Use of 3D Printed Components in the Creation of the Prosthetic Instruments

Ian Hattwick, Joseph Malloch, and Marcelo M. Wanderley *
Input Devices and Music Interaction Lab
Center for Interdisciplinary Research in Music Media and Technology
McGill University, Montreal, Quebec

July 23, 2013

Abstract

This article outlines the major uses of 3D printed components in the *prosthetic instruments*. A family of digital musical instruments, the prosthetic instruments were created with the intention that they would be worn by dancers as prosthetic devices in an interactive dance performance.

3D printing technology played a key role in the prototyping and manufacturing of the prosthetic instruments. In 2012, the Center for Interdisciplinary Research in Music Media and Technology (CIRMMT) acquired a Dimension uPrint 3D printer; almost immediately, it become a vital tool for our research. The use of ABS plastic for 3D printing allowed us to print key structural components, but the uPrint is so easy to use it quickly became our go-to tool for all sorts of custom fabricated parts.

This paper discusses the use of 3D printed parts during the design and fabrication of digital musical instruments used in an interactive dance performance. These instruments grew out of earlier collaborative work, and were intended specifically to function as prosthetic devices worn by dancers. Three specific instruments were designed, they include articulated spines, curved visors, and rib cages crafted using 3D printing and laser cutting.

When considering the use of 3D printed parts in the design of the prosthetic instruments, our most important consideration was durability. The instruments we were designing were not just prototypes, but would be used intensively for several months of rehearsals as well as during performances in Quebec and in Europe. We

*ian.hattwick@mail.mcgill.ca, joseph.malloch@mail.mcgill.ca, marcelo.wanderley@mcgill.ca

Figure 1: The Ribs. Performers: Sophie Breton and Marjolaine Lambert, Photo: Michael Slobodian

Figure 2: The Spine. Dancer: Sophie Breton, Photo: Michael Slobodian

needed to be confident that there would not be any mechanical failures during this time. While researching 3D printers, we learned that ABS plastic has the best reputation for durability, and that the Dimension uPrint uses practically the same ABS materials as its more expensive cousins. During the time we've spent using the uPrint, we have found that as long as parts are designed intelligently for their purpose, we can rely on them to perform as key structural components.

Clips and Mounts

Our first use of 3D printed parts were in the construction of clips and mounts for mounting the prosthetic instruments to the dancers' costumes. We had hoped to be able to find pre-manufactured clips for this purpose, but were unable to source any

Figure 3: The Visor. Dancer: Sophie Breton, Photo: Michael Slobodian

Figure 4: Three clips designed with varying parameters.

that fit our specifications. The ability to quickly iterate through different clip and mount designs proved to be extremely important, as nearly all of their parameters were changed multiple times through the course of designing the instruments.

We learned several lessons while designing and using these parts. The bond between layers of printed material is mostly very reliable; however, when this bond becomes a key component of a structure which is placed under stress, it is important for the layers to have enough surface area. In our case, we designed mounts with rectangular openings through which an acrylic mounting bar would be secured. In the case of the Ribs, the entire weight of the instrument is cantilevered and supported by the 3D printed mount. In the final designs, the walls of the mount were only 1/8"x1". During the final rehearsals and performances, we experienced no failures of the mounts.

We did experience mount failures in earlier rehearsals. The mounts used in those rehearsals had walls which were only 1/16"x1". The failures we experienced took the form of the top of the mount coming unsecured from the walls. While we took the precaution of thickening the walls for the final design, we suspect that the real cause of these problems were from mounts whose printing was interrupted

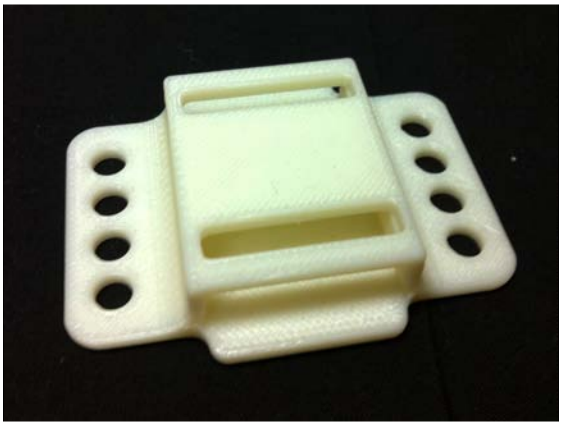

Figure 5: One of the Rib mounts. The holes on the side of the mount are for sewing the mount onto the dancers' corsets.

