Electronic Supplementary Material (ESI) for Lab on a Chip

Supporting Information

Control of Soft Machines using Actuators Operated by a Braille Display

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Custom Circuit Board-based controller

The braille display receives its commands through a custom circuit board via a universal serial bus (USB). A non-soldered board is shown in Figure S1. Each part is ordered via Olimex (Plovdiv, Bulgaria), Digi-Key (Thief River Falls, MN), or EMCO High Voltage Corporation (Sutter Creek, CA). Its designation upon the circuit board, description, part number and vendor of origin are described in Table S1.

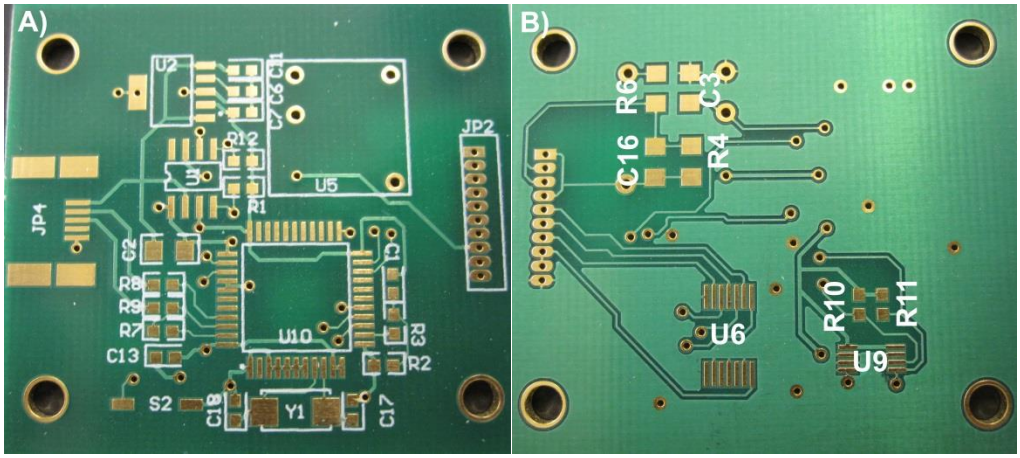


Figure S1. Non-soldered circuit board of custom braille USB controller. Component designations are detailed in Table S1.

Component Designation	Description	Part Number	Vendor of Origin
Circuit Board	Circuit Board	NF290305	Olimex
Y1	Crystal 12MHz 18pF SMD	300-8089-1-ND	DigiKey
U1	Mechanical Switch Debouncer	MAX6817	DigiKey
U2	Low Dropout Voltage Regulator	REG104GA-3.3-ND	DigiKey
U5	200V DC-DC Converter	Q05-2	EMCO
U6	Hex Inverter 14-SSOP	SN74AHCT04DBR	DigiKey
U9	64Kbit 400KHz EEPROM	24LC64-I/MS-ND	DigiKey
U10	USB Driver	428-1306-ND	DigiKey
S2	Tactile Switch	P8086SCT-ND	DigiKey
JP2	10-Pin Header	H3313-ND	DigiKey
JP4	Mini USB - B Connector	H2961CT-ND	DigiKey
C1	Capacitor 1µF 0603 SMD	PCC2224CT-ND	DigiKey
C2 & C3	Capacitor 10µF 1206 SMD	PCC2300CT-ND	DigiKey
C6 & C7	Capacitor 10000pF 0603 SMD	PCC1784CT-ND	DigiKey
C11 & C13	Capacitor 0.1µF 0603 SMD	PCC2277CT-ND	DigiKey
C16	Capacitor 1000pF 0603 SMD	PCC2291CT-ND	DigiKey
C17 & C18	Capacitor 33pF 0603 SMD	PCC330ACVCT-ND	DigiKey
R1, R2, & R12	Resistor 10.0KΩ 0603 SMD	P10.0KHCT-ND	DigiKey
R3	Resistor 100Ω 0603 SMD	P100HCT-ND	DigiKey
R4	Resistor 1.00MΩ 1206 SMD	P1.00MFCT-ND	DigiKey
R6	Resistor 1.00KΩ 1206 SMD	P1.00KFCT-ND	DigiKey
R7	Resistor 1.50KΩ 0603 SMD	P1.50KHCT-ND	DigiKey
R8 & R9	Resistor 22.1Ω 0603 SMD	P22.1HCT-ND	DigiKey
R10 & R11	Resistor 2.21KΩ 0603 SMD	P2.21KHCT-ND	DigiKey

Table S1. Components for Circuit Board. Component designations are references to the unsoldered circuit board in Figure S1.

