Supporting information for

Actuation of elastomeric microvalves using handheld, battery-powered instrumentation for point-of-care settings

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Description of the electronic test circuit using to power the solenoids. For initial testing of the solenoid actuation system, we used the NI USB-6009 DAQ card (National Instruments Inc) which provides a 5 V supply; 8 analog inputs (14-bit, 48 kS/s); 2 analog outputs (12-bit, 150 S/s); 12 digital I/O; 32-bit counter. The card is compatible with LabVIEW and MATLAB through the NI-DAQmx driver software. For our tests, we used MATLAB scripts. Since the solenoids represent inductive loads, we incorporated protective diodes to prevent the back EMF generated when the solenoid is suddenly turned off from damaging the integrated circuits used (Figure S1). The power rating for the solenoids was 1.15 W (100% continuous duty cycle, 6V supply) – 2.3 W (50% duty cycle 9V supply) equivalent to currents of 190 mA – 285 mA respectively. Switching transistors rated up to 3 A were used for switching the solenoids on and off. As a further precaution, opto-isolators were used to separate the computer control section from the solenoid section (Figure S2 and S3)

Description of electronic test circuit used to measure solenoid current. To measure the current drawn by the solenoid when switched on, we modified the test circuit in Figure S1. A separate regulated DC power supply (MASTECH HY3005D) with a current meter was connected to the circuit such that it provided power only to the solenoid part of the circuit (Figure S2). The solenoid was switched on and off 33 times using the same NI-DAQ card and the current measured by the power supply was recorded.

Characterization of valve response times. To investigate the time response of the valves (using both water and ionic liquid as hydraulic fluid), we used a MATLAB script which controlled the NI USB-6009 DAQ card (Fig. S2 and S3), and included subroutines to capture system time information for the control signals sent from the DAQ card as well as system time information for video frames captured using a QImaging Retiga 2000R 16bit monochrome camera. This setup allowed us to obtain timing information for control signals sent to the solenoid as well as that for the video frames captured, as all timing sources were synchronized to the system clock. The camera was configured such that the frame capture rate was 57 frames/second (~17 ms per frame). We used a Kent Scientific syringe pump operating at 1 μL/min to pump food color dye through the microfluidic channel. Mean pixel intensities were measured using image processing software across a rectangular region of interest occupying the center third of the valve area. We compared the two sets of system time information to determine the response of the valve after the control signal had been sent from the DAQ card.

Figure S1. Circuit diagram of the microcontroller. The figure shows a schematic of the electronic circuit diagram showing the microcontroller and the peripheral electronic components. The design includes electronic components to isolate the microcontroller inputs and outputs from electronic spikes that could be generated by the solenoids. It also incorporates switching transistors that provide the required current for the solenoids since the microcontroller is not capable of providing this current on its own. A voltage regulator provides a fixed (5 V) supply from the supply voltage (9 V) for the microcontroller. The portion of the circuit that controls a small micropump(Hargraves Advanced fluidic Solutions E219 -12) used in the enzyme substrate assay experiments is not shown. We programmed the microcontroller using the Atmel STK 500® starter kit through a serial communication port. We also run electrical continuity tests on signal traces on the manufactured printed circuit board between the various connection points to ensure there were no electrical breaks before soldering the electronic components in place.

Figure S2. Circuit diagram for measuring the response times of microvalves. The schematic shows the circuit diagram that shows connection of the NI USB-6009 DAQ card (National Instruments Inc) which provides a 5 V supply; 8 analog inputs (14-bit, 48 kS/s); 2 analog outputs (12-bit, 150 S/s); 12 digital I/O; 32-bit counter. Switching transistors rated up to 3 A were used for switching the solenoids on and off. As a further precaution, opto-isolators were used to separate the computer control section from the solenoid section. The computer also controlled the camera.

