FlowIO Platform

Making Prototyping with Soft Programmable Materials Seamless and Universally Accessible

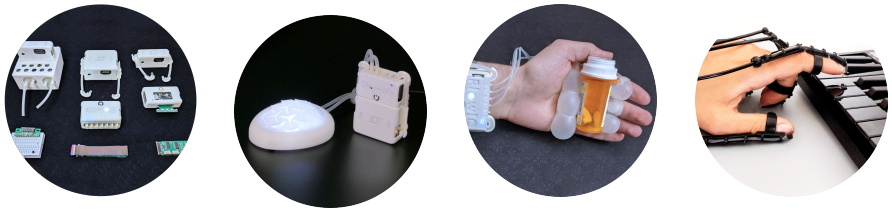
Ali Shtarbanov

mit media lab

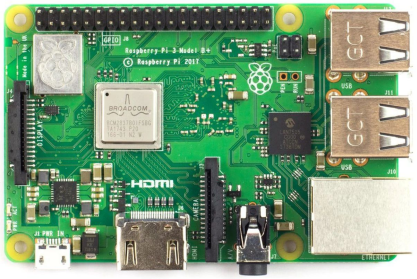
responsive environments

Personal Mission: *To make innovation and prototyping in emerging fields easily accessible for everyone...*

*...through the **development** and **deployment** of new tools and platforms that are highly versatile, general purpose, and simple to use.*



Portable Computing



Raspberry Pi

Electronics

ARDUINO

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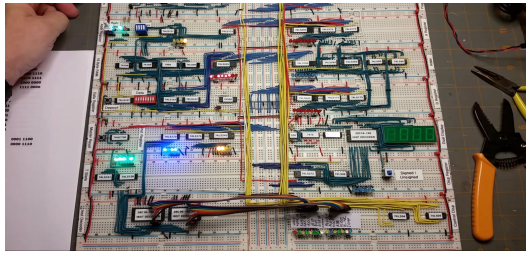
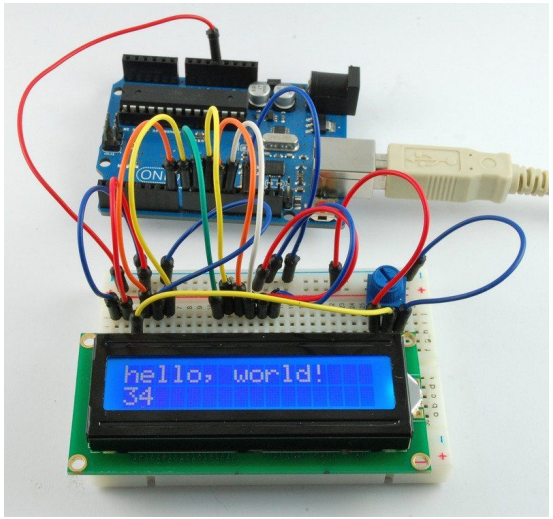
Electronics Prototyping Transformation



ARDUINO



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Soft Programmable Materials Across Disciplines

Haptics Researchers

Mechanical Engineers

Artists

Hobbyists

Designers

Roboticists

Material Scientists

Makers

Doctors

Interaction Designers

Patients

HCI Researchers

Biologists

Students

Educators

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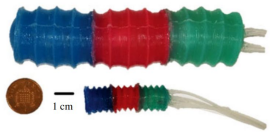
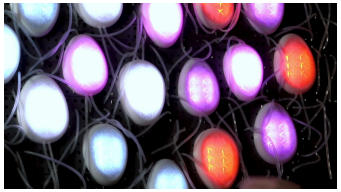
Soft Programmable Materials Across Applications

AeroMorph (UIST'16)

MorphIO (DIS'19)

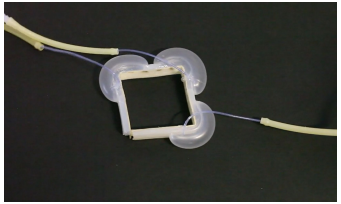


EuMoBot (2018)



AuxeticBreath (TEI'21)

Vine Robots (2018)

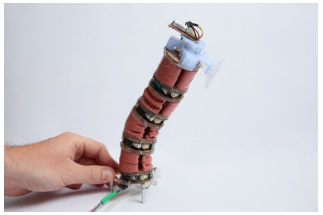


PneUI (UIST'13)

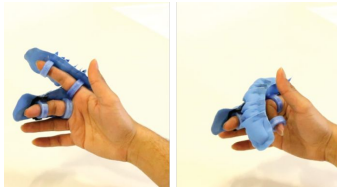
Bubble (CHI'19)

Jamming UIs (UIST'12)

Colorise (TEI'18)



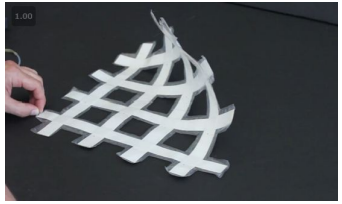
VSPA (Science'17)



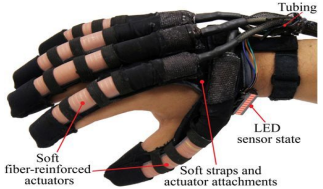
PrintFlatables (CHI'17)

Force Jacket (CHI'18)

Exoskin (2013)



JamSheets (TEI'14)



Soft Robotic Glove (2015)

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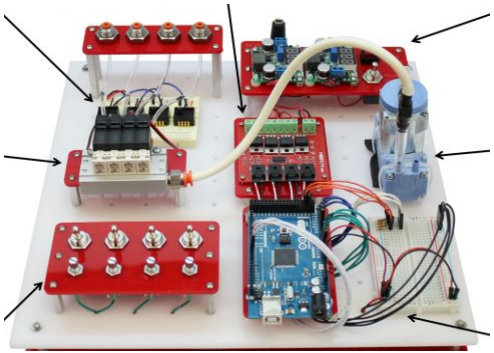
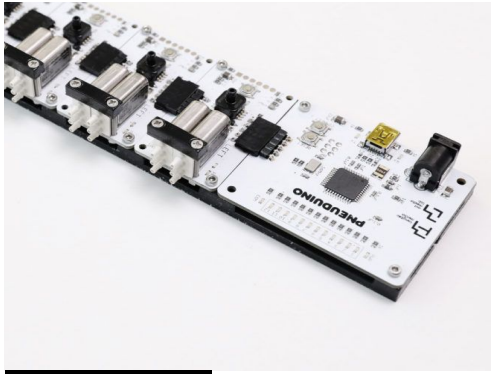
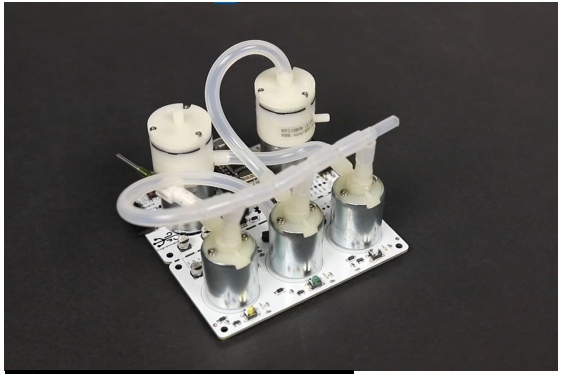
Existing Pneumatic Toolkit Attempts



Soft-Robotics Toolkit



Pneuduino



Programmable-Air

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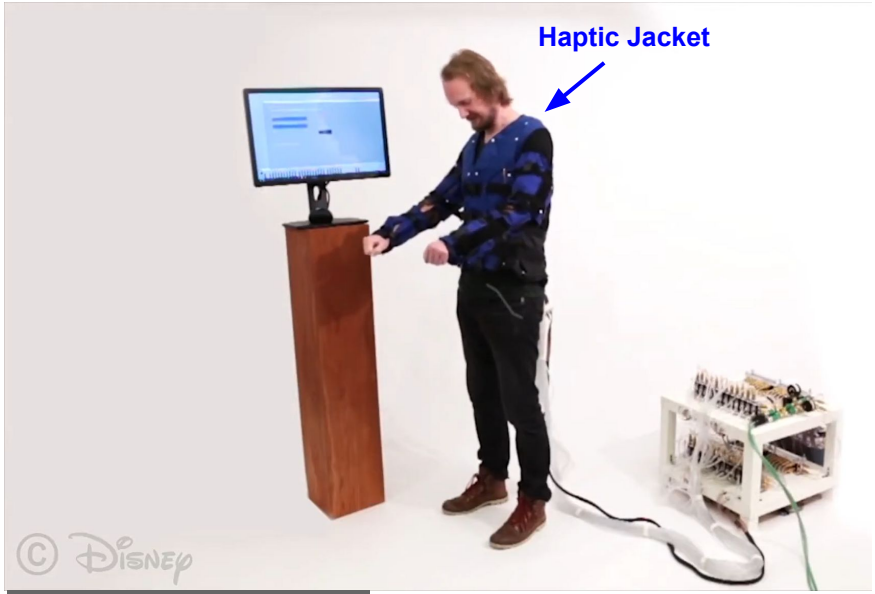
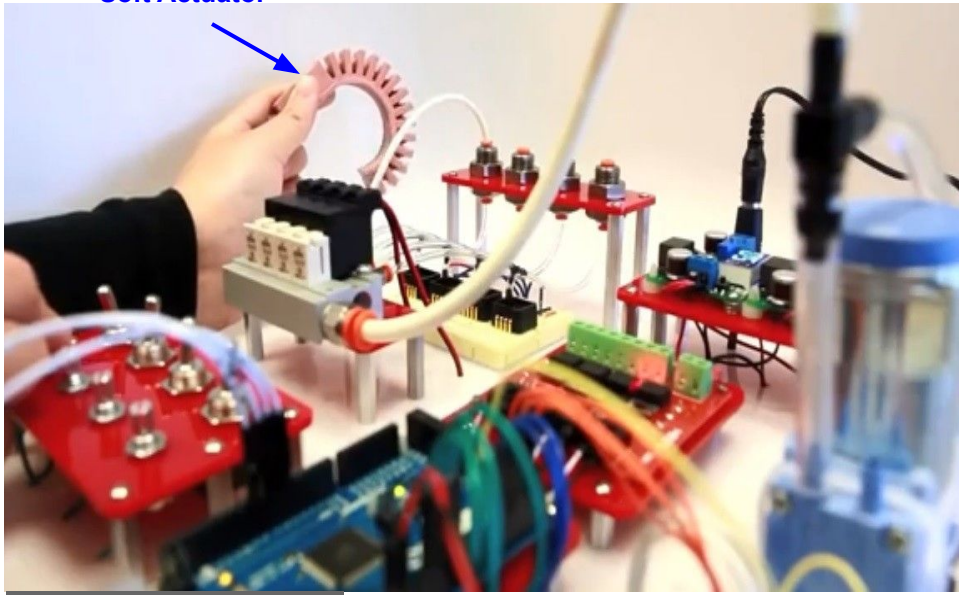
2 Examples of Pneumatic Controls used today



Force Jacket (CHI'18)



Soft Robotics Toolkit

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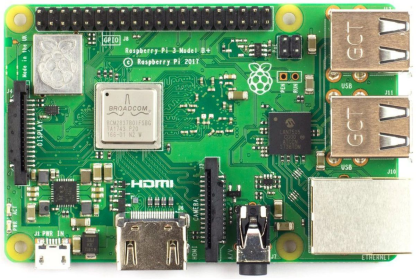
We developed silicone chambers that attach to the hand and are signaled to inflate or deflate by certain arm motions. An EMG sensor on the forearm detects the muscle activity, and the signal is processed via a neural network.

