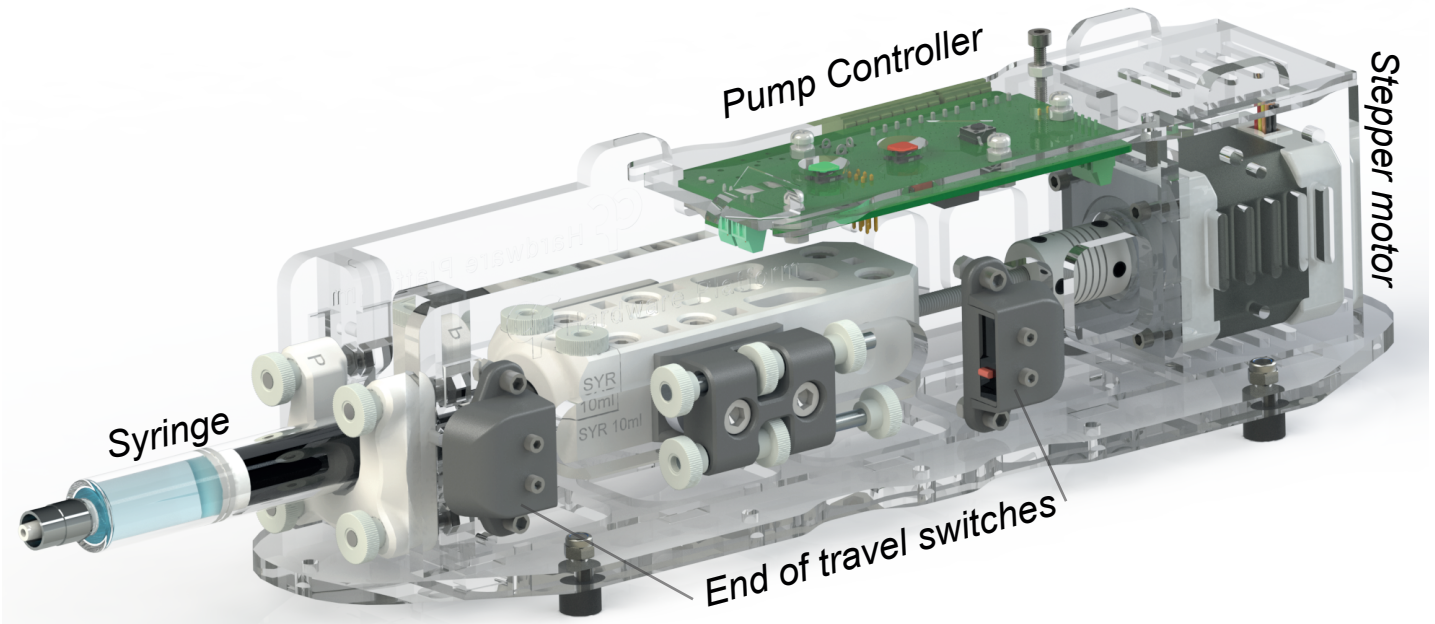
a

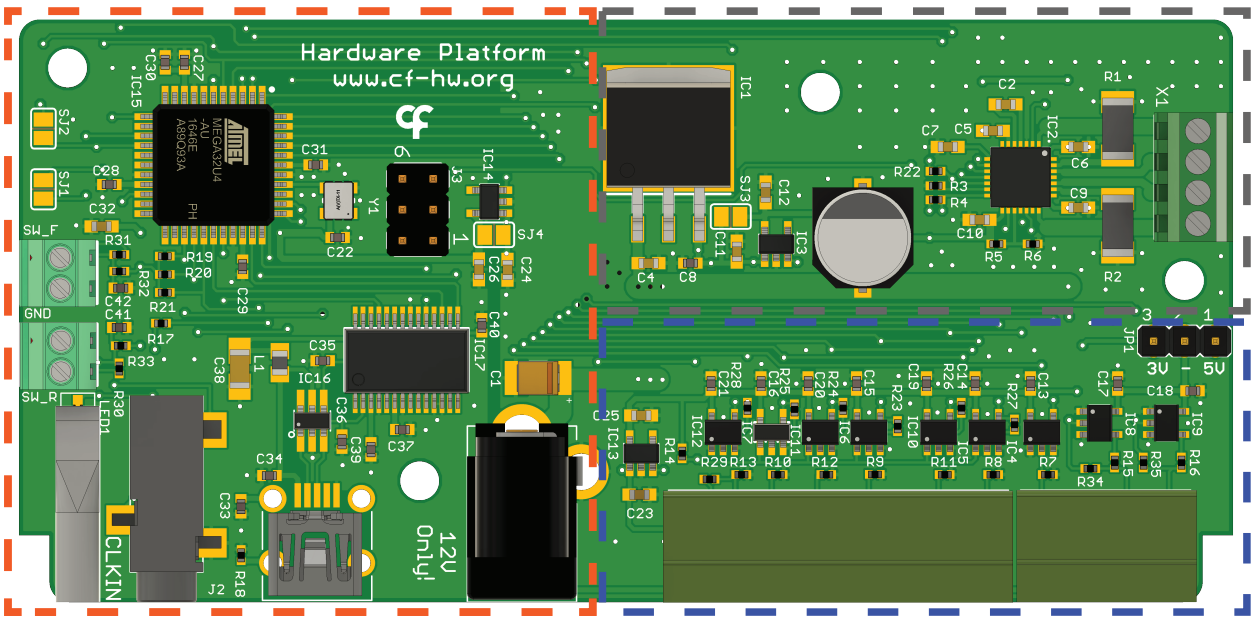


