3D-Printed Prosthetics for the Developing World

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(a) (b) (c) (d) (e)

Figure 1: *(a) A post-processed scan of a residual limb, and prosthetic socket designed in SocketMixer, (b) a 3D-print of the socket, (c) attaching the standardized post-and-foot assembly, (d) Rosaline wearing her 3D-printed socket, and (e) our mechanical testing apparatus.*

The Problem

The growing availability of 3D printing has made it possible for end-users to manufacture prosthetic devices tailored to their individual needs. For example, *Project e-Nable* (`www.enablingthefuture.org`) provides parametric 3D-printable prosthetic hand designs. However, the e-Nable hand is an assembly of standardized parts, customized via rigid-body transformations. For cases of trans-tibial and trans-femoral leg amputation, the required prosthetic must blend mechanical parts with a socket that conforms to the shape of the residual limb. The socket design also plays a critical role in minimizing pain by distributing the significant mechanical stresses to appropriate anatomical locations. As a result, design customization is much more challenging.

Despite the many advances in CAD technology, production of prosthetic legs remains primarily a manual process, even in the developed world. The standard approach begins with a plaster cast of the residual limb. A skilled prosthetist then performs a *recfication* process on the plaster positive, adding and removing material to make the socket comfortable to wear. This rectification stage is more art than science. Fabrication of the socket takes many forms, the most advanced involving complex carbon-fiber layups. In the developing world, however, rigid vacuum-formed polypropylene sockets are common. The result does not differ significantly from what can be achieved with widely-available consumer-grade fused-filament 3D printers. Hence, we have developd *SocketMixer*, a novel system for designing custom-fit trans-tibial prosthetic sockets which can be fabricated via 3D-printing.

We begin with a 3D scan acquired via low-end structured-light hardware. After postprocessing, the scan provides a sufficiently accurate representation of the residual limb for the prosthetist to perform a virtual rectification in SocketMixer. We experimented with many rectification interfaces, but found a mix of 3D sculpting and variational mesh deformation [Botsch and Sorkine 2008] to be the most accessible to CAD novices. Once the rectification is complete, we use a novel surface-offset computation based on dynamic mesh evolution to create the inner and outer walls of the socket. Finally, mesh composition combined with variational fairing is used to integrate solid CAD parts into the base of the socket, to allow for connection to standardized post-and-foot assemblies.

Initial mechanical testing showed that with suitable printing parameters, a 3D-printed socket withstood twice the estimated jumping load for an 18-year-old (4.5kN in 0.4s). Based on this and other positive testing results, we travelled to Uganda to validate our system in real-world conditions. We focused on the developing world because rigid plastic sockets produced via 3D-printing are comparable to what was already in widespread use. In addition, with our 3D-scan/edit/print workflow, the time to produce a prosthetic can be reduced from one week to one day. This speed-up is far more significant than any technical advance or cost saving, as availability of skilled prosthetists is the main constraint, and children frequently need new sockets as they grow.

In Uganda we trained prosthetists with no prior CAD expertise to use the system, and successfully created functioning prosthetics for a young woman and a 4-year-old girl. Informal feedback suggests that our 3D-printed sockets may be more comfortable, and may ultimately be cheaper to produce. We are now exploring 3D-printed replacements to the standard post-and-foot assembly, which are relatively expensive for the actual material involved. Our SocketMixer system - a Python extension to Autodesk Meshmixer - is freely available under an open-source license at `https://github.com/SemaphoreTO/socketmixer`.

References

BOTSCH, M., AND SORKINE, O. 2008. On linear variational surface deformation methods. *IEEE Trans. Vis. Comp. Graph.14*, 1.