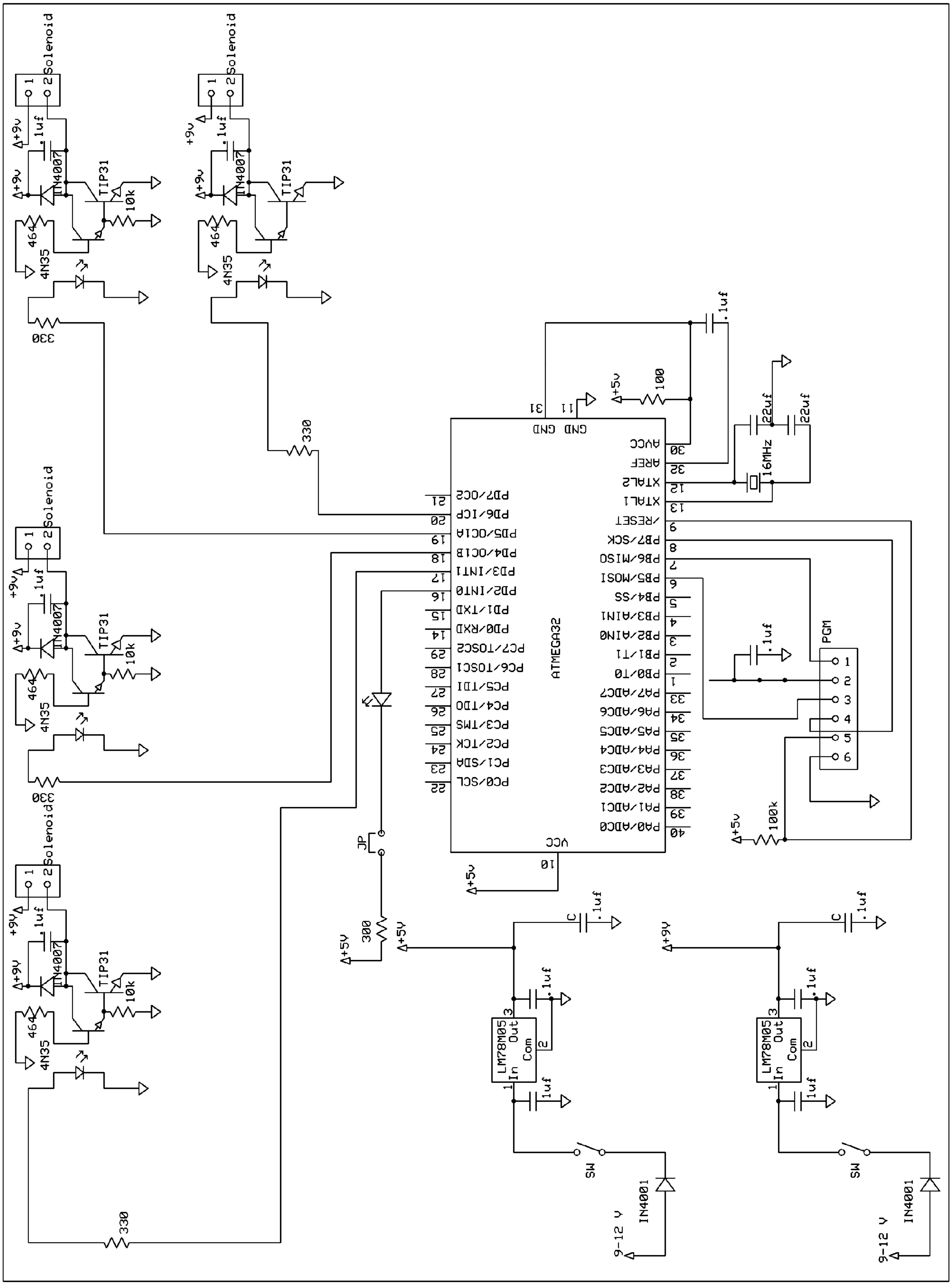
Figure S3. Circuit diagram for measuring the power drawn by solenoids. A separate regulated DC power supply (MASTECH HY3005D) with a current meter was connected to the circuit such that it provided power only to the solenoid part of the circuit. The solenoid was switched on and off 33 times using the same NI-DAQ card and the current measured by the power supply was recorded.

Figure S4. Response time of valves using ionic liquid inside control channels. The time response of valves 100 μm × 100 μm × 12 μm and ~8.6 mm long filled with ionic liquid which is used as the hydraulic fluid. The average time for the valve to close for devices filled with ionic liquid was 127.5 ms

Supplementary Movie 1

A movie of colored dye moving through two parallel channels in a microfluidic chip with the valves actuated in an arbitrary sequence described in Fig 3. The movie was taken with a high speed camera of the region with the valves.