b

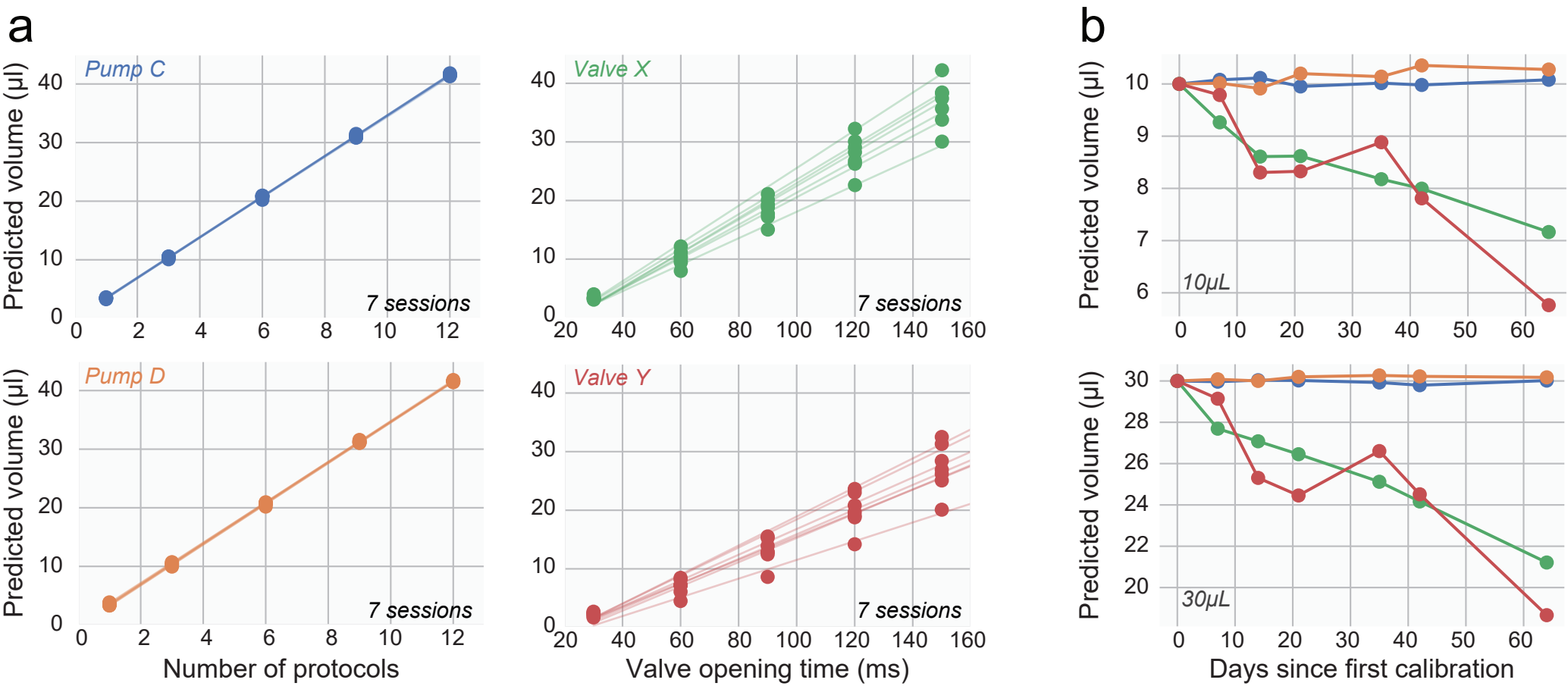
Pump Controller PCB