Portable Computing



Raspberry Pi

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Soft Robotics

FlowIO Platform

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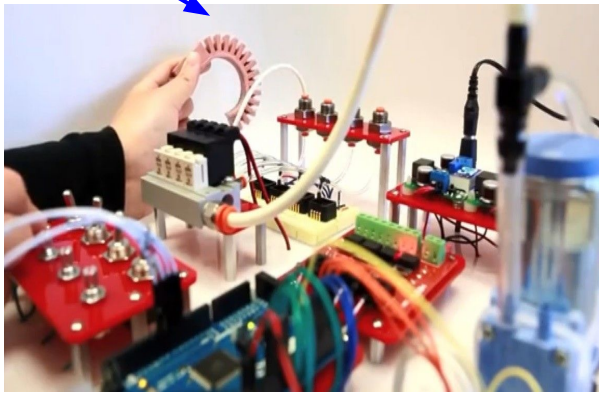
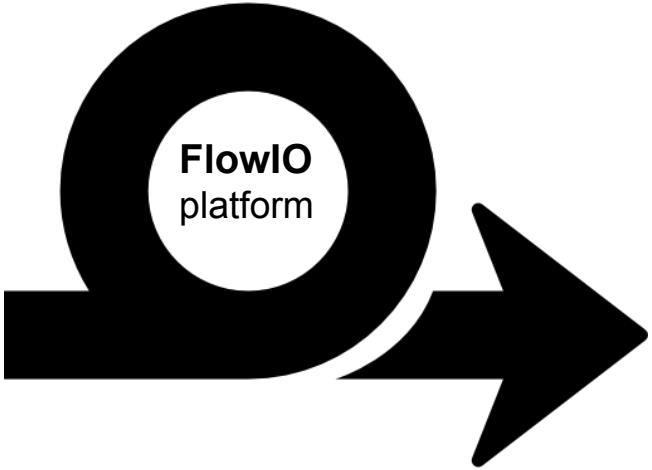
Soft Robotics Prototyping Transformation

Soft Actuator





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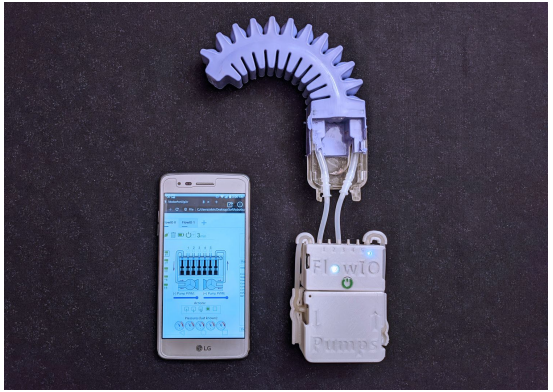

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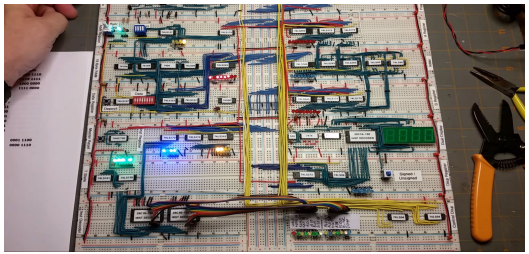
Electronics Prototyping Transformation



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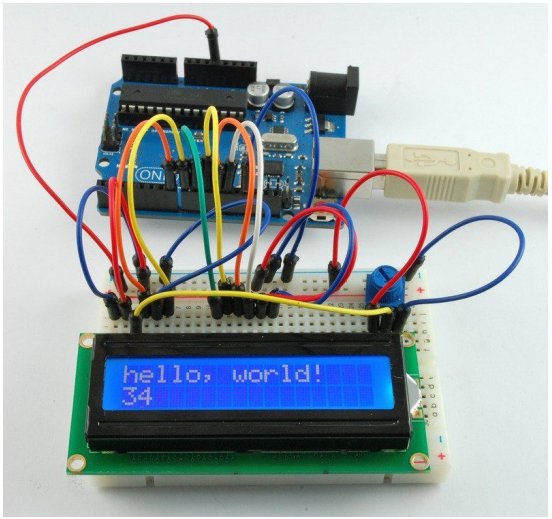

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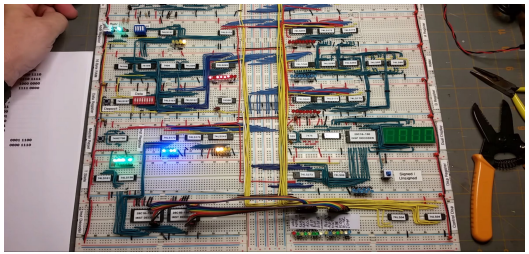

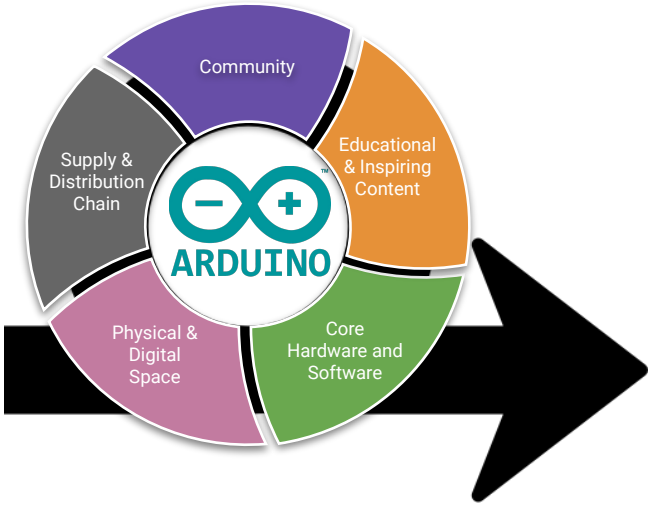

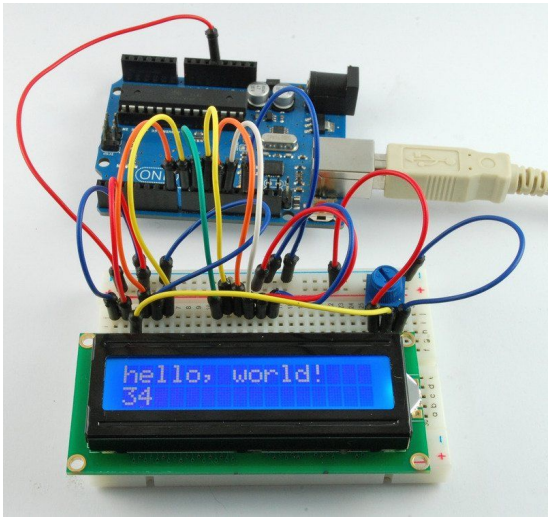

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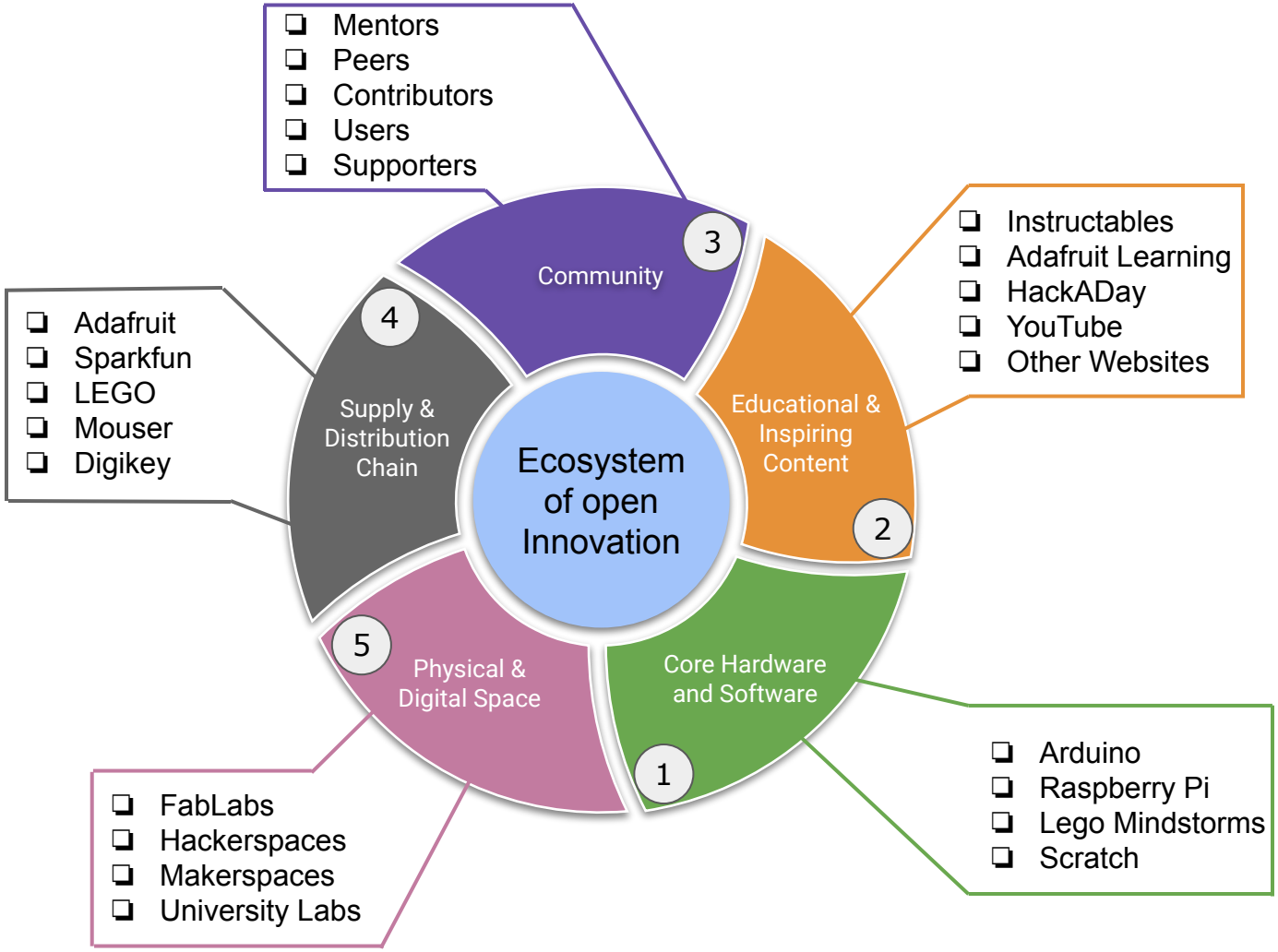

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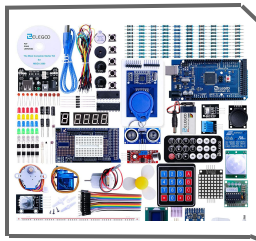
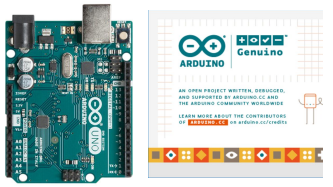
Community

Educational & Inspiring Content



Supply & Distribution Chain

ARDUINO



Core Hardware and Software

Physical & Digital Space

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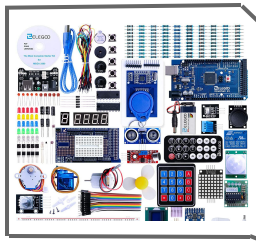
Community

Educational & Inspiring Content



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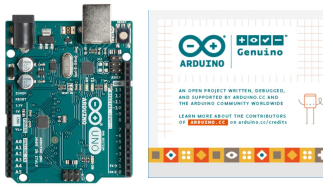

Core Hardware and Software

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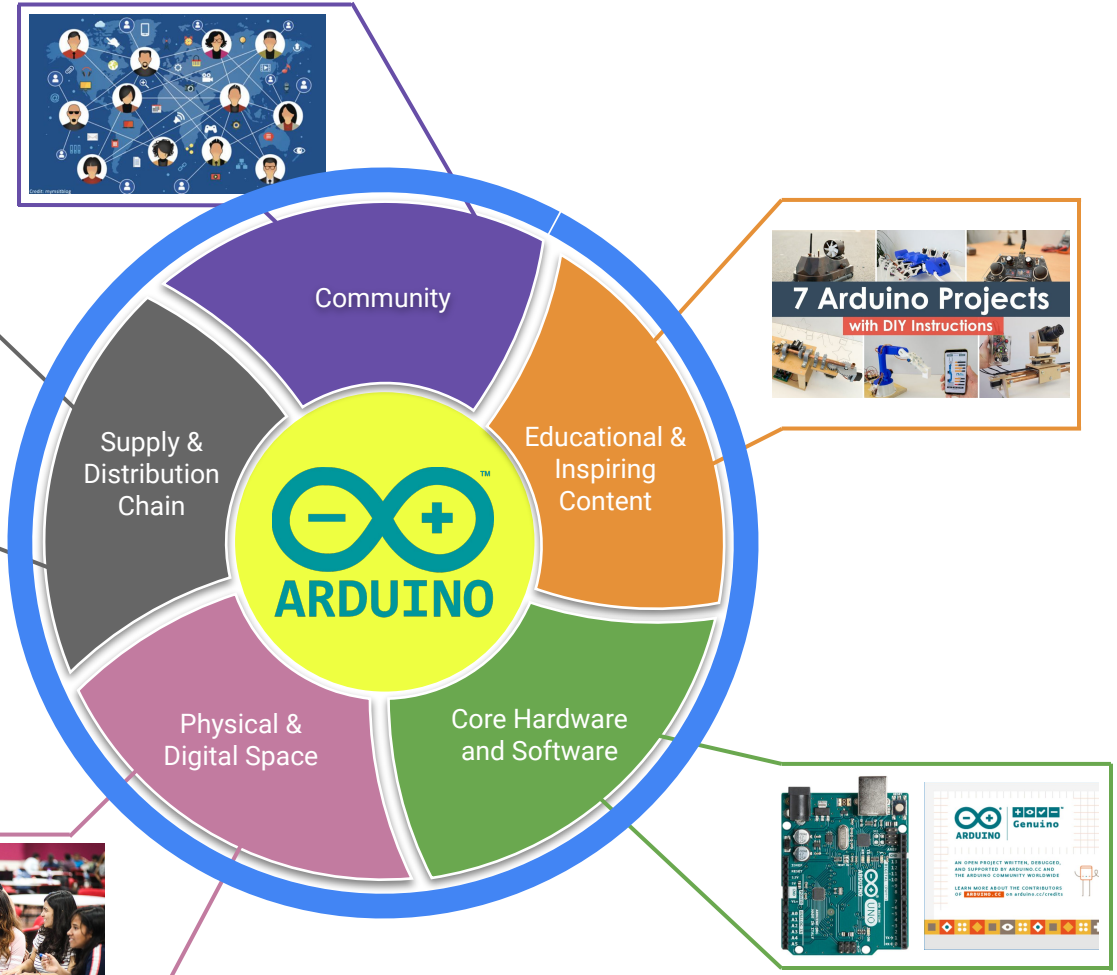

