### Why 3D Print Liquid Metal?

Soft robotics is dramatically expanding the mechanical and material options in robotics. Soft robots are intrinsically safe for human interaction, computationally simpler, cheaper, and more resilient than rigid robots. However, soft robots are very difficult to build; they require time-consuming and failure-prone molding processes. In order to make these robots a viable alternative, better production methods must be developed: we must be able to 3D print soft robots.



To 3D print soft robots, we must be able to print a flexible electrical conductor that is at least as robust as the material used for the robot. This conductor is eutectic Indium Gallium (eGaln), an alloy of indium and gallium that is liquid at room temperature, and can flow to fill small silicone channels as they stretch.

### What's Been Done Before?

For 3D printing applications, a liquid metal delivery system must be adaptable and highly autonomous.



Researchers have used a pneumatic needle delivery system to extrude beaded strands of liquid metal. However, this beading makes the strands more likely to break when encased in silicone and stretched, and makes high resolution printing difficult. This method is not adaptable enough.

Another delivery method is to use a ballpoint pen-like mechanism to roll the liquid metal onto a surface. Although this method can result in very high resolution prints, it is not adaptable enough. It requires specific substrates with specific coatings, and would not work on a half-cured silicone print.

Perhaps the most common method is hand delivery. It is versatile, but suffers from high failure rates: the manufacture of the strain sensor shown to the left requires complex molds, and only works 3 out of 10 times. Automation is required for a better product.

No technology has yet demonstrated precise, adaptable, and automatic liquid metal extrusion. Now, we present this technology - a novel liquid metal 3D printer.

# A Novel Liquid Metal 3D Printer Walker Gosrich, Osman Dogan Yirmibesoglu, Dr. Yigit Menguc

## **3D Printer Design**

The 3D printer was based on an existing design that uses slotted aluminum extrusions. However, there were a few key changes made:

- More space (the printer measures 26" x 26" x 28"), to allow for • Modularity - the use of many different extruder designs that can be easily interchanged
  - Versatility the addition of multiple extruder heads in the printer at once, allowing the printer to eventually print in silicone, liquid metal, and perhaps even hard plastic support material simultaneously
  - Accessibility the large size makes parts that were hard to access before easily adjustable
- Only one Z-axis motor: this design uses a cantilever in the Z-axis to simplify control and increase accuracy
- Belt adjustability: the tension of the belts can now be adjusted with only two screws - this ensures that properly tensioned belts will allow the highest level of X and Y-axis precision







#### Results

On only the fifth attempt, we were able to demonstrate marked improvements in the precision and quality of extruded liquid metal. Using hand extrusion, the liquid metal was very prone to beading up and creating short circuits between wires. Using the novel 3D printer and syringe extruder, there is only one bead (due to an inconsistency in print bed leveling), and the printed lines show little bridging and demonstrate mechanical accuracy.





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## **Extruder Design**

The syringe extruder (Figure A) uses a simple mechanism: the stepper motor rotates the lead screw, which moves the syringe plunger. This design can achieve 0.01mm resolution, extrude at a variety of speeds, and can reverse extrude, allowing for cleaner printing. Also, because it only uses a stepper motor, it can be easily controlled by using the machine code for a regular plastic extruder.

The co-extruder (Figures B, C) uses four concentric steel tubes of diameters ranging from 0.2mm to 1mm to extrude up to four materials in concentric wires. For example, the front two inlets could be attached to syringe pumps for silicone and liquid metal, respectively. When the pumps are actuated, a wire with a liquid metal core and a silicone casing would be extruded. A wire of this nature would be very adaptable and robust, and could be used in a soft robot as a longer connecting wire.



### After: 3D Printed



#### Conclusions

1. Using liquid metal in printable soft robotics is entirely feasible using existing technologies 2. Syringe extrusion of liquid metal is at least accurate and precise enough to be used as a primary method in soft robotics printing

#### **Future Work**

1. Determine the capabilities of syringe extruded liquid metal printing by measuring minimum distance between discrete lines as affected by:

- Extrusion Speed: the volume per unit time that is extruded from the needle
- Printhead Speed: the velocity at which the X and Y -axes move
- Z-axis separation: the distance between the needle and the surface being printed upon
- 2. Print a soft robot with integrated liquid metal circuitry
- 3. Explore other extrusion methods, such as co-extrusion
- 4. Integrate silicone, liquid metal, and hard plastic (for support material) into a single printer that can independently print a soft robot

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#### Citations

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