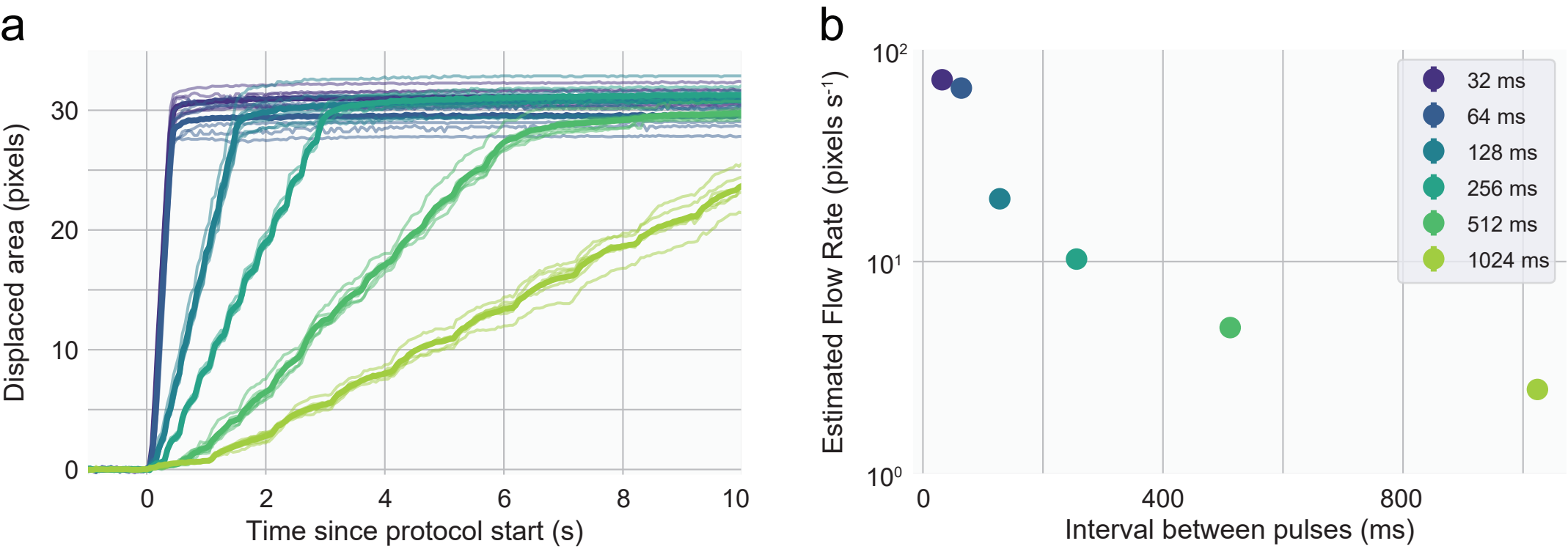
Microcontroller
(HARP implementation)