A Elastomeric Valve with 30µm PDMS membrane

Valve Dimension			Inlet Pressure					
Width (mm)	Height (mm)	Area (mm²)	5 psi	10 psi	15 psi	20 psi	25 psi	30 psi
0.625	0.7	0.69	X	X	X	X	X	X
0.625	0.5	0.49	0.76	0.454	0.693	X	X	X
0.625	0.25	0.25	X	X	X	X	X	X
0.625	0.1	0.10	X	X	X	X	X	X
0.5	0.7	0.55	X	X	X	X	X	X
0.5	0.5	0.39	X	X	X	X	X	X
0.5	0.25	0.20	0.056	0.073	0.429	X	X	X
0.5	0.1	0.08	X	X	X	X	X	X
0.375	0.5	0.29	X	X	X	X	X	X
0.375	0.25	0.15	X	X	X	X	X	X
0.375	0.1	0.06	0.209	0.329	0.269	X	X	X
0.375	0.05	0.03	X	X	X	X	X	X
0.25	0.4	0.16	X	X	X	X	X	X
0.25	0.25	0.10	X	X	X	X	X	X
0.25	0.1	0.04	0.044	0.073	0.101	0.176	0.275	X
0.25	0.05	0.02	X	X	X	X	X	X

Flow Rate (L/min)

B Elastomeric Valve with 30µm Ecoflex:PDMS membrane

Valve Dimension			Inlet Pressure					
Width (mm)	Height (mm)	Area (mm²)	5 psi	10 psi	15 psi	20 psi	25 psi	30 psi
0.625	0.7	0.69	X	X	X	X	X	X
0.625	0.5	0.49	X	X	X	X	X	X
0.625	0.25	0.25	X	X	X	X	X	X
0.625	0.1	0.10	X	X	X	X	X	X
0.5	0.7	0.55	X	X	X	X	X	X
0.5	0.5	0.39	X	X	X	X	X	X
0.5	0.25	0.20	0.24	0.573	1	1	X	X
0.5	0.1	0.08	X	X	X	X	X	X
0.375	0.5	0.29	X	X	X	X	X	X
0.375	0.25	0.15	X	X	X	X	X	X
0.375	0.1	0.06	0.039	0.16	0.433	0.65	0.911	X
0.375	0.05	0.03	X	X	X	X	X	X
0.25	0.4	0.16	X	X	X	X	X	X
0.25	0.25	0.10	X	X	X	X	X	X
0.25	0.1	0.04	0.043	0.102	0.147	0.223	0.288	X
0.25	0.05	0.02	X	X	X	X	X	X

Flow Rate (L/min)

C Elastomeric Valve with 200µm PDMS membrane

Valve Dimension			Inlet Pressure									
Width (mm)	Height (mm)	Area (mm²)	5 psi	10 psi	15 psi	20 psi	25 psi	30 psi	35 psi	40 psi	50 psi	60 psi
0.625	0.7	0.69	X	X	X	X	X	X	X	X	X	X
0.625	0.5	0.49	X	X	X	X	X	X	X	X	X	X
0.625	0.25	0.25	0.66	0.999	X	X	X	X	X	X	X	X
0.625	0.1	0.10	X	X	X	X	X	X	X	X	X	X
0.5	0.7	0.55	X	X	X	X	X	X	X	X	X	X
0.5	0.5	0.39	X	X	X	X	X	X	X	X	X	X
0.5	0.25	0.20	X	X	X	X	X	X	X	X	X	X
0.5	0.1	0.08	0.089	X	X	X	X	X	X	X	X	X
0.375	0.5	0.29	X	X	X	X	X	X	X	X	X	X
0.375	0.25	0.15	X	X	X	X	X	X	X	X	X	X
0.375	0.1	0.06	0.397	0.951	X	X	X	X	X	X	X	X
0.375	0.05	0.03	0.206	0.652	0.999	0.999	0.999	X	X	X	X	X
0.25	0.4	0.16	X	X	X	X	X	X	X	X	X	X
0.25	0.25	0.10	X	X	X	X	X	X	X	X	X	X
0.25	0.1	0.04	0.209	0.306	0.354	X	X	X	X	X	X	X
0.25	0.05	0.02	0.016	0.013	0.042	0.119	0.174	0.247	0.245	0.274	0.256	0.238

Flow Rate (L/min)

Figure S2. Characterization of elastomeric valves. A-C) Measured flow rates for elastomeric valves of varying geometries at different pressures with a A) 30 µm PDMS membrane, B) 30 µm Ecoflex:PDMS membrane, and C) 200 µm PDMS membrane. An "x" denotes unsuccessful closure of the valve.