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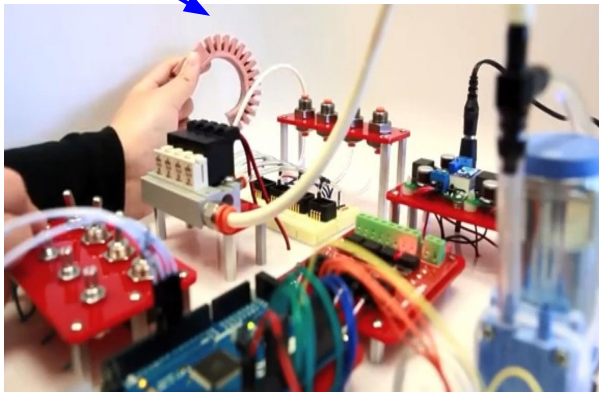
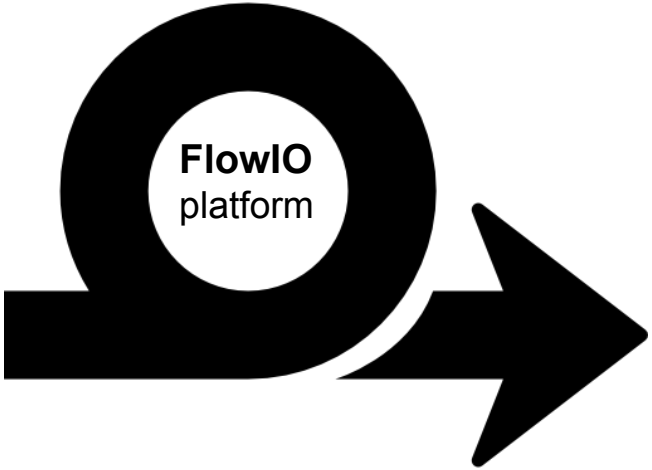
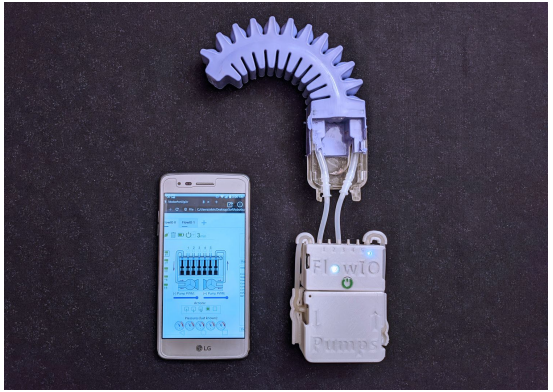
Soft Robotics Prototyping Transformation

Soft Actuator





Soft Actuator



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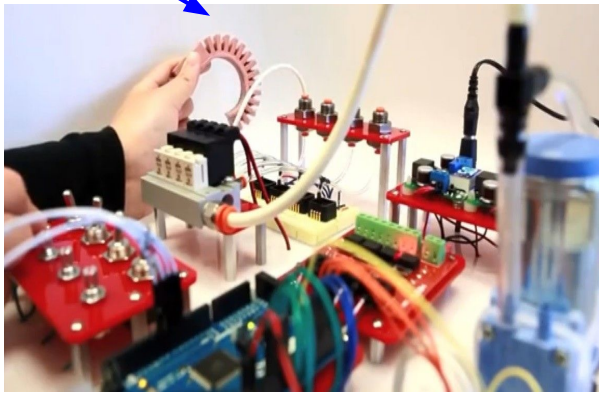

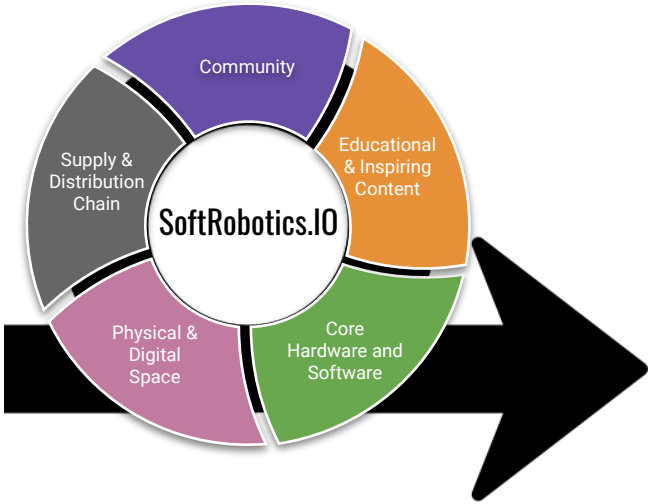

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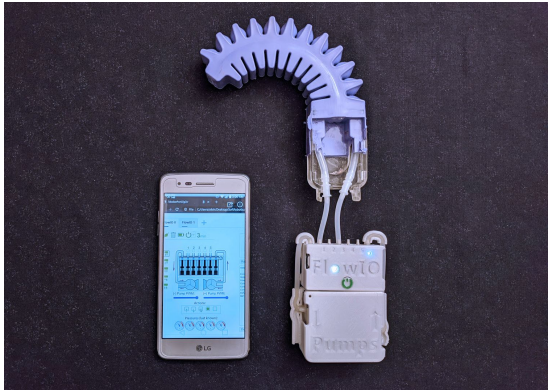

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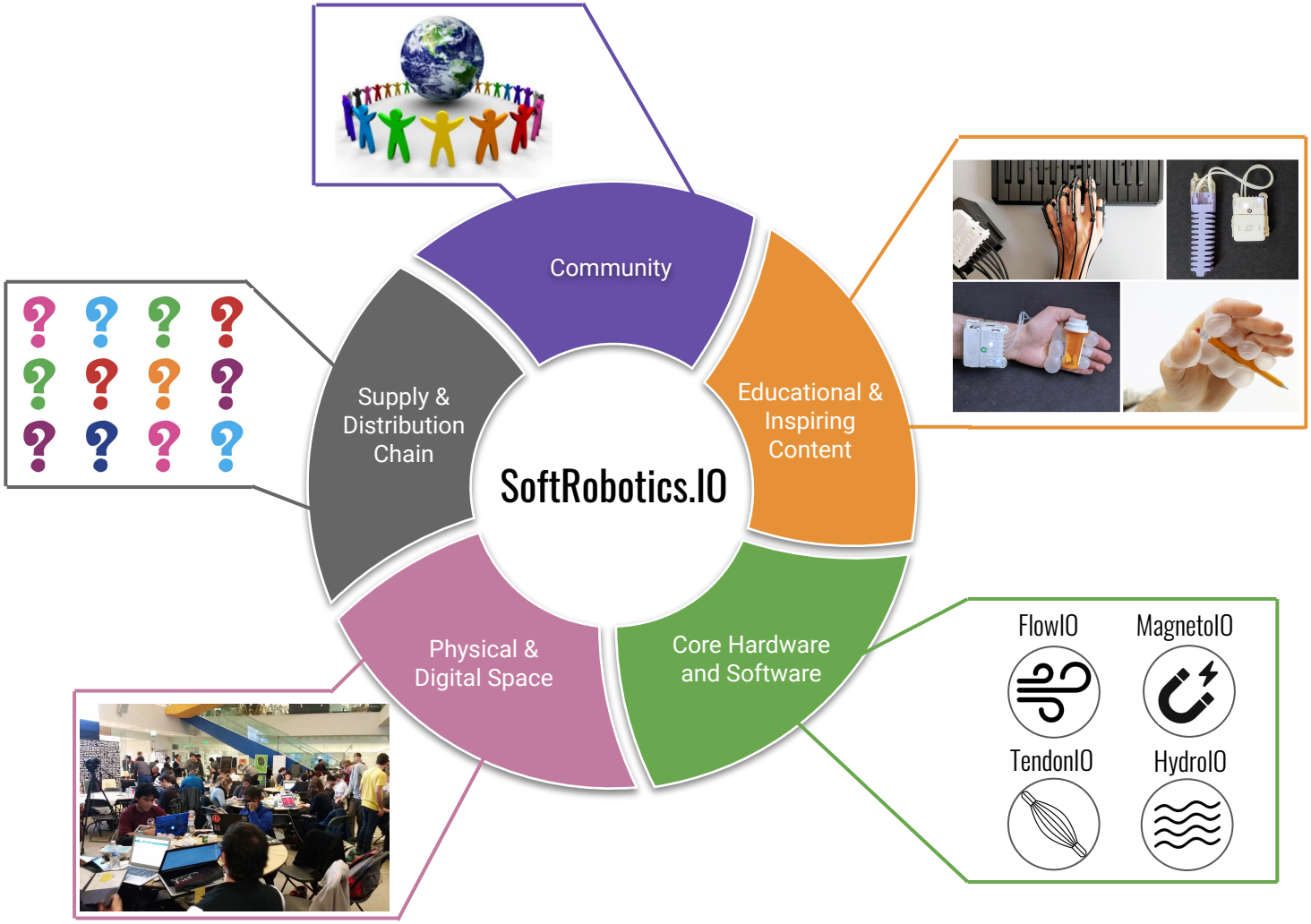

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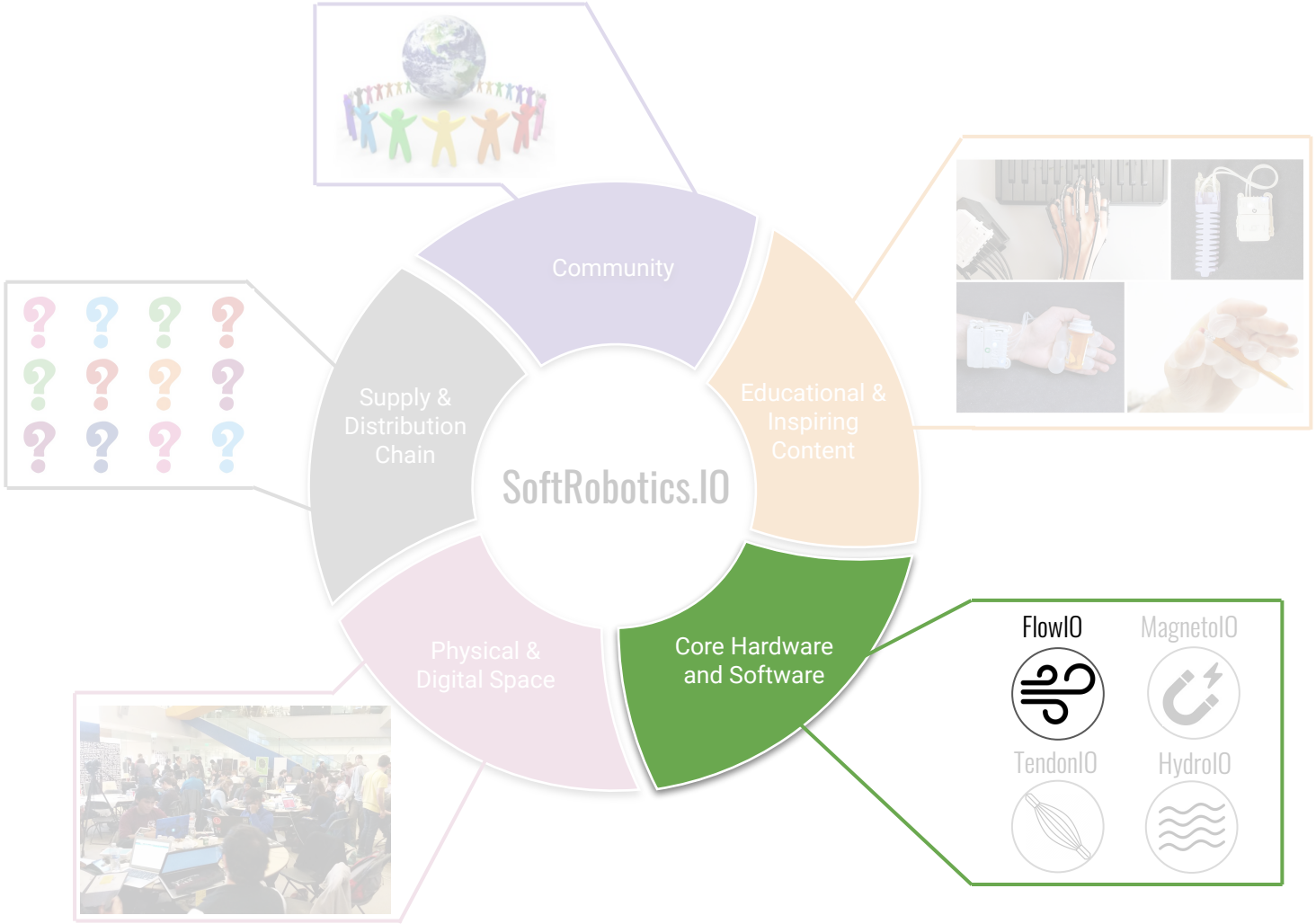