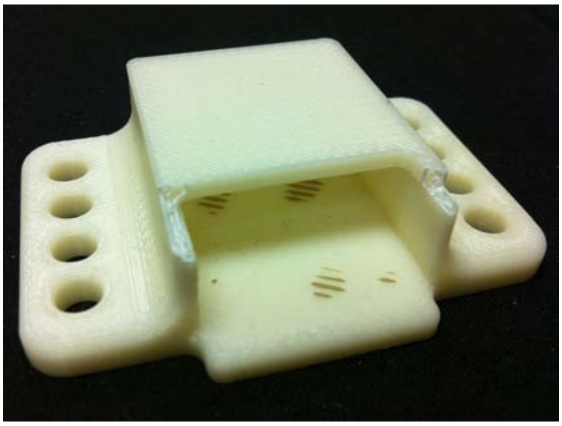

Figure 6: A mount where the top has come unsecured from the sides.

by the uPrint running out of material mid-print. The time it took to replace the material in the uPrint was enough for the bottom layer to cool enough that the bond between it and the succeeding layer was compromised. When we did experience these failures, we found that using epoxy to re-bond the parts was very successful.

Wedges

One observation during rehearsals was that the longer ribs tended to sag because of their weight and because of their position mounted at the bottom of the dancers torso. The dancers backs were naturally concave, with the position of the lowest mounts on the bottom of this curve such that it allowed the tip of the long Ribs

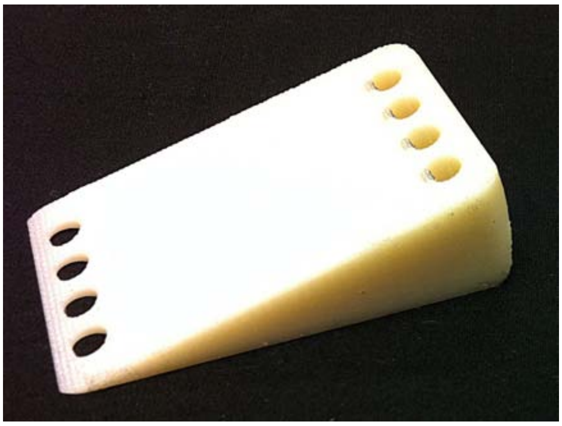

Figure 7: A wedge for underneath the Rib mounts. Notice the holes correspond to the holes in the mounts, allowing the mount and wedge to be sewn together to the corset.

to point closer to the ground. In order to resolve this issue, we designed wedges of different thicknesses to fit underneath the mounts to alter their vertical orientation. At first, wedges were created for both the top and bottom Ribs, bringing the tip of the top Rib down and the tip of the bottom Rib up. However, the wedges on the top Ribs brought their tip too far down, and we decided they weren't necessary. On the other hand, the wedges for the bottom ribs made a tremendous difference to their orientation, allowing their vertical orientation to go from mostly perfectly perpendicular to the floor when the dancers arched their back forward to an extreme downward angle when the dancers arched their backs backward.

Spine Rod Mount

The articulated Spine we designed uses triangular vertebrae supported by a flexible PET-G rod and two PVC tubes. The PET-G rod provides structural support for the entire shape. One problem we ran into was mounting the PET-G rod in the penultimate vertebrae near the head. During articulation of the Spine, its entire weight pulls on the rod at this point. Most of the components of the Spine are interference-fit, where holes laser-cut into the acrylic vertebrae are slightly smaller than the outer diameter of the PVC tubes and the PET-G rod is slightly bigger than the inner diameter of the PVC tubes. However, at the top of the Spine, interference-fit was sufficient to counteract the forces pulling on the rod. In addition, the PET-G rods would occasionally break if bent too far. In order to facilitate changing rods when this happened, we didn't want to use epoxy to permanently secure the rod.

Our solution to this was to design a mounting collar whose outer diameter fit

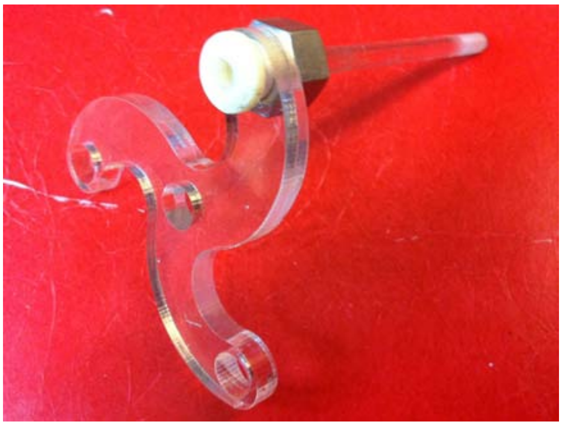

Figure 8: The collar for the Spine's PET-G rod.