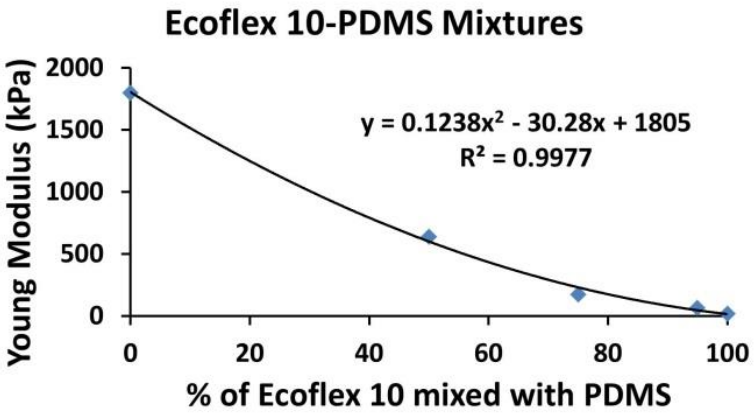


Figure S3. Materials testing of Ecoflex 10: PDMS mixtures. Calculated Young's modulus for different mixtures of Ecoflex 10 and PDMS as determined by stress-strain measurements.

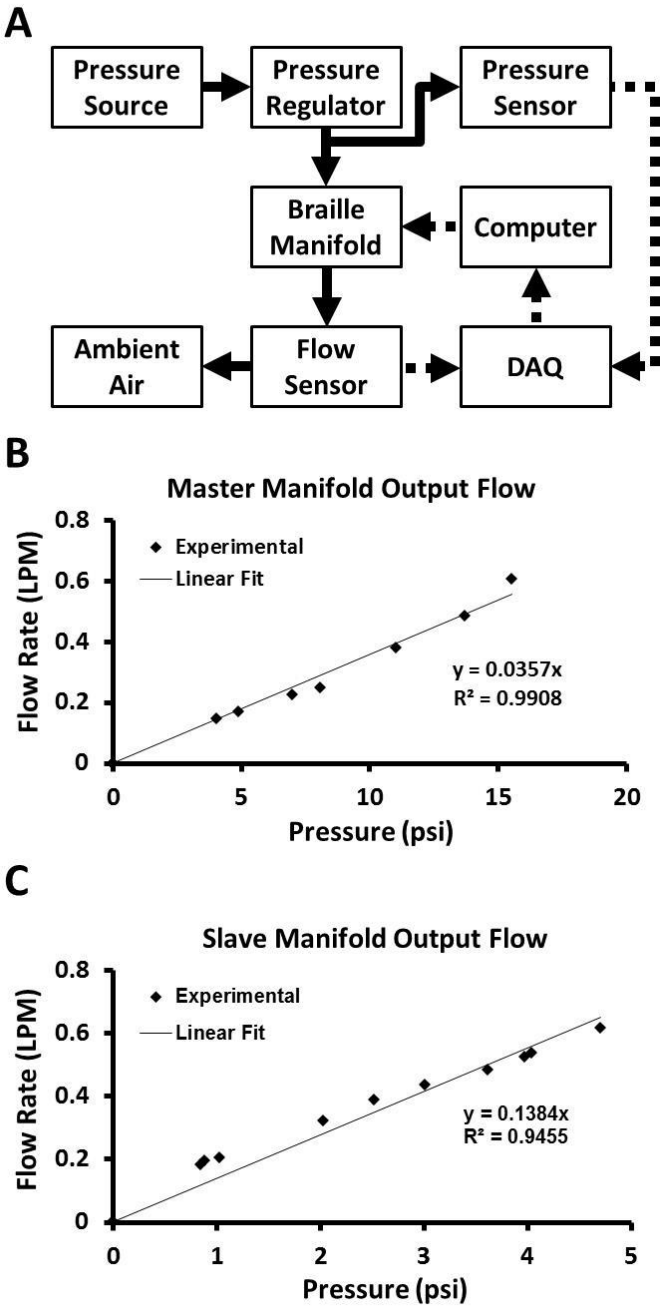
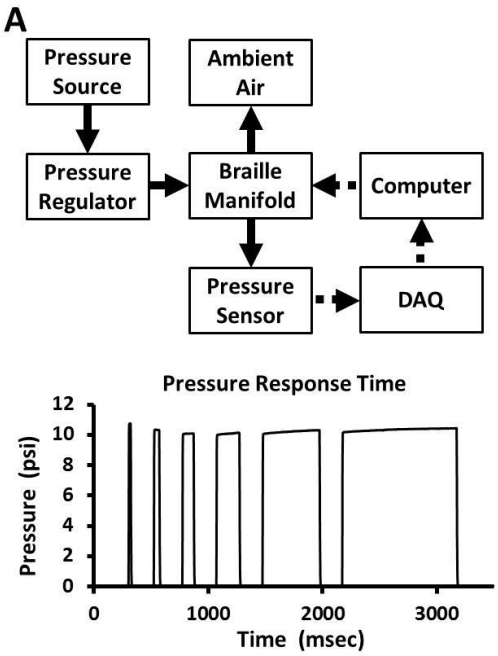