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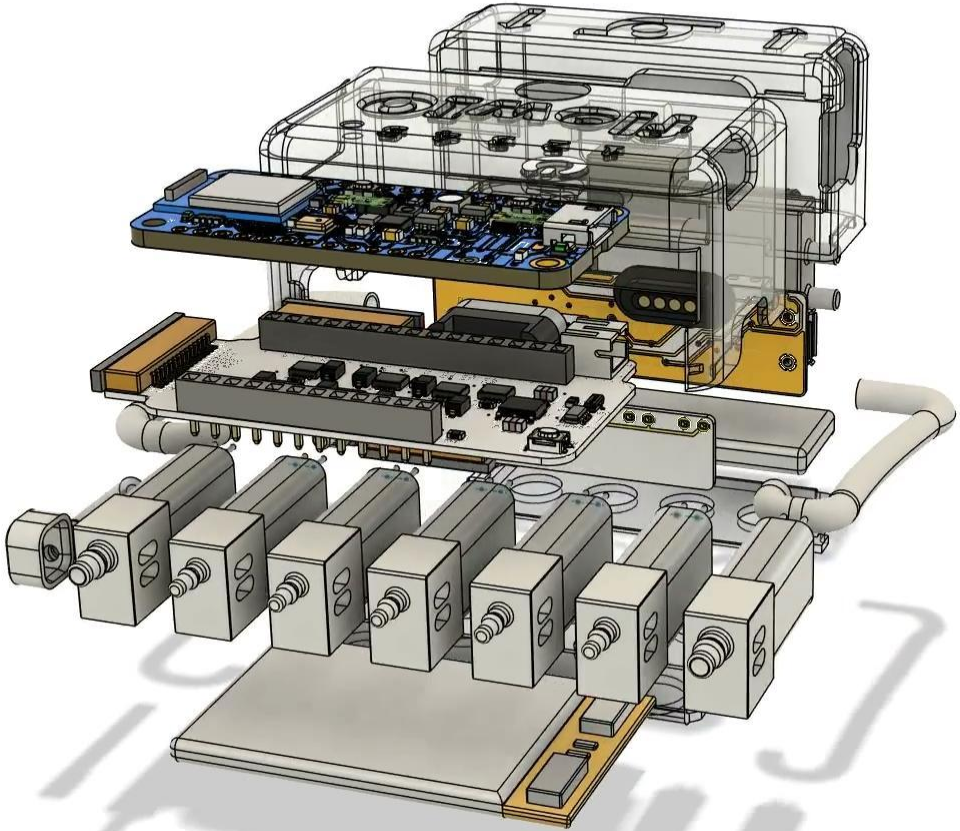
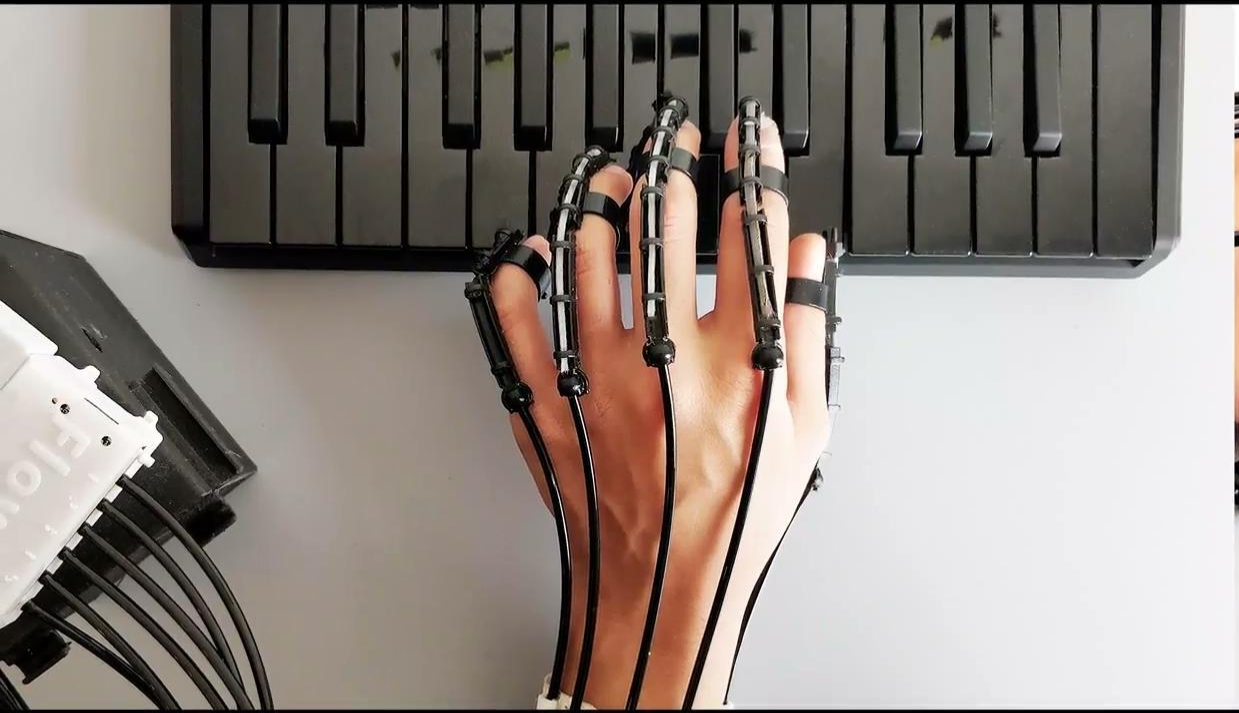
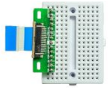




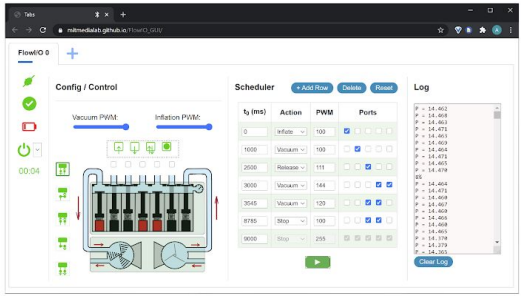
Ozgun Kilic Afsar

HARDWARE

Controller		 Main Module (59 x 33 x 28) mm	
Pumps	 Small (59 x 22 x 28) mm	 Medium (60 x 51 x 28) mm	 Large (70 x 66 x 64) mm
Expansion Modules	 Sensors++	 Expansion Breakout	 16-pin Analog Input
Accessories	 Wrist Strap	 Auxiliary Tube	 Lego Base

SOFTWARE

Web-GUI



APIs & Libraries

Compatibility

COMMUNITY

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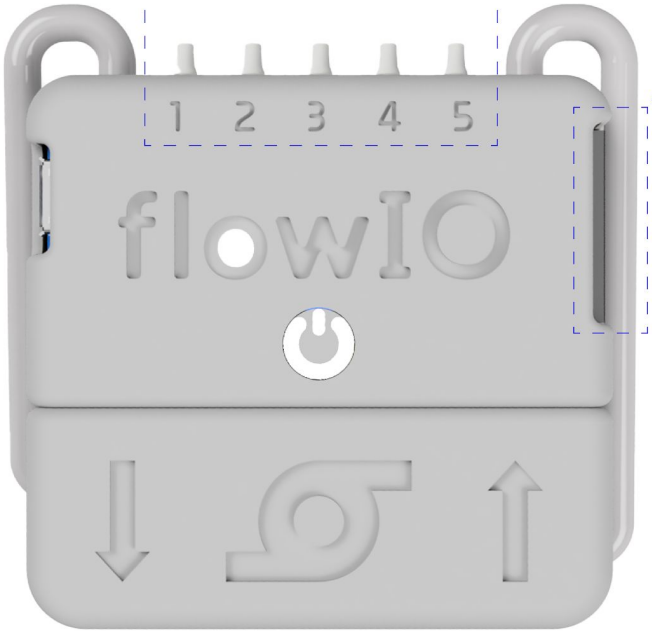
H A R D W A R E

5 Pneumatic I/O Ports

14-Pin Expansion Port



Pneumatic Actions

- Inflation
- Vacuum
- Release
- Hold
- Pressure Sense
- Flow Variability

Connectivity

- Bluetooth LE
- USB
- GPIO Pins
- SPI
- I²C
- UART

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H A R D W A R E

Controller		 Main Module (59 x 33 x 28) mm	
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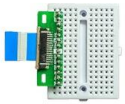
Expansion Modules	 Sensors++	 Expansion Breakout	 16-pin Analog Input
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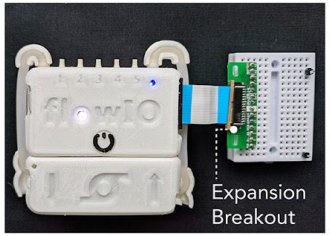

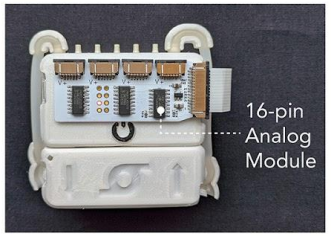

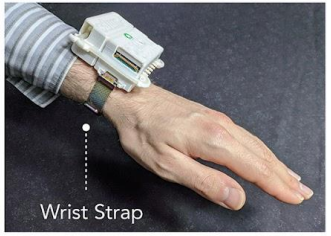

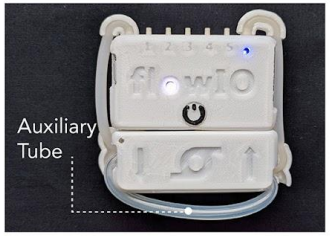

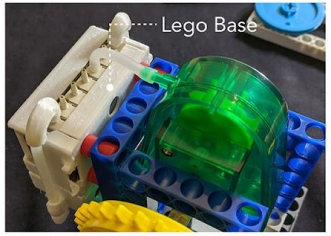

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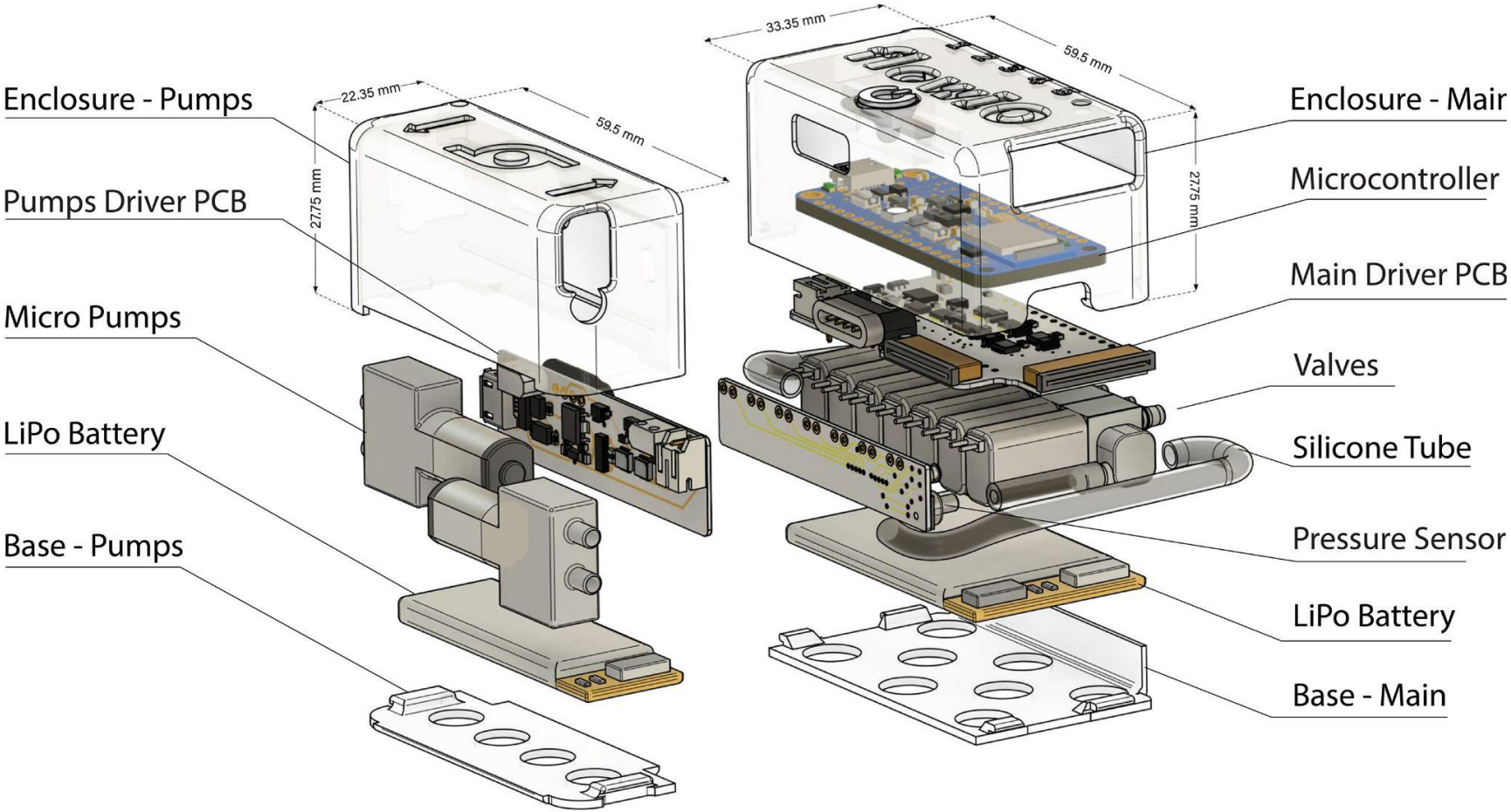

