Crafting Colorful Objects: a DIY Method for Adding Surface Detail to 3D Prints

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Abstract
Low-cost 3D printing methods have revolutionized DIY fabrication, and it is only a matter of time before high-fidelity color 3D printing technologies reach the average consumer market. In parallel to this trajectory, our paper describes an ultra low-cost, DIY method for augmenting 3D objects with surface detail. We developed a software tool that maps 2D images onto 3D surfaces and an easy workflow for layering the resulting, warped images onto 3D printed artifacts. We assessed our approach in a workshop where local makers created 3D-printed nested dolls overlaid with personally designed images. Our workshop demonstrates the feasibility of our ultra low-cost method for adding rich surface detail to 3D objects, and our ongoing work will streamline this process and support more complex shapes.

Author Keywords
Crafting; DIY; 3D printing

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Over the past decade, low-cost 3D printing methods and tools have revolutionized DIY fabrication, enabling

makers to design 3D objects ranging from creative art pieces to functional tools and hardware enclosures. However, while even the widely available platforms such as the Makerbot produce 3D objects with extreme amount of detail, there are still limitations to creating colored or textured 3D prints. The best commercially available 3D printers use binder-jetting, wherein colored ink is used in the construction of the 3D print [16, 17]. The resulting prints can display vibrant and varied color, but are limited in their depiction of representational images. Instead of being crisp and clear, the resulting images often appear fuzzy and diluted.

This paper presents a new, ultra low-cost method for adding colored and texture detail to 3D objects. We developed a software tool that maps 2D images onto 3D surfaces and an easy workflow for layering the resulting, warped images onto 3D printed artifacts. Using our system, one can design a 3D object and a corresponding 2D rendering of any image to overlay its shape. The distorted 2D image is then printed on paper and adhered to the 3D-printed artifact. We assessed the usability and potential applications of this process in a workshop where participants designed 3D printed nested dolls with custom overlay images and textures. We continue by reviewing related literature in 3D printing and texture mapping, and then describe our system and its assessment in a workshop with makers. We conclude by discussing our system limitations and suggest means to streamline the process and produce a greater variety of 3D printed forms.

Figure 1. Examples of finished models with extra layer of gel medium to give glossy finish. Because of the strong patterns, the cuts between the paper sections are not very noticeable.

Related literature

HCI research has been making the 3D printing process cheaper and faster to allow a wider audience to have access to the technology. For example, recent work has explored many alternative means of 3D printing, such as recycling existing prints to save on material costs, or printing out only a wireframe of the structure [10, 20]. Our goal is to allow users to add rich surface detail to 3D prints without having to print on specialized, more expensive color 3D printers. In addition, our approach will open up the option of replacing color surfaces on 3D prints without having to replace the entire print.

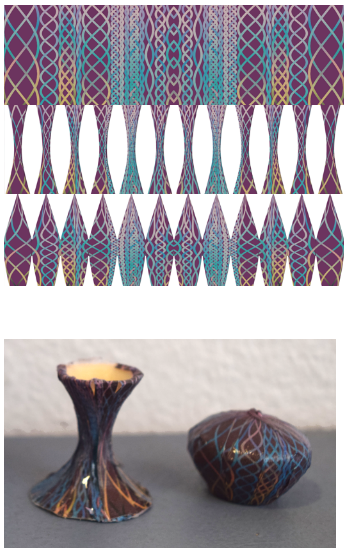

Figure 2. Top: source image. Middle: two different ways the image was warped based on different shapes. Bottom: 3D models covered with paper

Applying Images to 3D prints

While applying detailed color surfaces onto 3D models is relatively direct when working in a digital space, trying to recreate the model through color 3D printing requires costly machinery and results in a limited color range [1, 5]. Attempting to apply surface images onto existing 3D models presents a completely different set of problems, which revolve around accounting for the distortion that is caused by stretching a 2D image over a 3D surface. One way to navigate this dilemma is through the use of hydraulic printing, in which the 3D object is dipped through a colored film that will bind to it [22]. Alternatively, thermoforming can be used to attach colored sheets of plastic to objects [18]. There has also been research into providing color and surface detail to 3D prints through the use of several projectors, which would display the correct images onto the object from several angles [4]. In contrast to these approaches, our process uses standard printer paper and can be constructed with supplies found at a craft store, making it more accessible to the average user.

