ProtoSpray: Combining 3D Printing and Spraying to Create Interactive Displays with Arbitrary Shapes

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Abstract
ProtoSpray is a new fabrication method that combines 3D printing and spray coating, to create touch-sensitive displays of arbitrary shape. Our approach makes novel use of 3D printed conductive channels to create base electrodes and shape displays. A channelled 3D printed object is then combined with spraying active, electroluminescent, materials to produce illumination. This demonstration involves multiple different devices, created through the ProtoSpray process, showing its free-form applicability to irregular shapes such as a mobius strip and spherical surfaces. Our work provides a platform to empower makers with displays as a fabrication material.

Author Keywords
3D Printing, Spraying, Display, Electroluminescence, Rapid Prototyping, Fabrication

CCS Concepts
• Human-centered computing → Touch screens;

Introduction
ProtoSpray is a new process that we have developed for building irregularly shaped displays using a two-fold process of 3D printing and spraying of Electroluminescent (EL) materials. We build on the work of PrintScreen [3], which creates flat/deformable segmented displays, by introduc-
ing a fabrication process to create non-flat displays with irregular topologies. In previous work Electroluminescent (EL) ink has been deposited using methods such as screen printing [6], spin-coating [1] or bar coating techniques [4]. However, these processes are limited to substrates with flat topologies and can thus produce a limited range of display shapes. We introduce ProtoSpray as a method for creating segmented irregularly-shaped EL displays in a free-form manner.

**ProtoSpray Principles**

The ProtoSpray process involves 3D printing an object made of two materials (conductive and insulating) and then layering the components of an EL display using spray coating onto the object. We introduce spraying of EL materials in HCI as a way of fabricating displays on irregular surfaces. The conductive material is printed in channels through the insulating material that then define the shape of the display cells when the active materials are coated on the object’s surface.

For an EL display to emit light it requires four layers: a conductive bottom electrode, an insulating dielectric layer, an insulating light-emitting layer, and a conductive top electrode. The bottom electrode is often made from a highly conductive metal, such as copper or silver ink. For ProtoSpray the bottom electrode is replaced with conductive PLA that can be 3D printed [5]. The dielectric layer is an electrical insulator, and must spread beyond the electrode layers to prevent short circuits between the top and bottom of the structure. The light-emitting layer is EL phosphor suspended in solvent. The top conductive layer must be transparent as with some polymers or metal oxides. To light up, an alternating current of around 200V operates between the electrodes, across the dielectric layer, energizing the light-emitting layer.

A **cell** is an illuminated area of the display and an **electrode** can refer to either of the conductive layers (top/surface or bottom/base), connected to the power source. If a portion of any of the four layers is missing within a cell, it will not light up. If the conductive materials from separate electrodes come into contact with each other they will create a short circuit and none of the cell will function. It is thus important to have a thin dielectric layer to allow the bottom layer below to energize the light-emitting layer above, but uniform enough to not allow short circuits between the layers [2].

**Traditional masking:** Masks are commonly created via a physical stencil, tape or masking fluid between a material and the substrate. Masking performs two functions: the mask (1) gives a precise shape to the bottom electrode layer, which is used to shape the illuminating cell (though this can also be done by masking the light-emitting layer and/or top electrode); (2) prevents electrical interactions between layers by bounding electrical channels to and from cells. EL displays typically use a mask which shapes the bottom electrode connection sideways out of the display area along the substrate.