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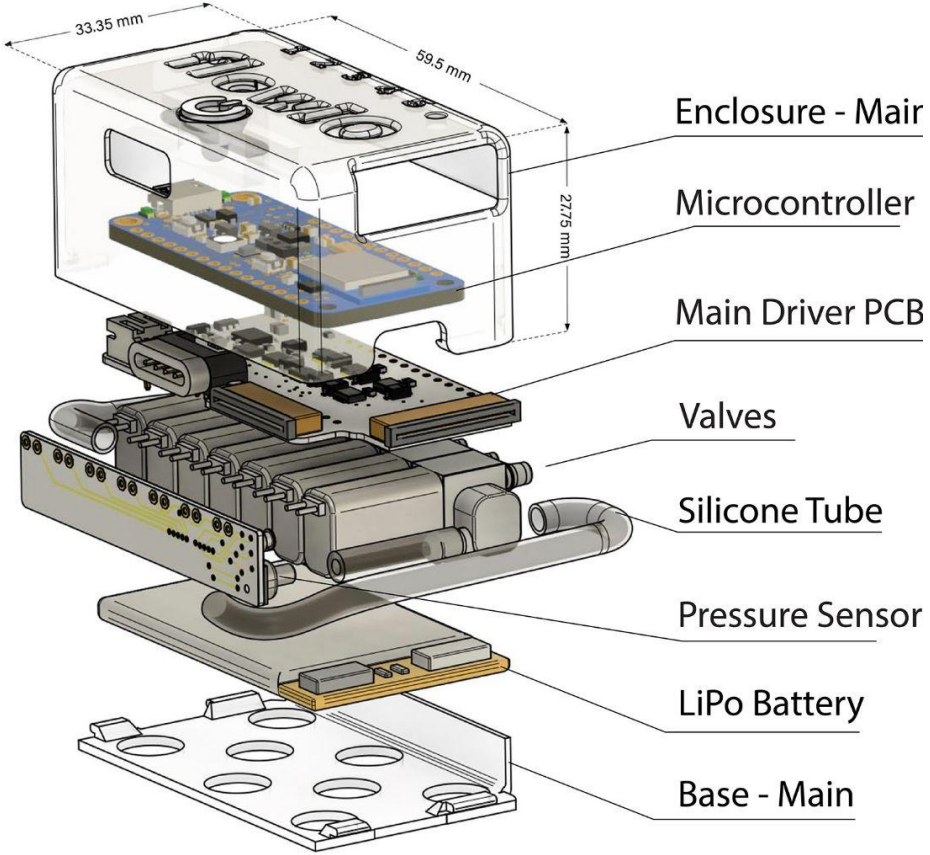

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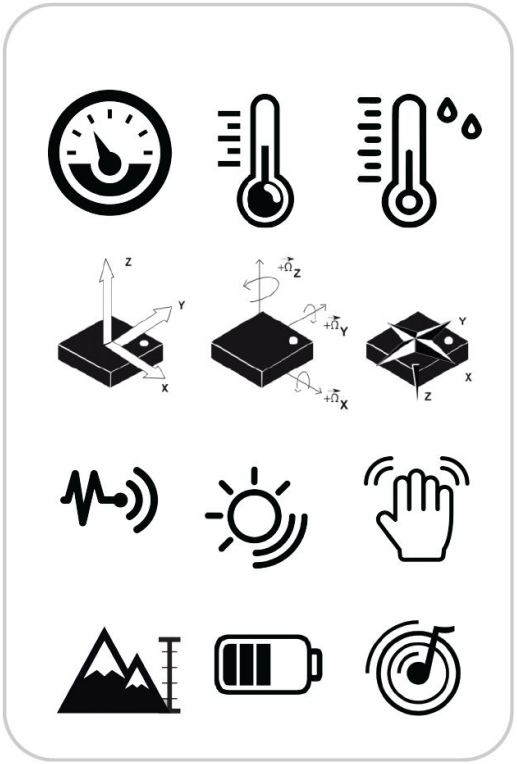

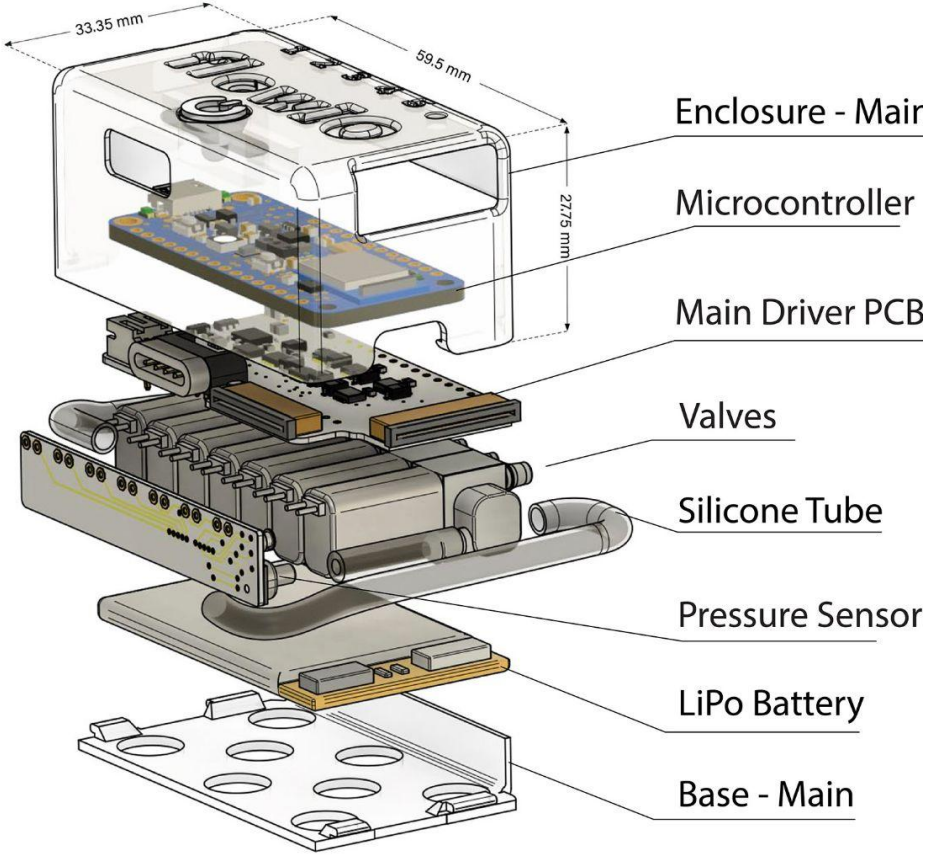

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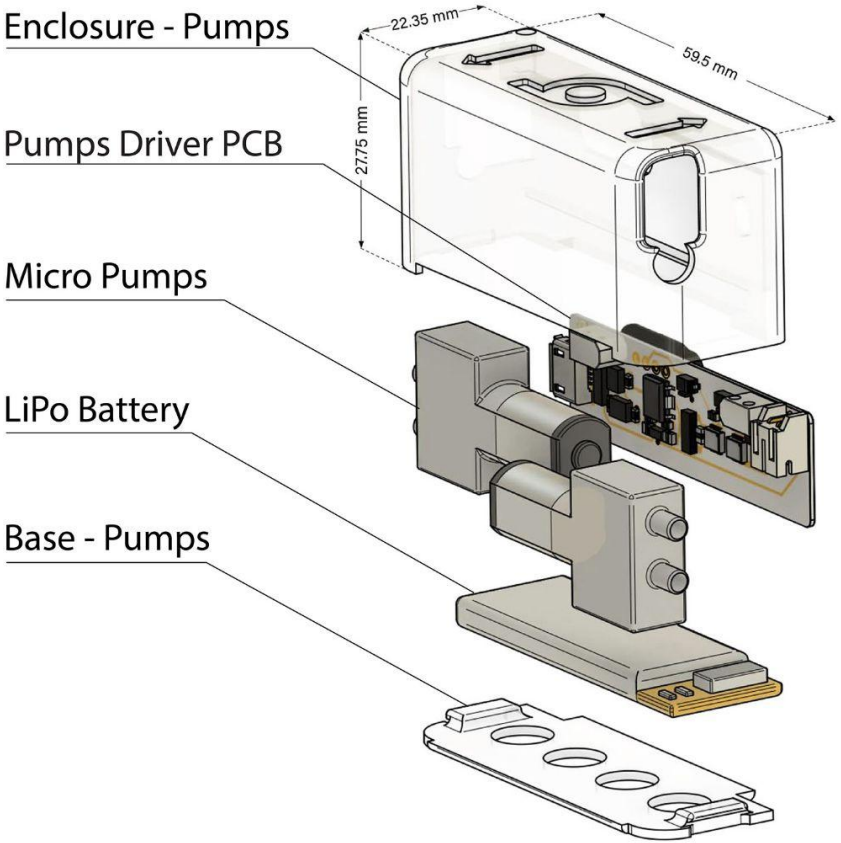

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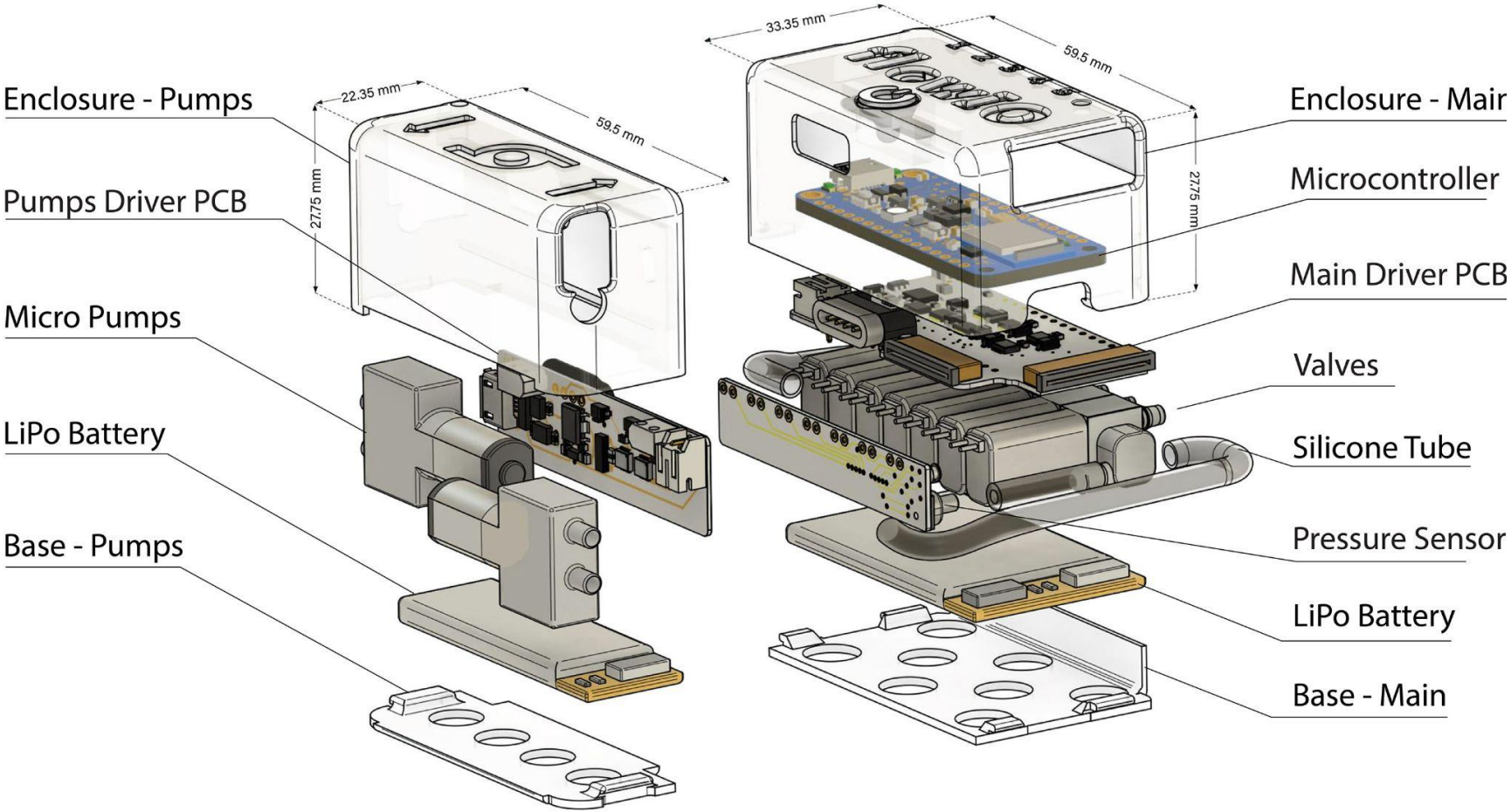

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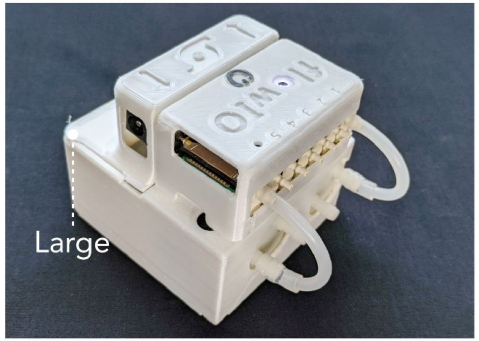
Small
(59 x 22 x 29) mm