Stepper motor driver
Power management



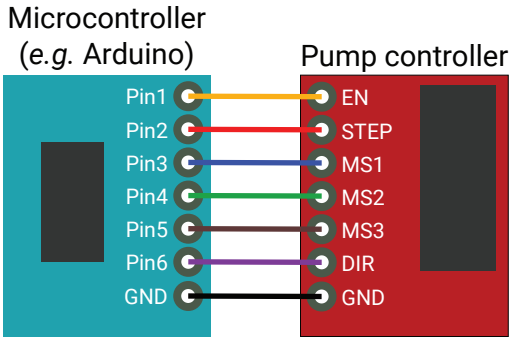
IO breakout


a
b
Pump C
Valve X
Pump D
Valve Y
7 sessions
Predicted volume (µl)
Number of protocols
Valve opening time (ms)
10µL
30µL
Days since first calibration


a
Displaced area (pixels)
0
10
20
30
0
2
4
6
8
10
Time since protocol start (s)
b
Estimated Flow Rate (pixels s-1)
10^2
10^1
10^0
0
400
800
Interval between pulses (ms)
32 ms
64 ms
128 ms
256 ms
512 ms
1024 ms

a

Low-level hardware control

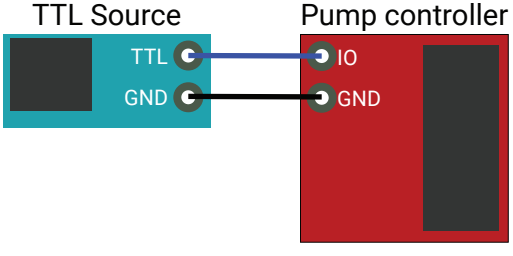


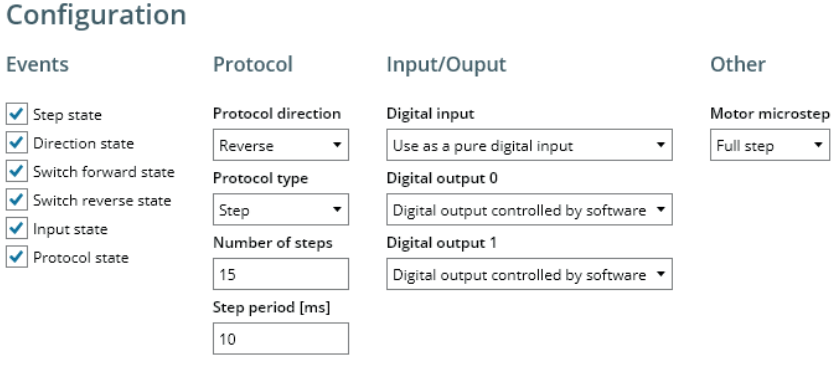
ControlPump.ino

```
(...)

void loop() {

  //Pulse with a 4s period
  //by toggling STEP input

  digitalWrite(Pin2, HIGH);
  delay(2000);
  digitalWrite(Pin2, LOW);
  delay(2000);
}
```

