A Series of Tubes: Adding Interactivity to 3D Prints with Hollow Chambers and Pipes

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ABSTRACT
Using different types of tubes with different topologies and different meda inside, we can make cool printable interfaces wtih a variety of input and output mechanisms.

Author Keywords
Prototyping; Fabrication; 3D Printing; Electronics

ACM Classification Keywords
H.5.2 [User Interfaces (D.2.2, H.1.2, I.3.6)]: Prototyping.

INTRODUCTION
3D printers on the rise, different kinds of materials, don't want to make knick knacks, personalizable interfaces, cheap components, etc.

RELATED WORK
- [12] - this uses an airspray machine to add conductive paths to surface of 3D prints
- [2] - fabricate latex + acrylic buttons and pressurize with air
- [3] - hold a speaker in your hands, and air pressure changes make it feel like you're holidng a living, squirming thing
- [6] - a basic mouse, but it inflates so you can store it and also use it more reasonably than a flat mouse
- [9] - the Touché with sound paper from last year's UIST
- [5] - a display made up of many balloons that inflate and deflate to change the shape
- [16] - the RepRap people using a syringe of hot solder to squirt flat circuits into flat channels
- [7] - inject liquid metal into really thin tubes in a soft substrate, sense stretching by changing resistance

- [8] - I'm a little unclear on what they did, but they fabbed something with a "3D circuitboard" that has a bypass that goes into 3D. they don't offer a routing algorithm or anything, though.
- [10] - fancy machines that spray conductive film
- [17] - robots that are made of squishy stuff where air pressure changes are sensed. input components designed to react to different manipulations (pushing, squeezing, twisting, etc.)
- [4] - an instructable I followed to make my first batch of conductive paint
- [1] - Jamming User Interfaces
- [11] - similar to injection of liquid metal, above
- [18] - creating silicone bendy things with embedded electronics to sense flexing, stretching, etc., supported by those shapes.
- [22] - PneUIs, creating interfaces with pneumatics
- [21] - InfraStructs, identification of 3d printed objects using Terahertz imaging
- [20] - Printed Optics. doing cool stuff with clear material (touch sensing and display)
- [19] - air vortex generation in free space. air haptics.
- [15] - Midas. routing in 2D to connect up capacitive sensors
- [14] - Sauron. computer vision of mechanical components obviates electronics installation.
- [13] - Touché. It's like Touché with sound, but without sound. SFCS.

Fabrication

Printing Electronics

Fluids For Interaction

Routing

The Design Space

Table 1. Existing systems are written in regular font. What's in *italic* are things that I think we could make. I don't know what else might go in the blank spaces... looking for suggestions! Also, I'm not confident this breakdown is the most clear: for example, the "liquids" category includes the copper paint, which functions as wires ("threadables"), but takes the form of a liquid...

	Gas	Liquid	Particles	Threadables
Visual	PneUIs, Harrison latex thingy, *smoke display*	Splash Controllers, *paint mixer*	*clear thing with popcorn*	*neon sign*
Aural	*resonance*	*bubbling/splashing noises*	*CNC maracas*	
Tactile/Haptic	PneUIs, *haptic textures*	Splash Controllers, *warm/cold liquid*	Jamming UIs, *sparse particle haptic textures*	Otherlab robots
Olfactory/Gustatory	*scents*	*smoothie mixer!*		
Touch Input	Harrison latex thingy	Harrison SFCS, *injectable capacitive sensors*	Jamming UIs	*capacitance on wires*
Pressure Input	Slyper printed doodads	*capacitance, flow meter*		
Other Input	Slyper (twist, bend, flex, etc.), *printed flex sensors*	*use traditional components*		*use traditional components*

A SERIES OF TUBES

Types of Tubes

- open - system to user, both ends open
- return - system to system, both ends open
- semi-closed - system to user, system side open, user side covered (e.g. elastic material)
- fully closed - no openings on system or user side (e.g. air bubbles, resonance chambers)

Topology of Tubes

- splitting - one tube becomes two (e.g., for grounding several components)
- mixing - two tubes become one (e.g., for mixing liquids)
- star - several tubes meet at a point (good for mixing I guess?)
- tree - a.. tree. easy to inject with goo.

Features of Tubes

- emphasize exterior connection points
- emphasize interior design/path of tubes (for display)

Media in Tubes

- Gas (compressible). Air with smells. Air with fog.
- Liquid (incompressible). Clear, colored, conductive, heated, flavored (smoothie!). Fill or coat.
- Particles. Single for games/display. Sparse for haptic feedback. Dense for jamming.
- Threadables. EL wire, conductive wire, fiberoptic cable, muscle wire.

