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

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ABSTRACT
This paper is awesome. Don't hate.

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Prototyping; Fabrication; 3D Printing; Electronics

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

INTRODUCTION
Hooray!

RELATED WORK
This should be thought about soon!

Fabrication

Printing Electronics

Fluids For Interaction

Routing

The Design Space

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)

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. 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

designing exterior connection points

Inputs
Flexing
Much like [**?**], 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).

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.

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 stuff with air.

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.

	Gas	Liquid	Particles	Threadables
Visual	PneUIs, Harrison latex thingy, *smoke display*	Splash Controllers, *paint mixer*	*clear thing with popcorn*	*neon sign*
Aural	*resonance*		*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*

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.

CONCLUSION
In conclusion... beef.

ACKNOWLEDGEMENTS
Yay, money!

REFERENCES

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

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

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