b

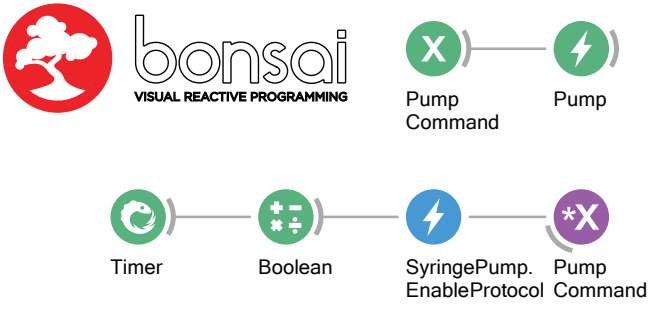
Hybrid control

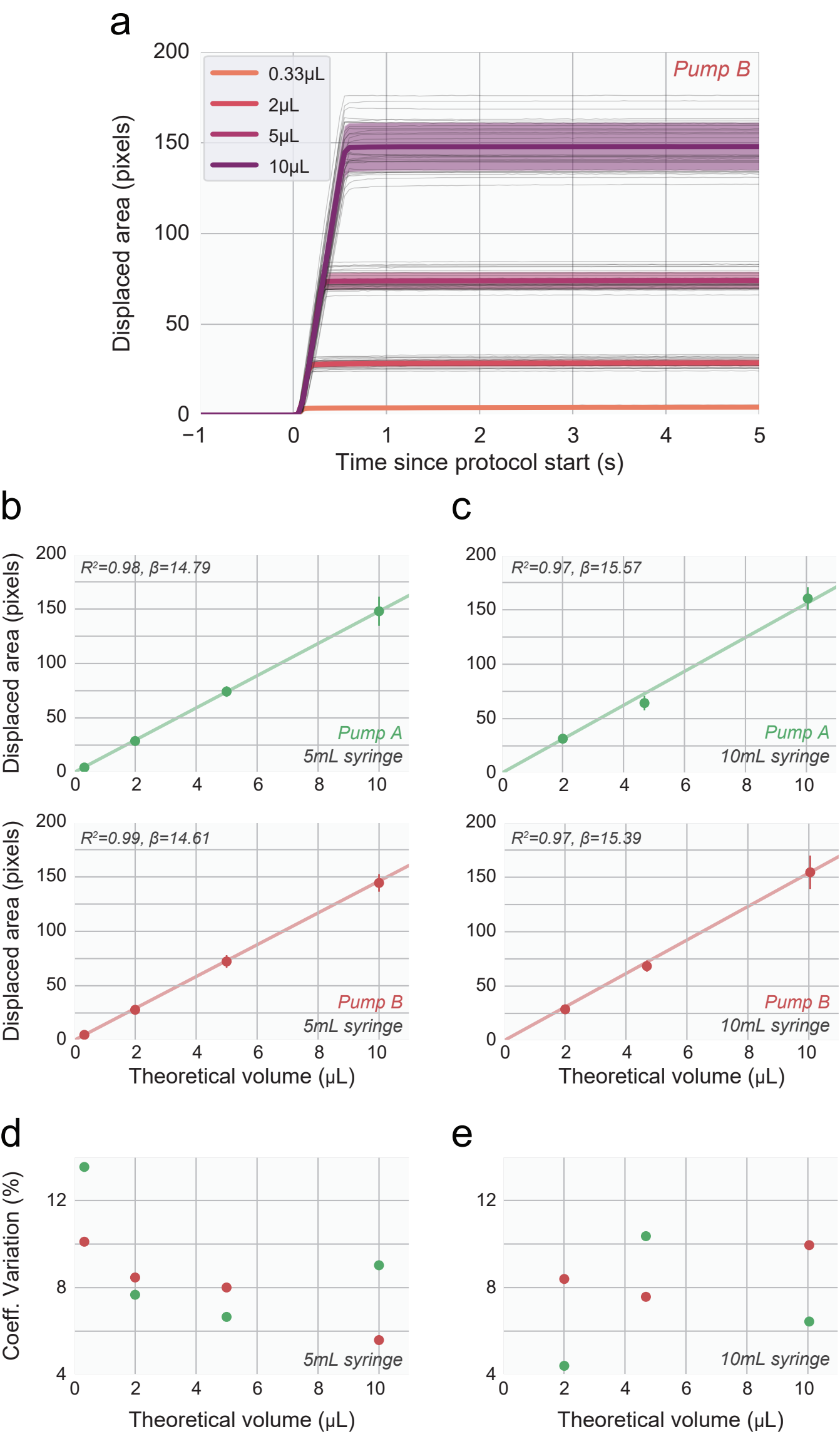


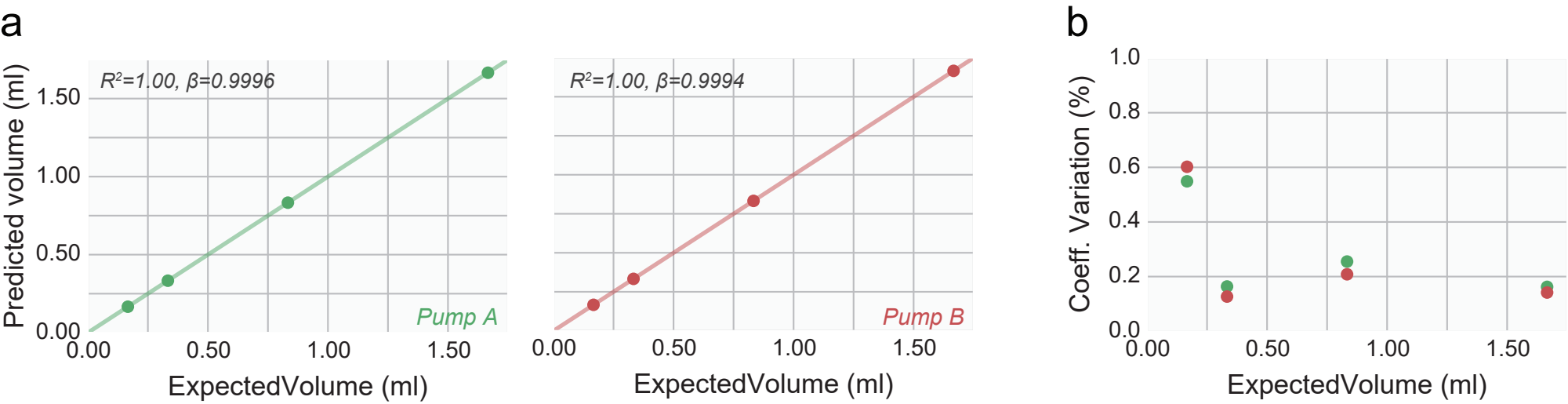


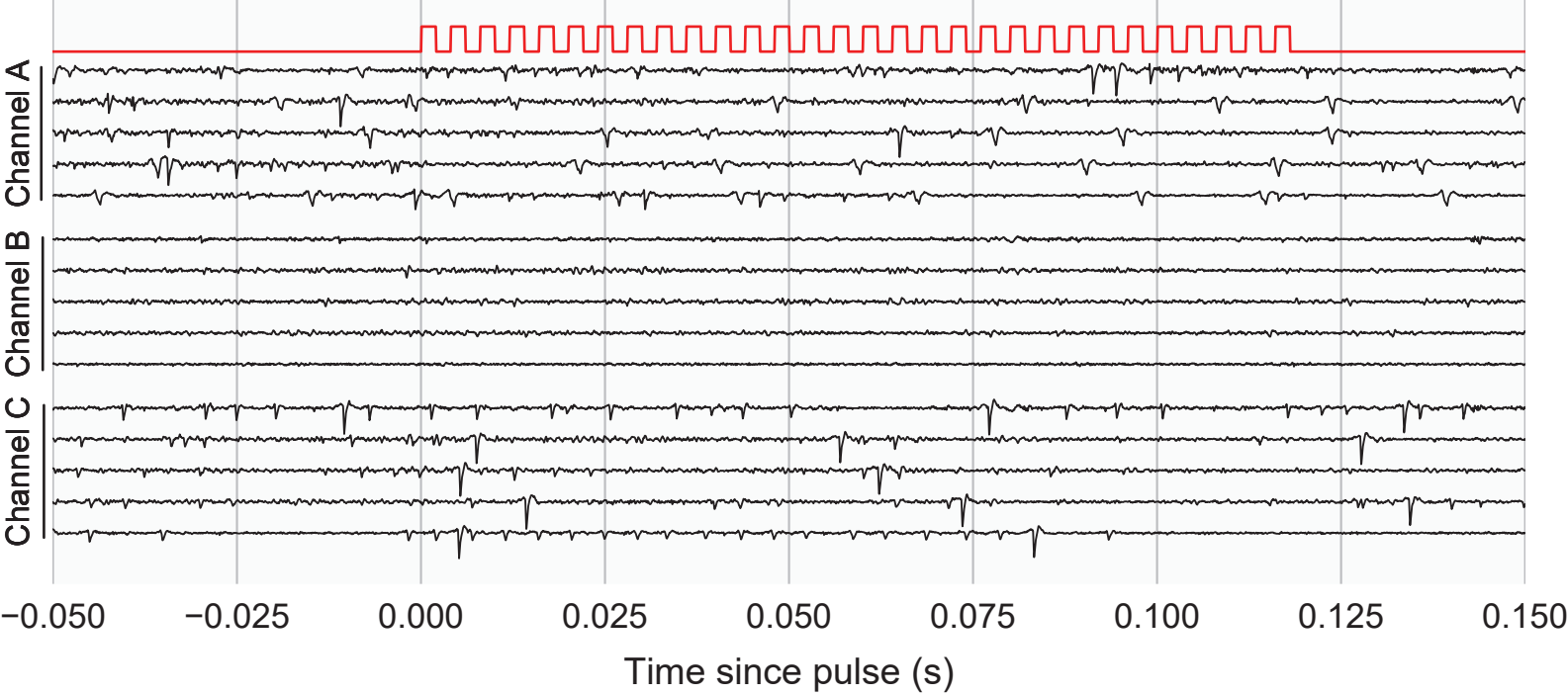
c

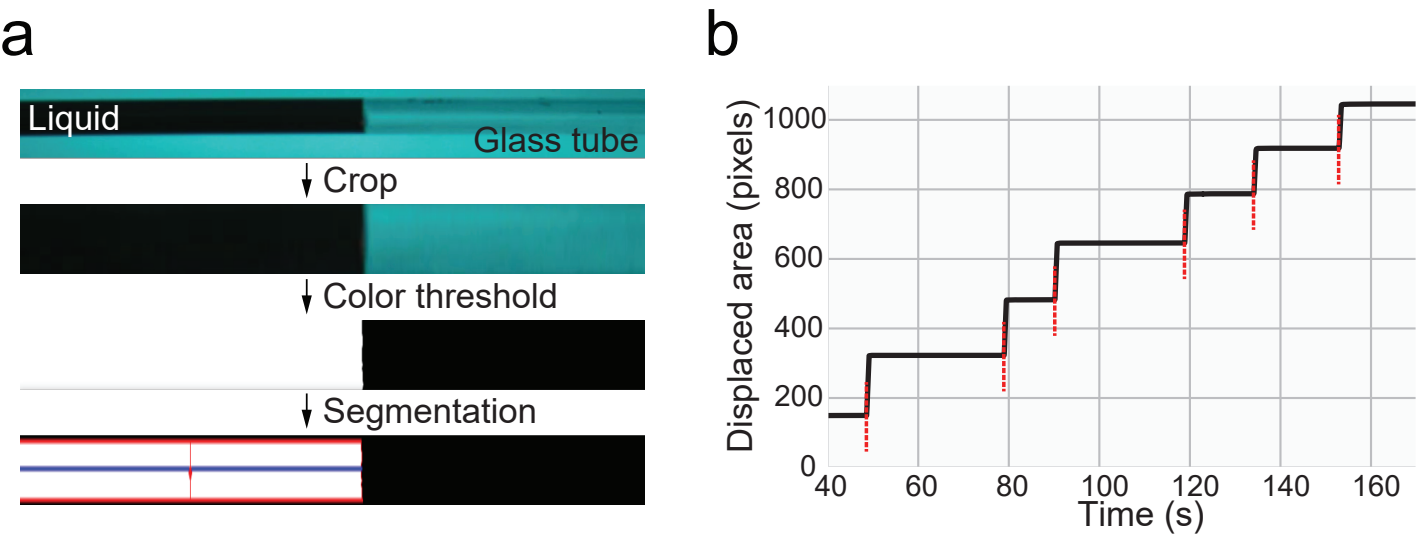
Software control

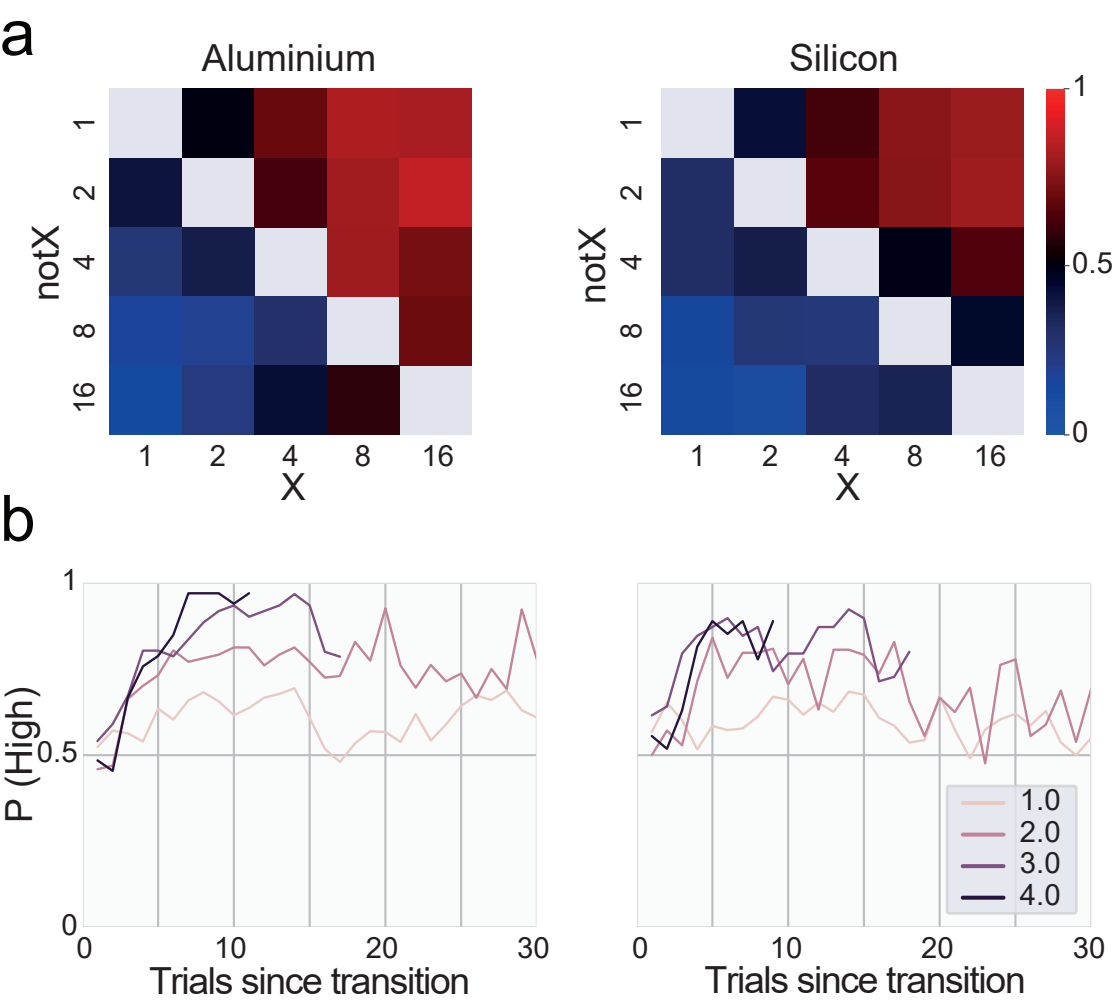



a
Displaced area (pixels)
Time since protocol start (s)
0.33µL
2µL
5µL
10µL
Pump B
b
c
R²=0.98, β=14.79
Pump A
5mL syringe
R²=0.97, β=15.57
10mL syringe
R²=0.99, β=14.61
Pump B
5mL syringe
R²=0.97, β=15.39
10mL syringe
Theoretical volume (µL)
d
e
Coeff. Variation (%)
5mL syringe
10mL syringe


a
b
R²=1.00, β=0.9996
Pump A
R²=1.00, β=0.9994
Pump B
Predicted volume (ml)
ExpectedVolume (ml)
Coeff. Variation (%)
0.00
0.50
1.00
1.50
0.0
0.2
0.4
0.6
0.8
1.0


Channel A
Channel B
Channel C
−0.050
−0.025
0.000
0.025
0.050
0.075
0.100
0.125
0.150
Time since pulse (s)


a
Liquid
Glass tube
Crop
Color threshold
Segmentation
b
Displaced area (pixels)
0
200
400
600
800
1000
40
60
80
100
120
140
160
Time (s)


a
Aluminium
Silicon
notX
1
2
4
8
16
X
1
0.5
0
b
P (High)
Trials since transition
1.0
2.0
3.0
4.0