When determining how an image will be stretched over an object, it is imperative that the geometry of the model is well understood, though that doesn't necessarily mean that it cannot be complex. Through resampling, a 3D mesh can be reduced onto a regular 2D grid, providing an approximation of the form as a flat surface [14]. Research has also been done to generate 3D models and animation as an alternative means to display either 2D or 3D data [3, 9, 19].

System and Fabrication process

We developed a system and workflow to generate colorful 3D-printed objects using low-cost, DY methods. Our process consists of two steps: first, a 2D image is processed by our software to generate a distorted rendering to fit any 3D shape; the rendering is then printed on paper, cut out, and adhered to the 3D-printed surface. We tested this process with geometric, radially symmetrical forms (e.g., orbs) to make sure that both the 3D models and warped 2D images would be printable. In the future, more complex objects could be built by combining several simple shapes.

Generating 3D models

We wanted to allow users to have control over what the 3D model would look like, albeit without having to manage a large number of variables. As a starting point, our software allows users to control the total height of the model, the radius of the top, bottom, and waist of the model, and the height of the circumference relative to the total height of the object (fig. 2). This can result in a wide variety of forms, which could potentially be combined into more complex objects. While this code generates both the 3D model and the warped image overlay, if the user found a pre-existing object that they are able to measure and recreate with the program, the printed image could be applied directly to that object without the need of 3D printing the model.

Figure 3. Example of a preview model that the user can view on the computer before printing and assembling the model.

Figure 4. Top: example of 3 Russian nesting dolls and paper pieces. Bottom: participants using x-acto blade and glue to create finished models.

Morphing Images

We developed a software and graphical interface in Processing 2.0 to convert 2D images into 3D overlays. The program takes as input a 2D image and dimensions and parameters describing the 3D shape. The system then processes 2D images to wrap them around the 3D model by sectioning the picture into segments. In our test pieces, which ranged from 1x1x2 to 4x4x5 inches in size, we found that cutting the image into twelve segments allowed the printed image to be adequately flexible without being too thin or easily torn. For the image to fully cover the object, its dimensions are based on the radius of the widest part of the 3D model and the length of the outer edge of the model (fig. 2). Then, for each of the vertical segments of the image, the width of the segment from the source image is compressed based on the radius of the corresponding part of the model.

Creating 3D Digital Preview

In addition to the 3D object and 2D image files that are created, our system also generates a preview so that the user can see exactly what the finished object will look like without going through the complete fabrication process. The preview version is composed of the 3D model as an .obj file with the colored image included as a digital texture. Any software used to view 3D models will be able to display the preview model (fig. 3).

Assembling Materials

To test the feasibility of our process in DIY contexts, we chose to print the 3D designs using a Makerbot, which is widely available in most makerspaces. The rest of the materials used in the process are commonly available in office or craft stores. We used generic printer paper and an inkjet printer to produce the colored prints of the distorted 2D images. The printed image is cut out and adhered to the 3D printing surface using a method similar to the DIY methods described in *Coconut XOXO* and *A Beautiful Mess* [6, 7]. After testing several adhesives, we used Liquitex gel medium to attach the paper to the 3D shape because it dries clear has thick but spreadable consistency.

Color 3d printing workshop

To assess our workflow, we organized a workshop with local makers in order to gain insights into how this approach would be used by people without extensive experience in programming or 3D modeling. The workshop invited attendees to create a set of 3D-printed Russian nested dolls with custom images of their choice.

Workshop Setup

We recruited 6 participants (ages 20's-30's; 3 female, 3 male). All had some experience using image-editing software, but only one had experience with computer programming, and two participated in a paper crafting activity in the recent past. A week prior to the workshop, participants were asked to design images they would be applying to a set of three Russian nesting dolls. Since the 3D printing process would take too long for the span of the workshop, the 3D printed models used by the workshop participants were printed ahead of time. Participants were compensated US$10 to bring image files to overlay on the 3D prints and an additional US$10 for every hour that they were present to participate in the study (about 2 hours).

Figure 5. When paper strips are applied without being pressed gently into place, they may shift during drying, causing the image to be mismatched on the surface.

Figure 6. Paper without extra layer of gel medium covering it. Due to the large area of solid white space, the cuts between the different paper sections are highly visible.

