NextManufacturing
Carnegie Mellon University

Monday, November 6, 2017
12:00-1:00 pm

Scott Hall 6142

3D Printing of Liquid and Soft Materials: Applications from Regenerative Medicine to Wearable Sensing

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ABSTRACT

We demonstrate the additive manufacturing of complex structures using fluid gels - soft hydrogels and various thermoset resins that are otherwise impossible to additively manufacture using alternative approaches. These structures are built by embedding the printed material within a temporary, thermoreversible, and biocompatible support fluid. This process, termed freeform reversible embedding of suspended hydrogels (FRESH), enables additive manufacturing of hydrated materials with an elastic modulus less than 500 kPa such as FDA-approved collagen type I hydrogel. It also allows for fabrication of thermoset and composite resins such as epoxies, acrylates, and siloxanes, many of which have better strength/weight performance characteristics than machined aluminum. FRESH can host a range of polymerization mechanisms depending on the printed material, including ionic crosslinking, enzymes, pH change, heat/light exposure, and time-sensitive gelation approaches. Traditional file formats such as parametric CAD and medical imaging data can be 3D printed at a resolution of 100 µm and at low cost (<$1500) by leveraging open-source hardware and software tools. Prints happen at speeds identical to modern FDM technologies on a variety of consumer-level desktop 3D printers retrofitted with syringe-pump extruders. Prints of medical imaging data include scale models of bones, arteries, adult brain scans, and even an entire human heart imaged using MRI. These highly complex prints recreate 3D internal and external anatomical architectures while simultaneously using gold-standard tissue engineering materials that were, until now, nearly impossible to additively manufacture. Parametric CAD and truss structure prints consisting of epoxies and siloxane rubbers are mechanically robust and provide a path forward for fabrication of high performance composites using industry standard resins such as Sylgard and Epon. Finally, we work to circumvent the limitations of our fluid printing approach – the volume of material printable at given time and the working build volume of the printers used. We show that volumes of ink equivalent to 60 g or 17.5 m of FDM filaments are possible at a given time, and prints can exceed 150 mm in diameter.

BIOGRAPHY

T.J. Hinton completed a bachelor's in Biomedical Engineering at Purdue University. Since 2011, T.J. has worked with Adam Feinberg and invented several novel methods for 3D printing soft or fluid materials, most notably FRESH Printing, which was published in 2015 in Science Advances. After completing his Master's in 2013, he continued developing his bioprinting techniques as a doctoral student and obtained his doctorate in May 2017. He now works with Adam Feinberg as a postdoctoral researcher while also commercializing his and others' expertise in bioprinting through a startup based on the FRESH printing approach.

T.J. spearheaded the 3D Printing Core in Adam Feinberg's lab, setting up and hacking open and closed source thermoplastic 3D Printers to print everything from cyanoacrylate adhesives to beating heart tissues. His Ph.D. revolved around combining bioreactors, bioprinting, and nanofabrication techniques to recapitulate breast cancer outside the body. As a soon-to-be CEO and founder of a startup, he focuses most of his free time on generating raw materials for AM of fluids and researching the AM markets.