Medium
(60 x 51 x 29) mm

Large
(70 x 66 x 65) mm



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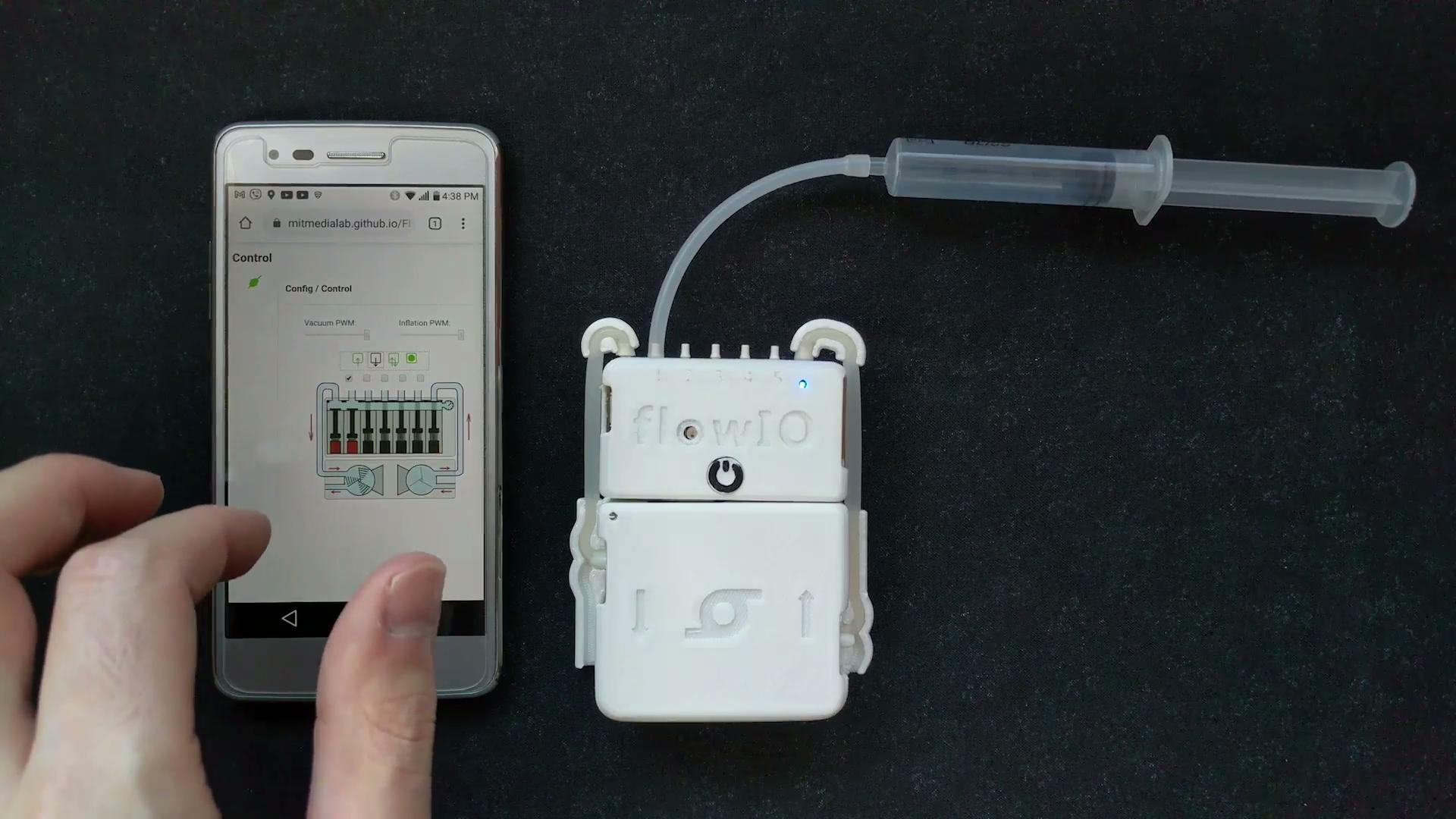
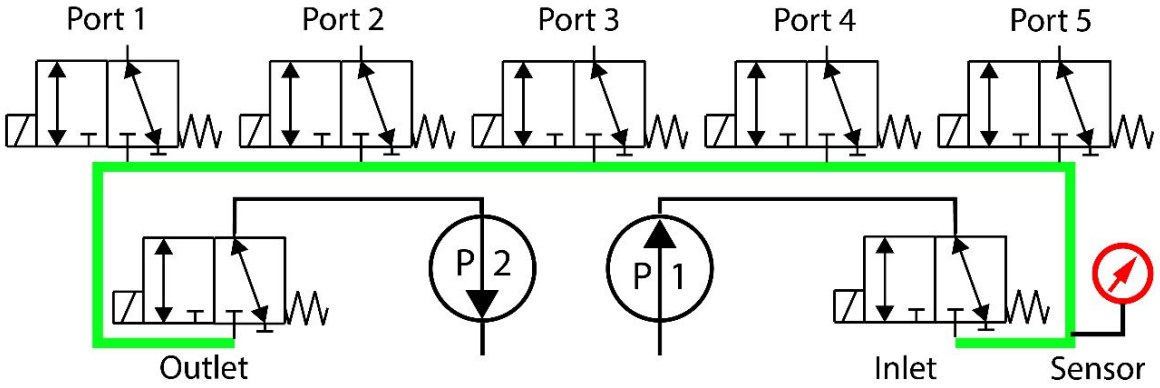
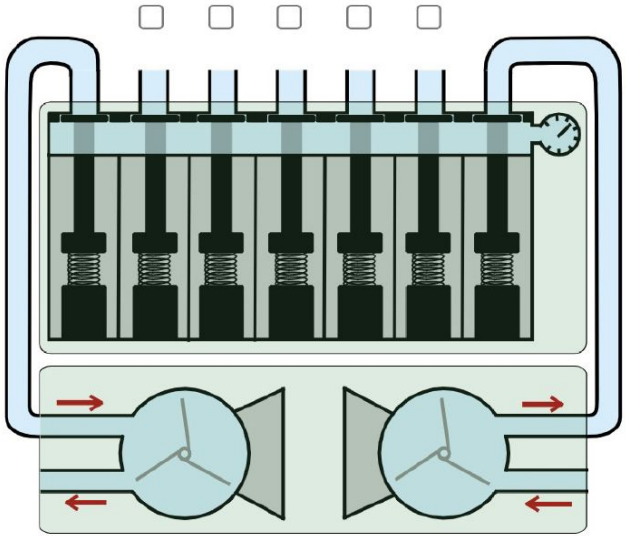
Dimensions: **6 cm** x **5.6 cm** x **2.8 cm**.
Mass: **114 g**.


4:38 PM
mitmedialab.github.io/Fl
Control
Config / Control
Vacuum PWM:
Inflation PWM:
flowIO

GENERAL Configuration





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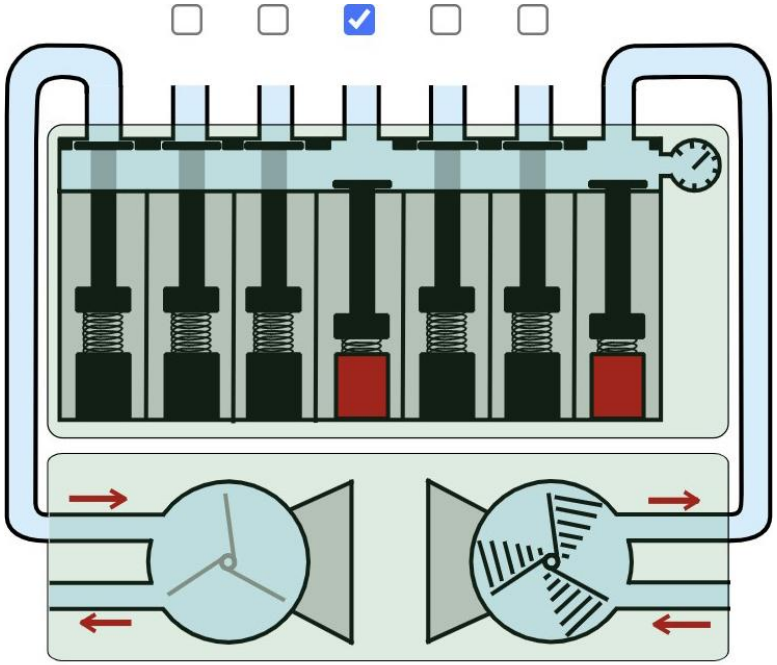
Inflation on Port(3)



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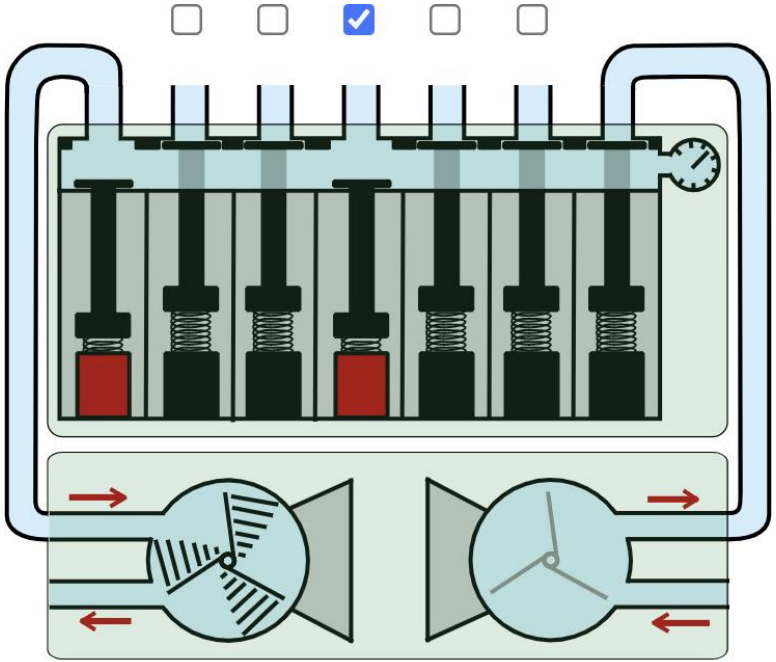
Vacuum on Port(3)



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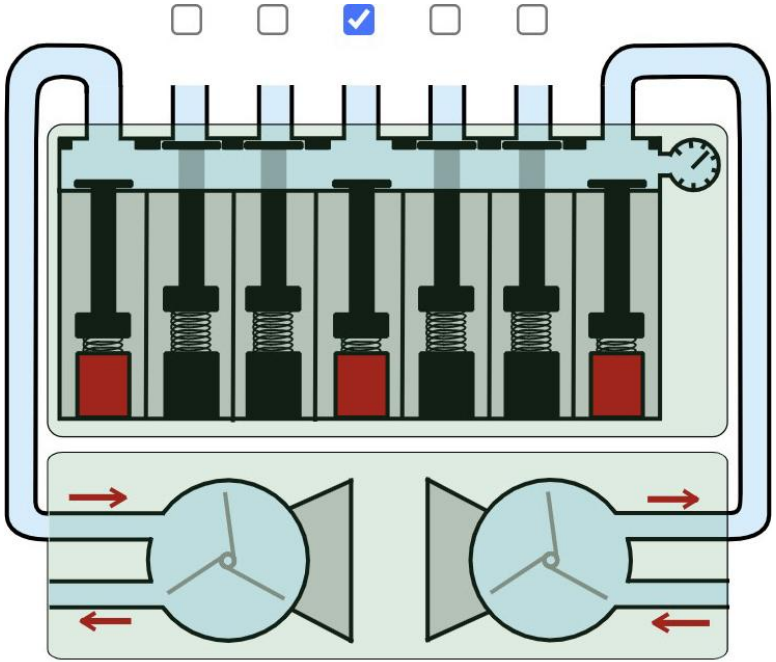
Release on Port(3)



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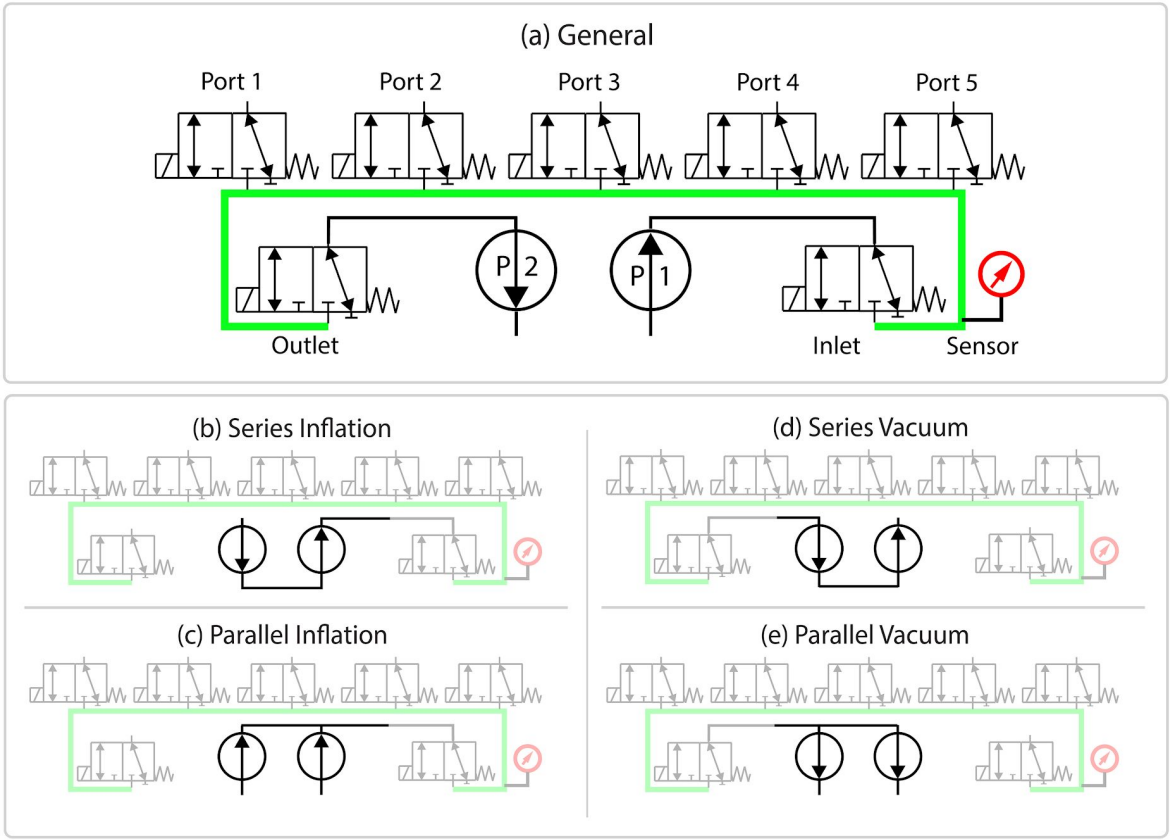