Workshop Activities
Participants were presented with a demonstration of our software, including an example of a flat image and its rendering over a 3D model. Participants then processed their images using our software, and based on the visualization, iterated on their images in Adobe Photoshop in order to arrive at the result they wanted. The images were then printed on an inkjet printer and participants cut out the rendered shapes with scissors or X-acto knives. Participants then applied the gel medium either to the paper or the 3D model itself to adhere the images to the dolls. At the conclusion of the workshop, attendees completed a short survey to gather feedback on their experience and potential future applications.

Findings
All six participants completed a custom set of nested dolls over the course of 1.5-2.5 hours. Based on participants' feedback, the rendered visualization of the image overlaying the 3D shape was particularly valuable. For example, three of the participants specifically wanted their pictures to be edited to allow the image's face to appear on the upper part of the model, similar to how a traditional Russian nesting doll would be structured. Cutting out the printed shapes was the most challenging or "tedious" step of the process. In the completed models, certain types of printed images hid the cuts in the paper better than others. Generally, large areas of a single color, particularly white, clearly revealed where the paper had been cut (fig. 6), while bold and complex patterns mask the location of the paper cuts (fig. 1). All participants also preferred to apply layer of gel medium to the top of the paper, such that the final artifact had a glossy finish (fig. 1, 5) and reduce risk of abrasion or damage (fig. 6).

Potential Applications
Participants suggested many possible uses for this technique, including fine arts, entertainment, and instruction. Because our current software is designed to create radially symmetrical models, multiple attendees suggested vases as a possible product. Others suggested that custom-made figurines or gaming pieces would benefit from this means of adding detailed surface color. One participant suggested that this could be used for biological medical models, which are often composed of curving, organic shapes and need to display colored surface details in order to be readily understood by students. In addition, because the finished pieces can be plastered over with images depicting different designs, this approach allows the users to replace the images on their 3D prints without needing to print new 3D models.

Discussion and Future Work

Limitations and Potential Solutions
Overlaying color, texture, and detailed images onto physical artifacts adds more information to the object through the surface details. Currently, our software generates the 3d objects using only a few parameters, but even with that limitation it is possible to create complex shapes through combining simpler ones. Based on our workshop, our workflow could be improved by automating the paper-cutting step with a laser-cutter.

Color 3D printing will undoubtedly change the way 3D prints are approached as information-rich surfaces rather than simple volumes in the near future. Several

Figure 7. Left: rectangular strips cover the entire model, but overlap and easily agglomerate. Right: curved triangle strips leave some of the model exposed, but easily lay flat.

high-fidelity 3D printing technologies and services are already moving in that direction [e.g., 13, 16] and the next few years will likely see affordable 3D printing systems in the consumer market. Before these developments reach the non-expert user-base, however, our low-cost DIY method can be leveraged to examine the possible applications and opportunities for color 3D printing amongst the maker community. Furthermore, even as color 3D printing becomes more pervasive, our method will continue to offer flexibility and speed as a rapid prototyping technique.

Future opportunities

As noted by our workshop participants, the new level of richness added through surface detail can benefit numerous domains. Potential applications might include educational tools in various medical fields (such as printed anatomical systems), fashion, and personalized tabletop gaming. Within these domains, our low-fidelity method could be used as a rapid prototyping precursor approach to test several designs before generating a higher fidelity, more expensive 3D printed model. Because new paper images can be pasted over any existing images on the model, users also have the option of recycling 3D prints, which would save time and printing material. Moreover, our method is not confined to 3D printed artifacts and can be used to overlay visual information onto any shape at virtually no cost, presenting new and creative opportunities for the maker and crafter communities. Future work can examine trade-offs in the level of detail and amount of information that can be presented in the 3D shapes.

Conclusion

This paper explored an ultra low-cost, DIY method for crafting color 3D artifacts. We developed a system that warps digital images in order to produce prints that can be over-laid onto 3D objects. While the field of color 3D printing is largely focused on automation and is still out of reach for the everyday maker community, we were able to achieve a detailed result by using the Makerbot, inkject printer, and paper. A workshop to assess our approach shows that our workflow can be completed by a non-expert, and allows room for innovation and experimentation both in the conceptual designs and the physical construction. Moving forward, we will expand the capabilities of our software to work with more complex 3D shapes and use our approach to study the exciting possibilities color 3D printing has to offer.

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