Design, Fabrication, Construction

Two Tools for Design

designing interior paths – take into account bend radius of desired material

designing exterior connection points – focus on either *shape* or *location*

Fabrication Techniques

printing - different strategies with Objet (all print-in-place) and Makerbot (may need to add things like balloons afterwards). Ryan just got flexible material, we should see how stretchy it is...! We could also consider assembleable things that are easier to create using parts that clip together... probably out of scope.

hand tools - post-fabrication modification is possible using hand tools. We can mark the surface to show where conduits are and how deep. I can also use this to test things beforehand.

Inputs

Flexing

Much like [18], we can sense flexing and bending of prints made on the Objet. We can make prints on the Objet and tunnel through them, though, without making crazytastic silicone molds.

Touch

Capacitance (digital). SFCS (possible with mixed resistance things).

Pressure

Pressure (capacitance (ish) or fluid pressure).

Tapping

Tapping (audio/resonance?) carried through particular tubes, like we talked about hard tubes in a soft thing. We use hard tubes in soft things, anyway, for the conductive goo.

Other stuff?
Could be.

Traditional Components
Obviously you can hook up traditional buttons, etc., the same way as always. With copper paint instead of traditional wiring, we can share grounds, and we don't have to solder.

Outputs

Visual
EL wire. Colored liquids. Mechanical motion by pushing light or plugging (like a big ball) stuff with fluid.

Aural
Resonance chambers. Air cavity design for sound/amplification (see passive iPhone speakers). I mean, this is basically just 3D printing instruments, which we know has been done.

Haptic
Compressible and incompressible fluids for actuation. Recreation of PneUIs. Tactile output. Adding particles to add extra feedback.

Olfactory/Gustatory
Different chambers filled with different scented/flavored fluids. We can mix them using pipes and pressure.

Identity

Resonance chambers for identification.

LIMITATIONS

Issues of drying time for fluids in long tubes. Flexible material doesn't work forever. Water in Objet prints discolors them. Can be difficult to get certain materials through certain kinds of tubes. Makerbot tubes must be at particular angles for printing (w/o support). Some tubes are hard to clear on Objet.

CONCLUSION

In conclusion, tubes are cool. You can do lots of things with them. There are different kinds and topologies of tubes. There are different things you can put in them. This is cool for makers and also people with really expensive machines.

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REFERENCES

1. Follmer, S., Leithinger, D., Olwal, A., Cheng, N., and Ishii, H. Jamming user interfaces: Programmable particle stiffness and sensing for malleable and shape-changing devices. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology*, UIST '12, ACM (New York, NY, USA, 2012), 519–528.
2. Harrison, C., and Hudson, S. E. Providing dynamically changeable physical buttons on a visual display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, ACM (New York, NY, USA, 2009), 299–308.
3. Hashimoto, Y., and Kajimoto, H. A novel interface to present emotional tactile sensation to a palm using air pressure. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '08, ACM (New York, NY, USA, 2008), 2703–2708.
4. icecats. Paper electronics: Conductive paints, inks, and more. `http://www.instructables.com/id/Paper-Electronics-Conductive-Paints-Inks-and-Mo`, Accessed January 2014.
5. Iwata, H., Yano, H., and Ono, N. Volflex. In *ACM SIGGRAPH 2005 Emerging Technologies*, SIGGRAPH '05, ACM (New York, NY, USA, 2005).
6. Kim, S., Kim, H., Lee, B., Nam, T.-J., and Lee, W. Inflatable mouse: Volume-adjustable mouse with air-pressure-sensitive input and haptic feedback. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, ACM (New York, NY, USA, 2008), 211–224.
7. Majidi, C., Kramer, R., and Wood, R. J. A non-differential elastomer curvature sensor for softer-than-skin electronics. *Smart Materials and Structures 20* (2011).
8. Navarrete, M., Lopes, A., Acuna, J., Estrada, R., MacDonald, E., Palmer, J., and Wicker, R. Integraded layered manufacturing of a novel wireless motion sensor system with GPS. *Technical Report what kind* (2007).
9. Ono, M., Shizuki, B., and Tanaka, J. Touch & activate: Adding interactivity to existing objects using active acoustic sensing. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, UIST '13, ACM (New York, NY, USA, 2013), 31–40.
10. Optomec. Optomec machines. `http://optomec.com`, Accessed January 2014.
11. Park, Y.-L., Chen, B.-R., and Wood, R. J. Design and fabrication of soft articial skin using embedded microchannels and liquid conductors. *IEEE Sensors Journal 12*, 8 (August 2012), 2711–2718.
12. Sarik, J., Butler, A., Villar, N., Scott, J., and Hodges, S. Combining 3D printing and printable electronics. In *Proc. TEI 2012*, ACM Press (2012), NO IDEA.
13. Sato, M., Poupyrev, I., and Harrison, C. Touch: Enhancing touch interaction on humans, screens, liquids, and everyday objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, ACM (New York, NY, USA, 2012), 483492.
14. Savage, V., Chang, C., and Hartmann, B. Sauron: Embedded single-camera sensing of printed physical user interfaces. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, UIST '13, ACM (New York, NY, USA, 2013), 447456.