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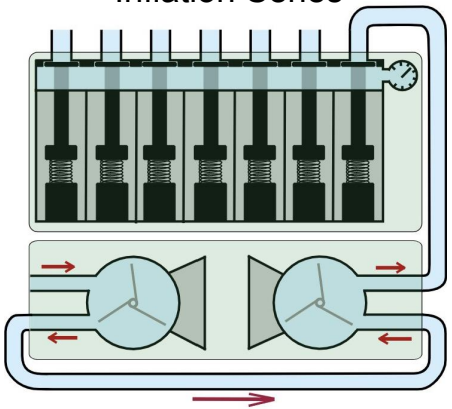
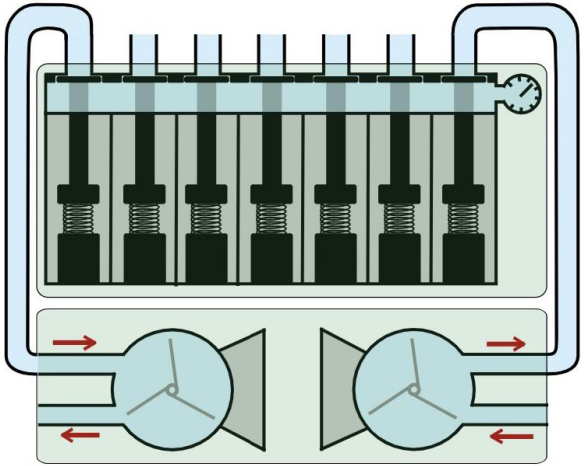
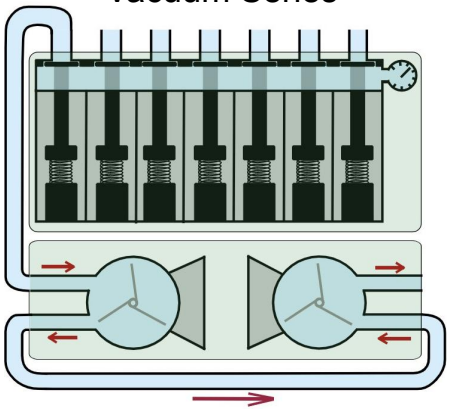
Inflation Series



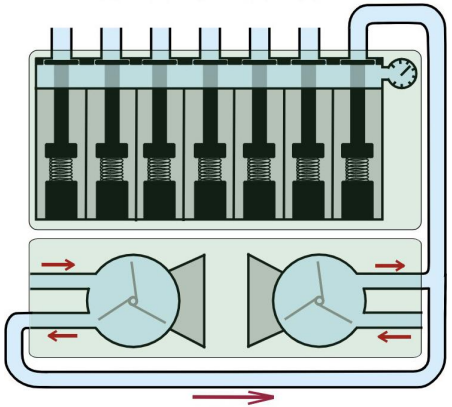
General



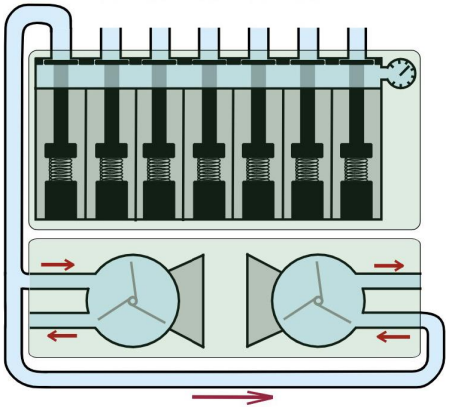
Vacuum Series



Inflation Parallel



Vacuum Parallel



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Technical Evaluation of the Hardware

		General	Series Inf	Parallel Inf	Series Vac	Parallel Vac
Small	**P (min,max)**	(-9, 9) psi	(0, 18) psi	(0, 9) psi	(-15, 0) psi	(-9, 0) psi
	Q (max)	0.5 L/min	0.45 L/min	0.95 L/min	-0.45 L/min	-0.95 L/min
Medium	**P (min,max)**	(-13, 22) psi	(0, 27) psi	(0, 22) psi	(-20, 0) psi	(-13, 0) psi
	Q (max)	1.6 L/min	1.5 L/min	1.8 L/min	-1.5 L/min	-1.8 L/min
Large	**P (min,max)**	(-19, 22) psi	(0, 30) psi	(0, 22) psi	(-26, 0) psi	(-18, 0) psi
	Q (max)	3.1 L/min	3.1 L/min	3.2 L/min	-3.1 L/min	-3.2 L/min

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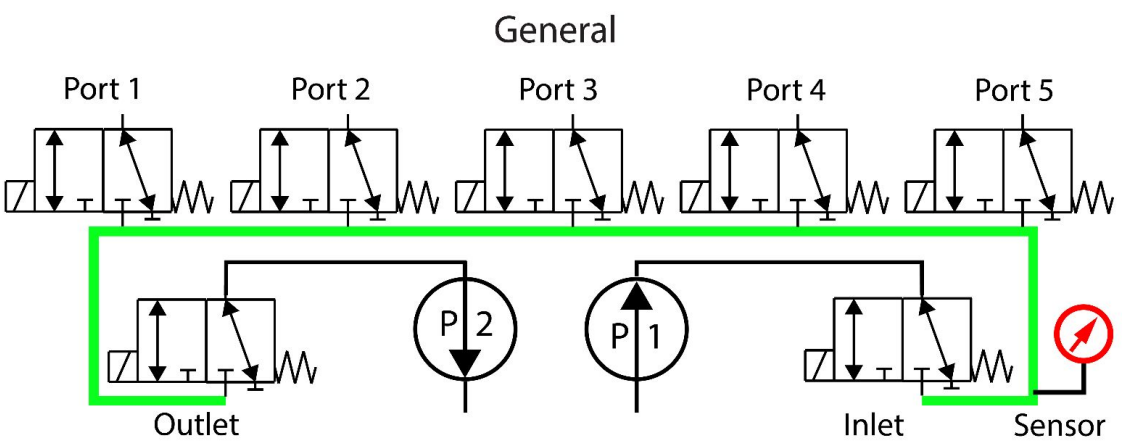

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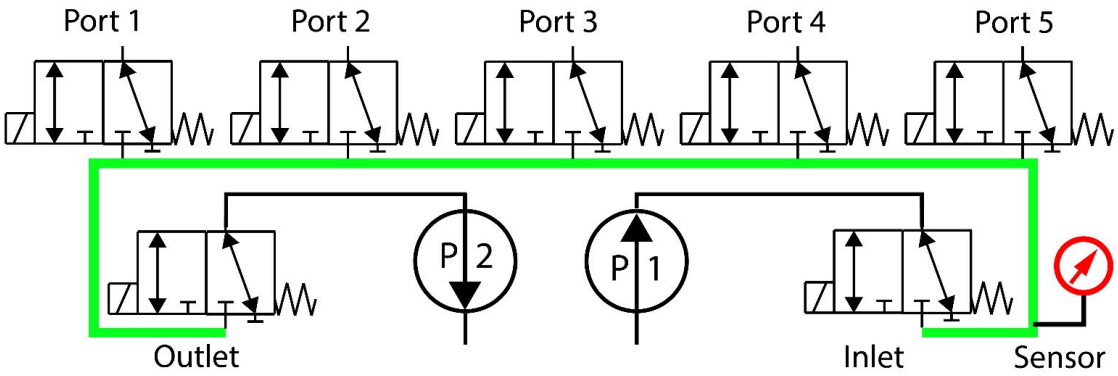
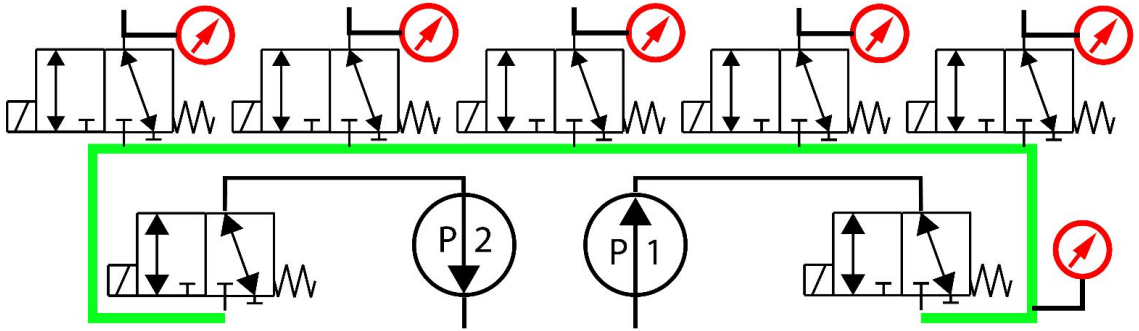
General



General with Sensors++



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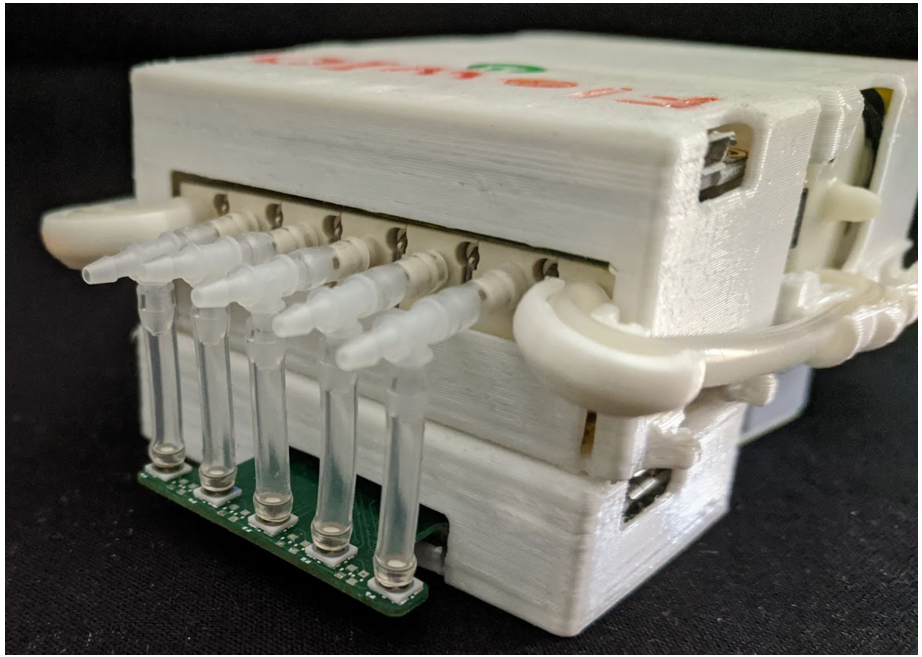
Sensors++

FlowIO with Sensors++



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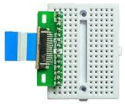
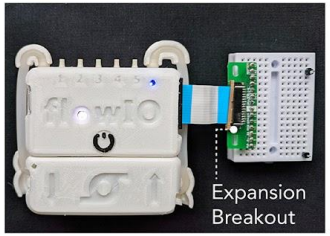
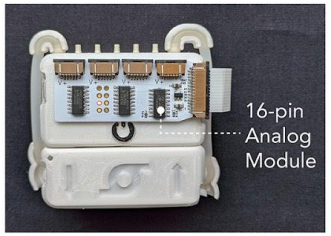
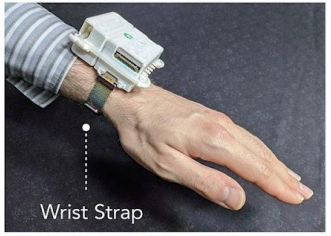
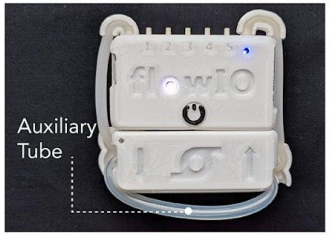
H A R D W A R E

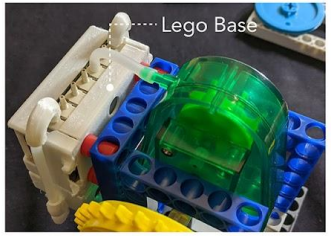
Controller		 Main Module (59 x 33 x 28) mm	
Pumps	 Small (59 x 22 x 28) mm	 Medium (60 x 51 x 28) mm	 Large (70 x 66 x 64) mm
Expansion Modules	 Sensors++	 Expansion Breakout	 16-pin Analog Input
Accessories	 Wrist Strap	 Auxiliary Tube	 Lego Base











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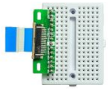
HARDWARE