Figure 9: Threading one of the Spine's collars.

the hole designed for the PVC pipe, and whose inner diameter fit the PET-G rod. The outside of the collar was threaded with a #3/8-16 die in order to secure it to the vertebrae with a machine nut. The inside of the collar was tapped with a #10-24 tap, and the rod was threaded with a #12-24 die. This allowed the rod to thread into the collar with a close friction fit. We were very happy with the ability of the printed collars to accommodate being tapped and threaded by hand! On the tour, we had a failure of a PET-G rod, and were able to swap a new one in for the next performance with no problem.

Problem-solving with 3D printed parts

In addition to using the uPrint for fabricating structural components, we also found ourselves using it anytime we had a need for a part with a specific shape.

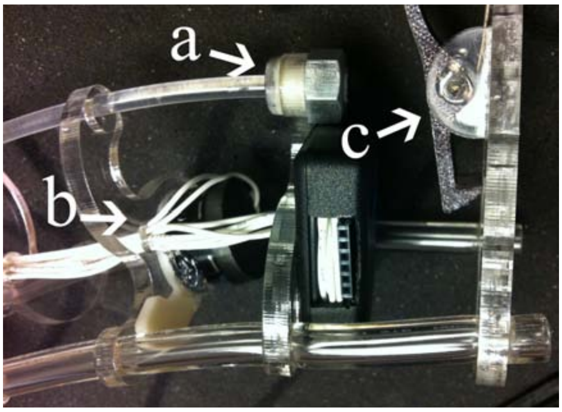

Figure 10: The top of the spine, showing the locations of: a) the PET-G collar, b) the lighting with its printed mounting collar and top, and c) the clip.

We printed small domes to surround the power buttons, preventing the dancers from turning the instruments off accidentally. We re-purposed LED flashlights for lighting in the Spine; in order to mount the flashlights to the vertebrae, we printed a small mounting collar with an opening for the flashlight. This mounting collar was solvent-welded to the acrylic vertebrae using Weld-On 3. In our tests, this solvent weld seemed just as strong as welding two acrylic parts together. We also printed caps for the top of the flashlight, both protecting and hiding the led driver PCB.

Mass Fabrication and Coloring of the 3D Printed Parts

Towards of the end of the instrument development, we asked for a quote from an external manufacturer for the fabrication of the 24 clips and mounts we would use in the final instruments. We were interested in outsourcing the parts both because of the time it would take to manufacture all of the parts ourselves and also because we wanted the parts to be printed out of black ABS. Ultimately, however, we decided to fabricate all of the parts using our own uPrint.

The reason we decided to fabricate everything ourselves was largely just because the uPrint is so easy to work with. While it did take around two weeks of nearly constant printing to fabricate all of the parts, it required very little work on our part. We were very lucky that the CIRMMT staff also helped with this.

In addition, the ABS takes coloring very well. We colored the parts black in two ways. We painted some of the parts black using primer-less automotive spray paint. For most of the parts, though, the costume designer chose to color them using black sharpies. Her rationale for this was that it was easy to color the parts this way after they have already been attached to the costumes; and in addition, if

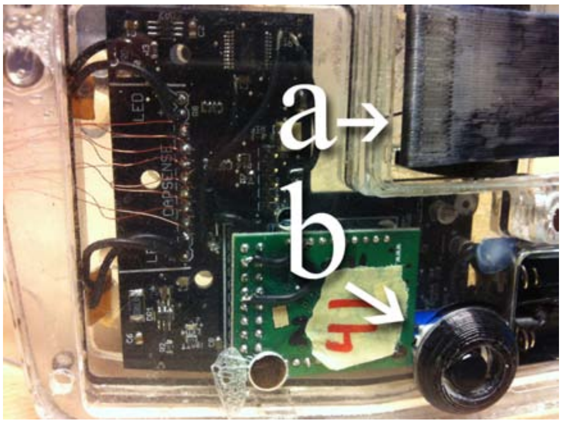

Figure 11: The electronics enclosure of a Rib, showing the location of a) the clip and b) the dome surrounding the power button. The clip was colored via Sharpie, the dome with spray paint.

there was any loss of color during the tour it would be easy to touch up. However, we never needed to do any touch-up- all of the parts held their color throughout the rehearsal and touring.

Acknowledgements

This research was supported by the Programme dappui la recherche-création from the Fonds de recherche sur la société et la culture (FQRSC) of the Quebec government, by the Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT), and the Natural Sciences and Engineering Research Council of Canada (NSERC). We would also like to thank the CIRMMT staff Harold Kilianski, Julien Boissinot, Jacqueline Bednar, and especially Yves Méthot, for their help.