Executive Summary

My work is highly interdisciplinary, exploring the intersection between the fields of robotics, biomedical engineering, and manufacturing. I have worked to upgrade a specialized 3D printer to enable the fabrication of multi-material structures necessary for tissue scaffolds and microfluidics, and have worked to create a pulse oximeter specifically targeted to developing regions. I plan to continue both of these projects, and aim to further pursue interdisciplinary research and design as a graduate student and professional.

Multi-Material Micro-Stereolithography

Goal

Design and build a system that will allow a presently existing mask projection micro-stereolithography machine to fabricate parts using two or more materials

Background and Significance

Micro-stereolithography (µSLA) is a promising technique for producing ordered, customizable structures with micron-scale features. Few additive manufacturing techniques are able to produce multi-material structures; the few that can lack the resolution to fabricate structures with micron-sized features. Achievable feature size and resolution in µSLA, however, far outperform those of other techniques. Moreover, the technique affords the possibility of material change-out during part fabrication.

The realization of multi-material µSLA would thus be hugely impactful for such fields as tissue scaffolds and microfluidics, which require complex structures produced at currently unachievable scale. Tissue scaffolds, for example, would benefit tremendously from the selective placement of materials whose properties would selectively guide the attachment and growth of varying cell types.

Current Work

The current machine has overhead optics projecting UV light onto a single vat of material below. The basic principle of my design involves replacing this single vat with a motorized carousel that rotates to place the required material vat in line with the build stage and cleans the part between materials.

The greatest challenge so far has been ensuring proper layer height. Multi-material prints complicate this process by adding and removing material from vats. Further exacerbating the problem is the formation of a meniscus within the material whose height dwarfs the layers' by orders of magnitude. I have come up with a novel solution to this problem. After using a digital microscope to evaluate an earlier idea for leveling, I realized that I could see the height of the liquid quite well, and that computer vision could be applied to regulate layer height. I have been speaking with Dr. Devi Parikh, a Virginia Tech professor specializing in computer vision, to determine the best way to implement this solution, and plan to use Matlab to take imagery from a digital microscope, analyze it, and then use precise syringe pumps to submerge the part at the precise depth needed to produce the specified layer height. I am currently assembling the system and writing the control code.

Tempo, a Pulse Oximeter for Resource-Limited Settings

Goal

Design a pulse oximeter to address the unique challenges of cost, infrastructure, and sanitation present in developing nations.

Background and Significance

Essential for monitoring pulse and oxygen saturation levels during surgical procedures, pulse oximeters are universal in developed nations' operating rooms. Worldwide, however, more than 77,000 operating rooms lack pulse oximeters, and 31.5 million operations are conducted annually without these devices [1]. This is largely responsible for patients in developing regions experiencing mortality rates 100-1000 times those in developed nations, and the World Health Organization has declared closing this "pulse oximetry gap" a global health priority [1,2]. Existing devices moreover fail to address the unique constraints of resource-limited settings that contribute to this gap [3]:

- **Cost:** Hospital-grade oximeters are far too expensive for developing nation healthcare providers to purchase, and moreover do not consider the total lifetime costs of their devices incurred by repair and replacement [4].
- **Infrastructure:** Much of the developing world lacks the consistently available power demanded by current devices, and lack effective waste management systems for disposing of environmentally-hazardous disposable batteries [5].
- **Sanitation:** Current models are typically sanitized with chemical wipes or rubbing alcohol, which is often done improperly by medical staff, leaving residual pathogens [6]. Boiling the devices in water presents an alternative, more convenient method for healthcare providers in developing nations, but would damage existing devices [3].

Accomplishments

My biomedical design team and I thus designed a new, thermoelectric pulse oximeter to address these issues. The device dramatically reduces lifetime costs by using solar cells to recharge onboard lithium-ion batteries, eliminating the need for disposables. In addition to reducing healthcare providers' financial burdens, this also reduces the device's environmental impact and allows it to function independently of a robust power grid. Moreover, the design integrates circuitry that prevents the batteries from discharging below a critical operational level, allowing for safe usage of the device. To improve sanitation, we designed all surfaces contacting the patient to be detachable. These pieces can then be placed in boiling water or treated with chemical disinfectants and wipes. This not only improves sanitation, but also protects the device's electronic components [9].

Along with my contributions to the rest of the project, I was personally responsible for the vast majority of the mechanical design. I originated the idea of the detachable elements, and I CADed and prototyped the entire system. Documentation of these models and prototypes are posted below. This documentation shows the original embodiment of our idea, which included thermoelectric generators in place of solar cells. Known as Peltier modules, these components generate power from the temperature differential between the body and the surrounding environment, and I was able to maximize this differential by devising a system of removable conductive plates that contacted the patient's skin and a heat sink that dissipated heat from the Peltier module. Though the thermoelectric generators were eventually replaced with the more powerful solar cells in the current iteration of the design, the removable elements stayed on as a useful feature.

Future Work

The team and I are currently working to integrate the device's circuitry onto a single printed circuit board, refine the user interface, and finalize its mechanical design and ergonomics. We also plan to take this project beyond academic research – we plan to turn it into a marketable product, partnering with governmental and non-profit organizations to distribute it to healthcare providers in the developing world. I am currently optimizing the device's parts for manufacture, and am eager to see our product help bridge the pulse oximeter gap.

References

[1] World Health Organization, "Global Pulse Oximetry Project," 2008. [Online]. Available: http://www.who.int/patientsafety/events/08/1st_pulse_oximetry_meeting_background_doc.pdf. [Accessed: 27- Feb- 2016].

[2] LM Funk, "Global operating theatre distribution and pulse oximetry supply: an estimation from reported data. - PubMed - NCBI", *Ncbi.nlm.nih.gov*, 2016. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/20598365. [Accessed: 27- Feb- 2016].

[3] A. Cohen *et al* (2016). "Problem Statement and Solution," unpublished.

[4] Hopkinsmedicalproducts.com, "Pulse Oximeters | Hopkins Medical Product", 2016. [Online]. Available: http://www.hopkinsmedicalproducts.com/category.jsp?path=-1&id=5662. [Accessed: 01-Mar- 2016].

[5] The Economist, "Power to the people", 2010. [Online]. Available: http://www.economist.com/node/16909923. [Accessed: 27- Feb- 2016].

[6] W. MC, "Residual bacterial contamination on reusable pulse oximetry sensors. - PubMed - NCBI", *Ncbi.nlm.nih.gov*, 2016. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/10145923. [Accessed: 27- Feb- 2016].