Figure S4. PDMS manifold. A) Schematic of experimental setup for determining fluidic resistance of a single flow path through the braille manifold. B-C) Flow rates of pressurized air for a range of pressures for a master manifold with 32 outputs (B) and a slave manifold with eight outputs (C). The slope of the linear fit provides the inverse of the fluidic resistance.

Figure S5. Manifold characterization. A) Schematic of experimental setup and corresponding data for pressure readings for a singular output activated for durations of 10 ms, 50 ms, 100 ms, 200 ms, 500 ms, and 1000 ms in a 32 output braille manifold. B) Schematic of experimental setup and data showing the performance of braille pins in the holding state. Input pressure manually regulated to test for fluctuations in output pressure (downstream of the elastomeric valve). Sensor 3 and 4 represent properly functioning valves and sensor 2 has a leak.



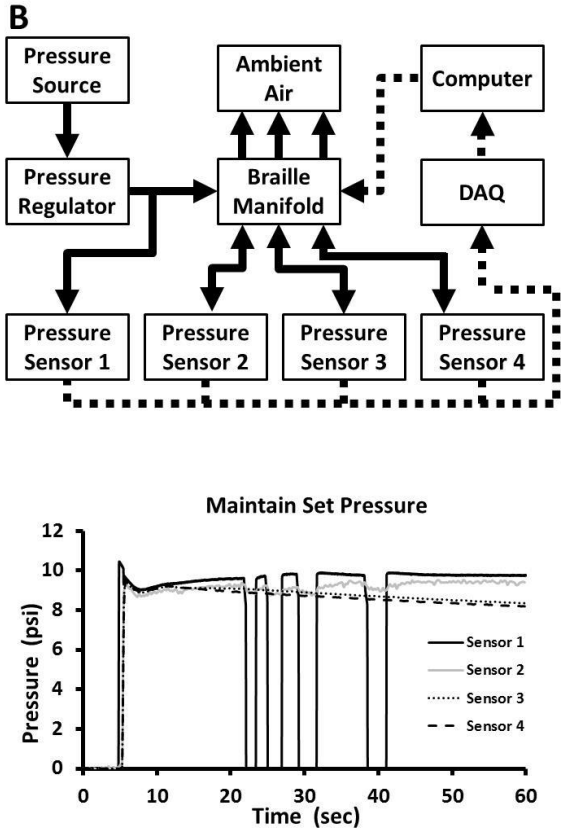


Figure S6. Actuation of array of balloons. A) Image of experimental setup including laptop, braille display, array of balloons, and braille manifold. Scale Bar: 4 cm. B) Close-up image of tubing interfaced with braille display. Scale Bar: 1 cm. C-D) Images of the array of 32 balloons. Scale Bar: 2 cm. The braille manifold independently pressurizes each balloon. Each row is held at a different pressure by inflating for four different durations (blue: 3 sec, yellow: 0 sec, green: 1 sec, red: 0.5 sec).

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