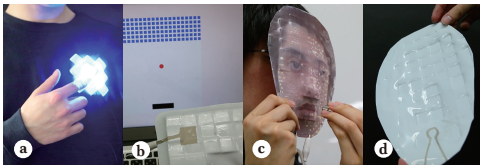


Figure 4: Workshop Examples.

## 3 WORKSHOP EXAMPLES

### 3.1 Illuminating Wearable Badge

By attaching an LED and battery to a plastic sheet, it is possible to create a illuminating badge (Figure 4a). The user designs the circuit

and shape of the badge using the software. The system then prints the circuit on a plastic sheet and molds it from the finished shape data. After molding, the user attaches an LED and battery, confirms the brightness and reflection, and can remold the object.

### 3.2 Talking Mask

The user can draw a coil with conductive ink on the surface and connect it to a 12 V amplifier. When the sheet is laid over a magnet, it generates sound like a speaker (Figure 4b, c). This example is a talking mask which the user can talk with another person's voice.

### 3.3 Game Controller

While prototyping a device, such as a game controller, the system allows the user to rearrange the positions of buttons (Figure 4d). The system prints a circuit of a touch sensor at the position of a button which will be molded. After printing the circuit, the user molds the shape of the button using ActMold and connects the touch sensor and a microcomputer.

### 3.4 Participants Experiences at SIGGRAPH

At SIGGRAPH 2017 Studio, we plan to install a molding space with ActMold and a soldering space so that workshop participants can experience the whole process of creation from molding to circuit making. They can create an original illuminating wearable badge using full color LEDs and take the finished products with them. We estimate that the entire process would take 15 mins (5-10 min for modeling, 1 min for molding, and 5 min to attach the components). Moreover, participants can experience to create the talking mask in long time workshop (approximately 40min). We will prepare plastic sheets which were previously printed with electric circuits using conductive ink. Usually, participants would have to wait several hours to obtain 3D printed objects using a 3D printer. However, using ActMold, participants can create and take out customized objects on demand.

## 4 CONCLUSION

We proposed a fabrication tool called ActMold, which prints objects based on user input using vacuum forming and a dynamic pin array. We have shown several applications of ActMold, such as molding 3D objects with circuit printing technology. In the future, we plan to develop a new method for printing an automatic shape changing object using a heater circuit and a shape memory plastic sheet for application of an augmented human.

## 5 ACKNOWLEDGEMENT

This research is supported by ERATO, JST.

## REFERENCES

- Beyer, D., Gurevich, S., Mueller, S., Chen, H.T., and Baudisch, P., "Platener: Low-fidelity fabrication of 3D objects by substituting 3D print with laser-cut plates," ACM Conference on Human Factors in Computing Systems (CHI '15). ACM, New York, NY, USA, pp. 1799-1806.
- J. Yamaoka, Y. Kakehi, "ProtoMold: An Interactive Vacuum Forming System for Rapid Prototyping", ACM Conference on Human Factors in Computing Systems (CHI '17).