**Eliminating masking:** ProtoSpray eliminates masking by 3D printing base electrodes (channels) of conductive PLA, housed within the substrate object and printed simultaneously in a desired shape. By doing so we benefit from the printer resolution to reach similar or better precision than existing masking techniques, without requiring additional masking or sanding of the 3D printed shape. Masking by hand is a time intensive and skill dependent process. Manual masking is not straightforward or easily replicable for objects which are strongly curved. It is also limited in scope with regards to being automated as a process and suffers from issues with scalability.
Using conductive channels rather than ‘on surface’ base electrodes also has a number of advantages to object design. Using 3D printed channels allows digitalisation of the process for defining cell shape, increasing the potential for fully automating this process. Routing a conductive pathway inside the printed object allows the only points on the surface to be the EL cells and the electrode attachment points, without the need for an on-surface conductive trace between the two. As a result, base electrode channels can cross each other in ways they wouldn’t be able to in 2D. Advantages of limited conductive traces on an object’s surface are: (1) a wider range of possible cell placement. This both opens design options and gives a potential for higher resolution of display due to denser cell placement, since space on the object’s surface is no longer required for base electrodes merely for the attachment sites; (2) easier electrode attachment points can be 3D printed in a wider range of potential locations, being less dependent on segment sizes/shape/location; (3) improved spraying, as using the back of the object for channel attachment sites means less use of masking in spraying and so reducing the risk of a short circuit; and (4) reduced error as there is less base electrode area that could create potential contact with top electrode material which would lead to shorts, or with other base electrodes leading to cross-talk between cells. These benefits increase the range of designs and potential for ProtoSpray as a fabrication method, compared to what would otherwise be possible through simply spraying EL materials on pre-existing objects.

**Demonstrators**

Our prototypes demonstrate applications of ProtoSpray, the benefits of using 3D printed channelling as well as range of topologies showing that we can go beyond current techniques.

**Display Demonstrations**

We present three of the objects that the full ProtoSpray paper uses to explore this new method. We start with a classic example of a 7-segment display taking advantage of conductive channelling (Figure 1). The demonstration shows the potential for creation of usable and customisable luminescent widgets through ProtoSpray. The channelling allows for a design without needing to accommodate conductive surface traces or for masking electrode contact points.

We also present a spherical dome surface that uses the benefits of conductive channels to obscure connection points to base electrodes under the object both for the spraying process and usage (Figure 2). The dome additionally demonstrates a curvature in two planes that is impossible to create through deformation of a flat surface such as using a prefabricated EL cell. It also further demonstrates benefits of the channelling in ProtoSpray compared to traditional EL layering methods: central cells are enclosed by the outer cells. Creating such an object through other fabrication processes without the use of conductive channels (such as layering an ink-based base electrode through hydro printing) would require electrodes crossing other outer cells causing short circuits (or complicated bridging requiring multiple additional layers and further risks of failure).

The Mobius strip has 7 segmented EL cells in the shape of arrows that can light up sequentially, providing a visual indication of the movement around the strip (Figure 3). This demonstrator show the benefits of channelling to the spray process as the electrode connection points are obscured from creating short circuits by the bulk of the object, even though they are each at different angles on the strip. It also demonstrates the benefit of spraying EL material as the materials were each applied in one go despite curved EL cells...
with normals in all directions. The channelling provides accuracy of base electrodes, without the need for masking, which is a challenging and highly skill dependent process on such a topologically complex object. Channelling is necessary to reduce the surface area taken up by surface electrodes and to simplify electrode connection points to areas on the Mobius strip that are away from EL cells but still attached. Spraying allowed the coating of each of the layers required for EL cells in a single pass, despite the complicated base object topology, and having EL cells in 7 planes dependent on their position on the Mobius strip. Additionally, material that was too thinly applied to ensure a working prototype could be corrected by adding more material in real time, with no distortion.

**Conclusion**
ProtoSpray is a novel fabrication method for creating arbitrary shaped objects with EL displays embedded into them. We have introduced spraying as a method for layering thin EL displays onto irregular surfaces as well as the use of conductive channelling for producing objects with EL display elements. We have combined these through 3D printing with insulating and conductive PLA and then spraying on surfaces to create interactive custom displays. These combined fabrication tools allow the creation of custom displays using EL materials with irregular topologies which goes beyond that of previous work. We hope our work can be an inspiration for the HCI community, which has been thriving in recent years in producing examples of interactive devices that go beyond rectangular shapes. Our technique can be used to create a large range of new interactive devices with exotic form factors and has potential applications in many domains such as handhelds and interactive controllers, signage, ambient displays, and many other areas that could benefit from democratised fabrication of displays directly embedded onto 3D printed objects.

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