Figure S1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4N35
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GND
AVCC
AREF
XTAL2
XTAL1
/RESET
VCC
PD7/OC2
PD6/ICP
PD5/OC1A
PD4/OC1B
PD3/INT1
PD2/INT0
PD1/TXD
PD0/RXD
PC7/TOSC2
PC6/TOSC1
PC5/TDI
PC4/TDO
PC3/TMS
PC2/TCK
PC1/SDA
PC0/SCL
PB7/SCK
PB6/MISO
PB5/MOSI
PB4/SS
PB3/AIN1
PB2/AIN0
PB1/T1
PB0/T0
PA7/ADC7
PA6/ADC6
PA5/ADC5
PA4/ADC4
PA3/ADC3
PA2/ADC2
PA1/ADC1
PA0/ADC0
+5v
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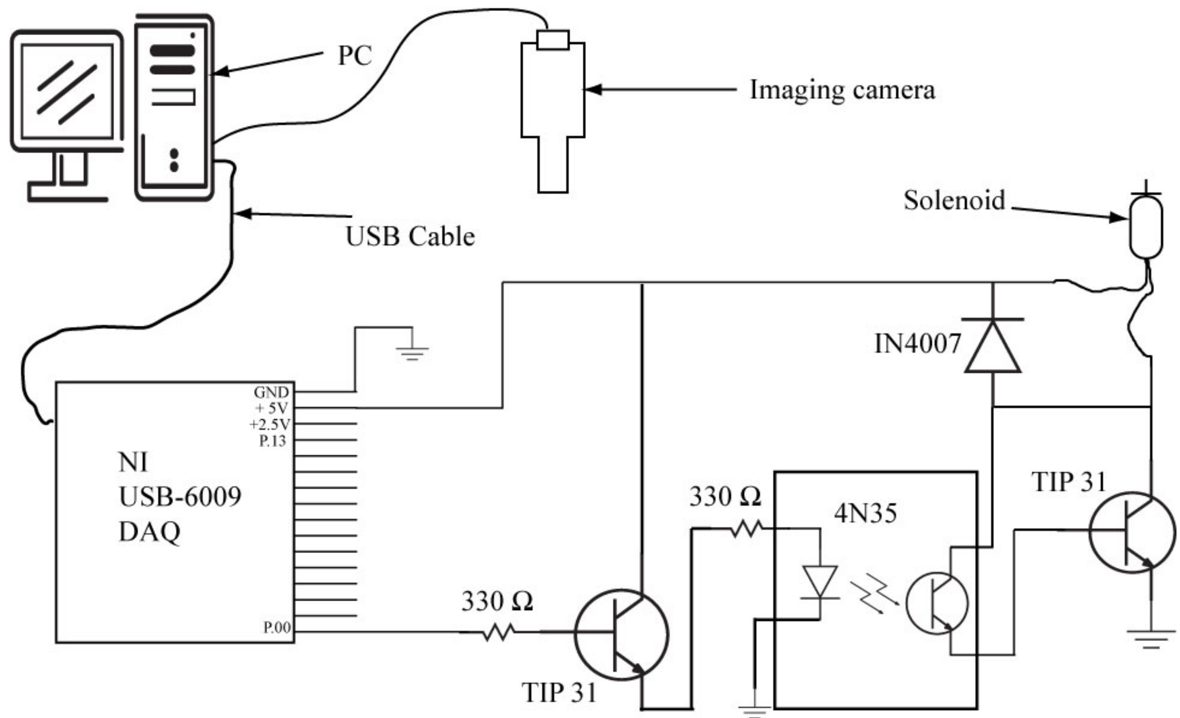
In
Out
Com
SW
IN4001
9-12 V

Figure S2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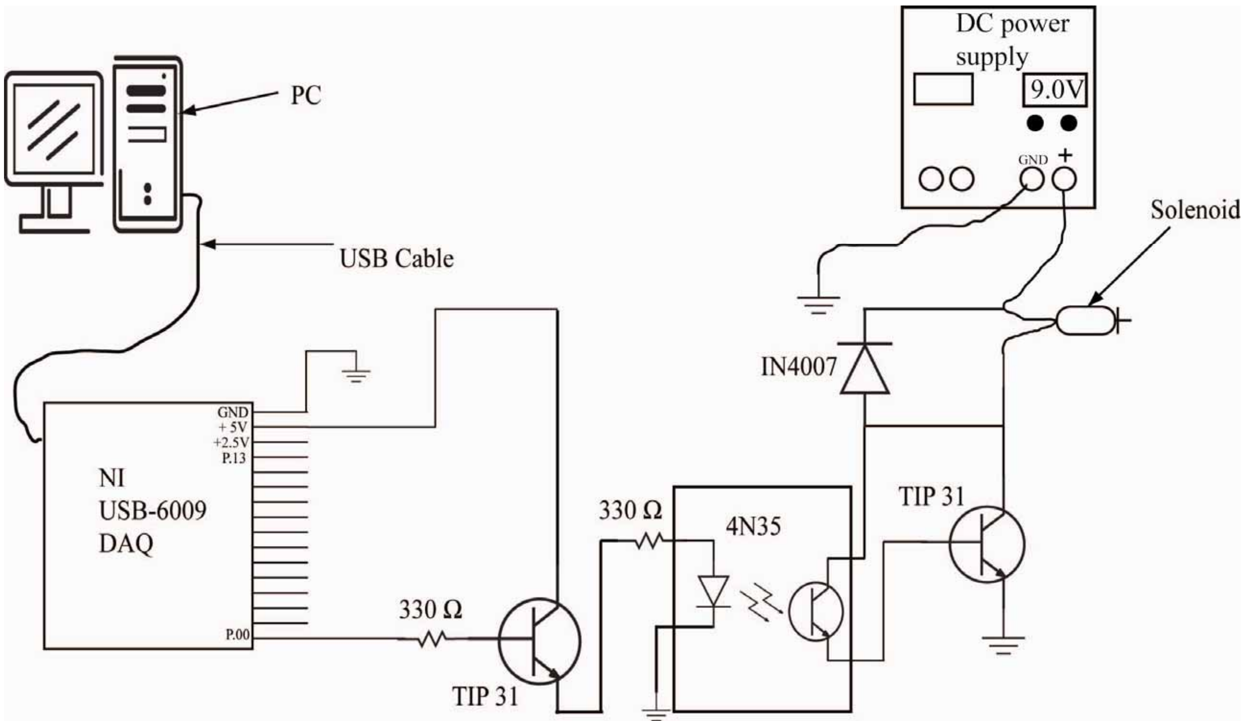
330 Ω
4N35
TIP 31