15. Savage, V., Zhang, X., and Hartmann, B. Midas: Fabricating custom capacitive touch sensors to prototype interactive objects. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology*, UIST '12, ACM (New York, NY, USA, 2012), 579588.

16. Sells, E. Rapid prototyped electronic circuits (technical report). **http://fennetic.net/irc/reprap_circuits.pdf**, 2004.

17. Slyper, R., and Hodgins, J. Prototyping robot appearance, movement, and interactions using flexible 3D printing and air pressure sensors. *IEEE Xplore* (2012).

18. Slyper, R., Poupyrev, I., and Hodgins, J. Sensing through structure: Designing soft silicone sensors. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '11, ACM (New York, NY, USA, 2011), 213–220.

19. Sodhi, R., Poupyrev, I., Glisson, M., and Israr, A. AIREAL: interactive tactile experiences in free air. *ACM Trans. Graph. 32*, 4 (July 2013), 134:1134:10.

20. Willis, K., Brockmeyer, E., Hudson, S., and Poupyrev, I. Printed optics: 3D printing of embedded optical elements for interactive devices. In *Proceedings of the 25th annual ACM symposium on User interface software and technology*, UIST '12, ACM (New York, NY, USA, 2012), 589598.

21. Willis, K. D. D., and Wilson, A. D. InfraStructs: fabricating information inside physical objects for imaging in the terahertz region. *ACM Trans. Graph. 32*, 4 (July 2013), 138:1138:10.

22. Yao, L., Niiyama, R., Ou, J., Follmer, S., Della Silva, C., and Ishii, H. PneUI: pneumatically actuated soft composite materials for shape changing interfaces. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, UIST '13, ACM (New York, NY, USA, 2013), 1322.

APPENDIX

INJECTION MEASUREMENTS

We injected the copper a distance of 1.16m (according to the spiral length calculator at http://www.giangrandi.ch/soft/spiral/spiral.shtml) in a spiral whose cross-section was a square of area $9mm^2$. I suspect that is about as far as we can go without using a vacuum at the end.

OBJET 260 CONNEX DIGITAL MATERIALS

Softer materials (concentration of $> 65\%$ Tango-series material) do not easily accept the copper paint (it cracks when bent and is easy to wash off). This may preclude flex sensors made of interior copper paint (conductive thread or other materials may be able to be used for some parts of this).

BEND RADIUS MEASUREMENTS

- EL wire diameter 2.3mm: minimum bend radius .35in = 8.89mm
- Water: uh. None?
- Muscle Wire: ?
- Fiber Optic Cable: ?

MATERIAL PROPERTIES

Name	Material	Resistance	Drying Time	Application Notes
CuPro-Cote Coating	Copper	2Ω/inch	O(1 day)	Syringe
Spectra 360 Electrode Gel	Liquid/Electrolytes	125kΩ/inch	O(hours)	Does not conduct dry
Wire Glue	Carbon/Graphite	23.6kΩ/inch	O(minutes)	Syringe, very runny
Bare Conductive Electric Paint	Carbon/Graphite	110Ω/inch	O(days)	Syringe
Homemade Conductive Paint	Carbon/Graphite	120Ω/inch	O(hours)	Too thick for syringe, apply externally with brush
Conductive Thread	Steel	1.8Ω/inch taut 2.5Ω/inch loose	N/A	Difficult to feed through turns
Solder Paste	Lead	2Ω/inch	N/A	Too thick for syringe, must bake to conduct