Figure S3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+
Solenoid
IN4007
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+ 5V
+2.5V
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NI
USB-6009
DAQ
P.00
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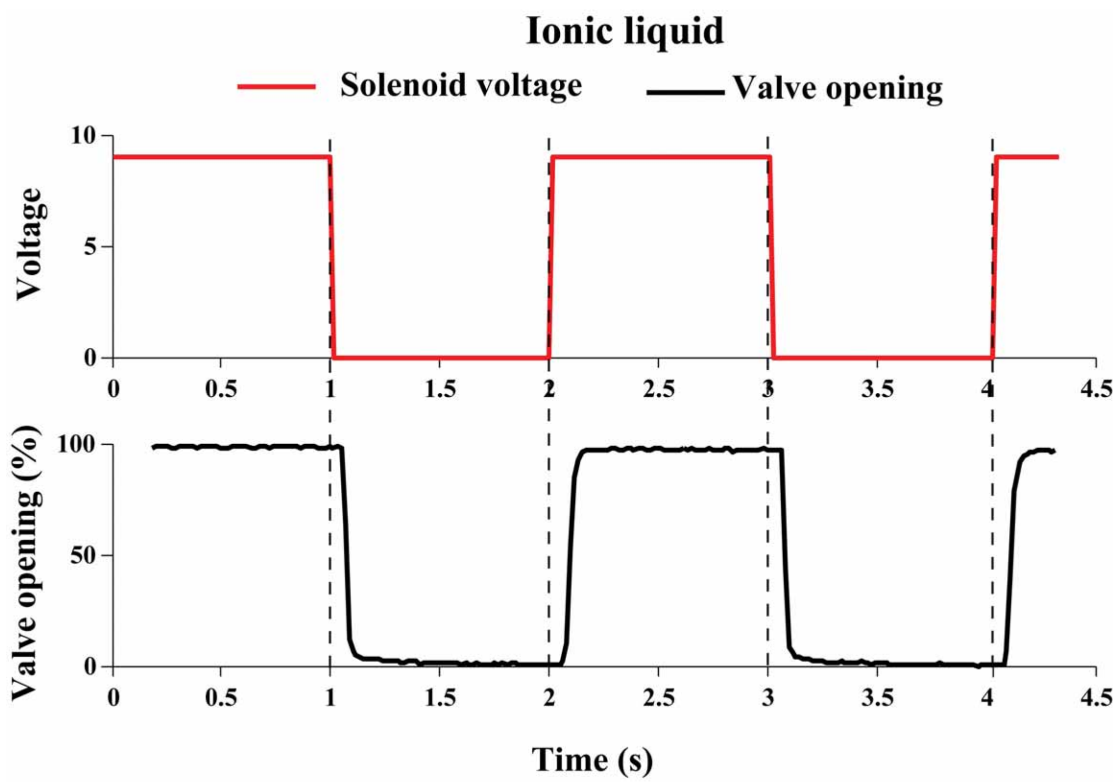
TIP 31
330 Ω
4N35
TIP 31

Figure S4


Ionic liquid
Solenoid voltage
Valve opening
Voltage
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0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Valve opening (%)
100
50
0
Time (s)