Controller		 Main Module (59 x 33 x 28) mm	
Pumps	 Small (59 x 22 x 28) mm	 Medium (60 x 51 x 28) mm	 Large (70 x 66 x 64) mm
Expansion Modules	 Sensors++	 Expansion Breakout	 16-pin Analog Input
Accessories	 Wrist Strap	 Auxiliary Tube	 Lego Base

SOFTWARE

Web-GUI

APIs & Libraries

Compatibility

COMMUNITY

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HARDWARE

Controller

Main Module
(59 x 33 x 28) mm

Pumps

Small
(59 x 22 x 28) mm

Medium
(60 x 51 x 28) mm

Large
(70 x 66 x 64) mm

Expansion Modules

Sensors++

Expansion Breakout

16-pin Analog Input

Accessories

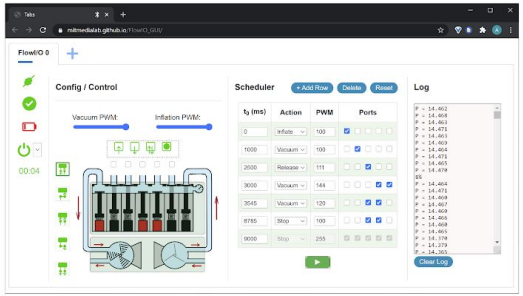
Wrist Strap

Auxiliary Tube

Lego Base

SOFTWARE

Web-GUI



APIs & Libraries

ARDUINO

Compatibility

ANDROID

iOS

COMMUNITY

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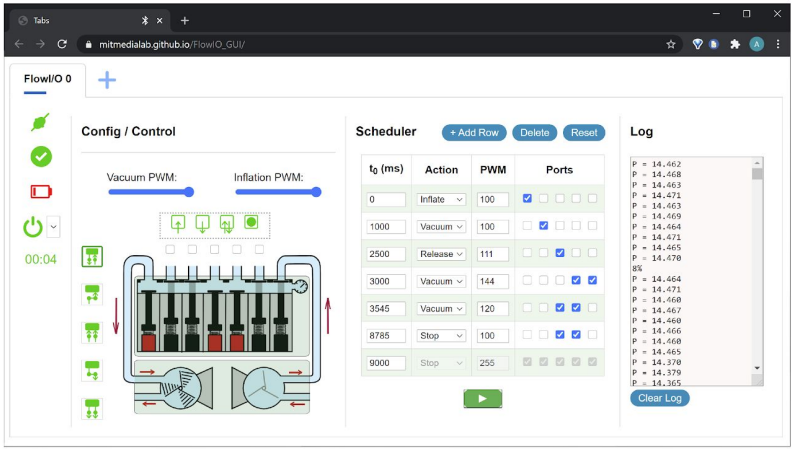
SOFTWARE

Web-GUI



Compatibility

APIs & Libraries

Additional future support for

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You Can Control **FlowIO** from any Device and any OS

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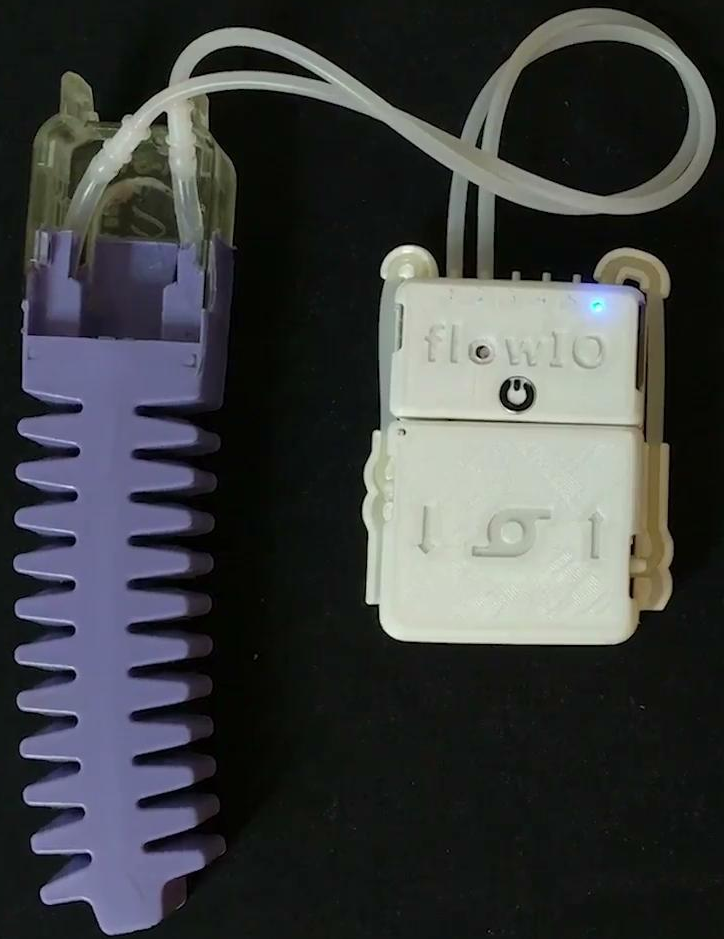
Introduction
Documentation
GUI Overview
GUI
Software Stack
Arduino API

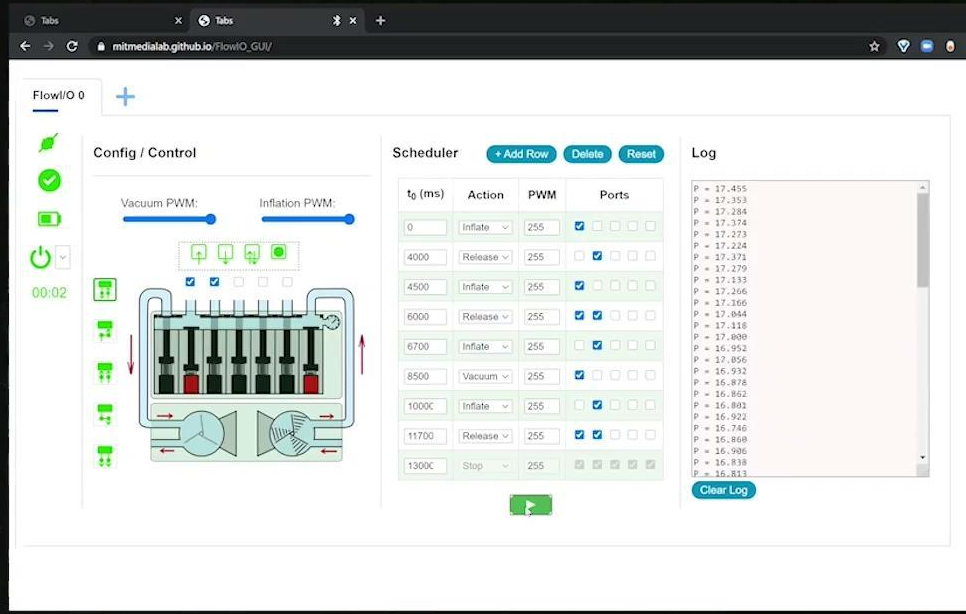
Launch the GUI

After launching the GUI, click the Connect button in the upper left corner to connect to your FlowIO device and activate the controls.

There is much more documentation, tutorials, project videos, and other content that is slowly being added to this website. If interested in helping with any of these or other tasks, please consider volunteering.

Get Involved
Find out how you can help


flowIO


Tabs
Tabs
mitmedialab.github.io/FlowIO_GUI/
FlowI/O 0
Config / Control
Vacuum PWM:
Inflation PWM:
00:02
Scheduler
+ Add Row
Delete
Reset
t0 (ms)
Action
PWM
Ports
0 Inflate 255
4000 Release 255
4500 Inflate 255
6000 Release 255
6700 Inflate 255
8500 Vacuum 255
10000 Inflate 255
11700 Release 255
13000 Stop 255
Log
P = 17.455
P = 17.353
P = 17.284
P = 17.374
P = 17.273
P = 17.224
P = 17.371
P = 17.279
P = 17.133
P = 17.266
P = 17.166
P = 17.044
P = 17.118
P = 17.000
P = 16.952
P = 17.056
P = 16.932
P = 16.878
P = 16.862
P = 16.801
P = 16.922
P = 16.746
P = 16.860
P = 16.906
P = 16.838
P = 16.813
Clear Log

SOFTWARE

Web-GUI

Compatibility

APIs & Libraries

ARDUINO

JavaScript

Additional future support for

SCRATCH

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FlowIO()	Class Definition: **/FlowIO/FlowIO.h** Keywords: **/FlowIO/keywords.txt** Class Source: **/FlowIO/FlowIO.cpp**

CONSTRUCTORS:

`FlowIO(Configuration config);`

`config` - the type of pneumatic configuration. Can be one of the following:
`GENERAL`, `INFLATION_SERIES`, `INFLATION_PARALLEL`, `VACUUM_SERIES`, `VACUUM_PARALLEL`

NOTE: If you specify no parameters in the constructor, then the GENERAL configuration is assumed, where pump1 is for inflation and pump2 for vacuum.

(You must instantiate the flowIO object outside the setup loop, and you must initialize it at the top of the setup loop, before any Bluetooth commands. If you initialize it after you have set up Bluetooth, then you may run into issues.)

You can check the current configuration or change it at any time using the following methods:
`void setConfig(Configuration config);`
`Configuration getConfig();` returns the configuration as a single byte whose value is between 0 and 4.

Pressure-Sensing API

`bool activateSensor();`
Initializes the I2C communication with the integrated pressure sensor, and checks the status byte sent by the sensor.
RETURNS: `true` if the status byte is as expected; otherwise returns `false` and error code 222.

`void setPressureUnit(Unit pUnit);`
Sets the unit that will be used by the getPressure() method. Use this method only if you want to change the default - PSI. You can change the units at any point in the code. Possible argument values are `PSI`, `ATM`, `KPA`, `PA`, `MBAR`.

`float getPressure();`
Gets a new absolute pressure reading from the integrated sensor in terms of the unit in `setPressureUnit()`.

`float getPressure(Unit pUnit);`
Gets a new absolute pressure reading from the integrated sensor in terms of the unit specified in the argument.
Possible argument values are `PSI`, `ATM`, `KPA`, `PA`, `MBAR`.

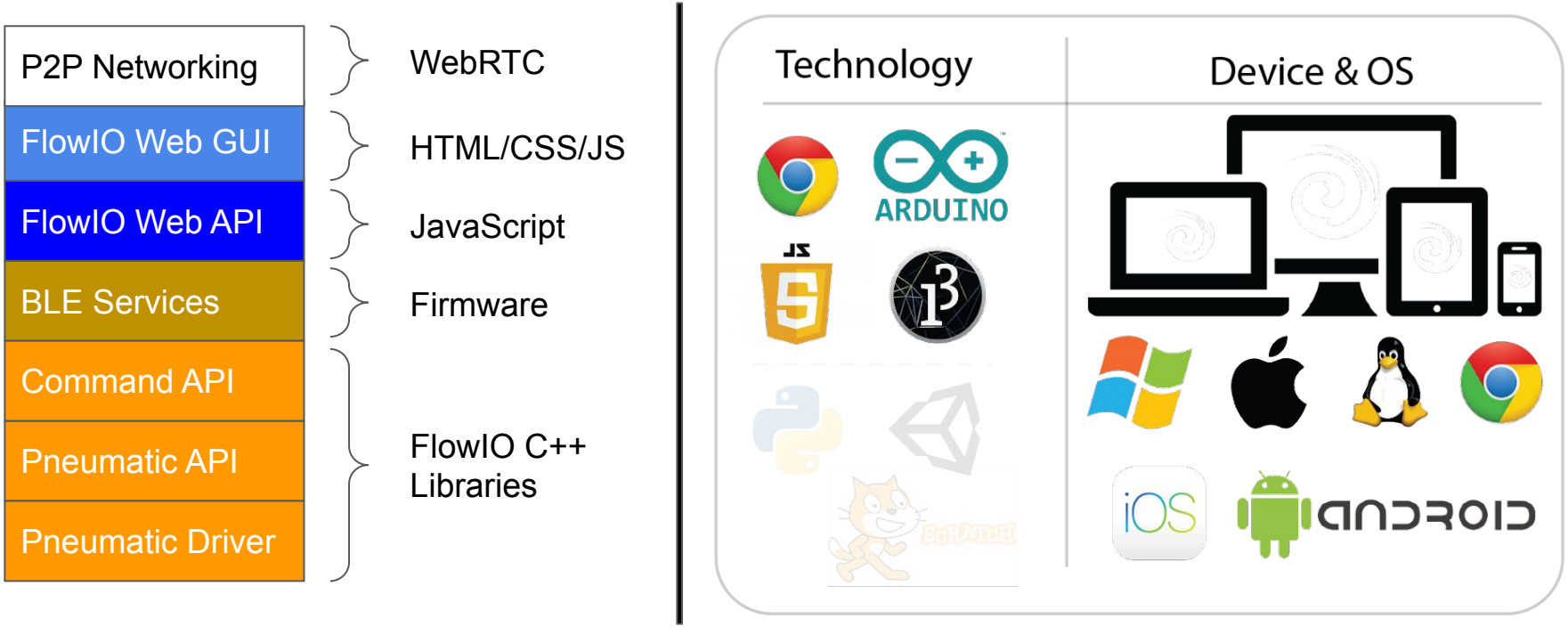
NOTE: Sensor must be activated before requesting pressure. Otherwise `getPressure()` will return the value 888.8.

Indicators API

`void blueLED(bool power);` Controls the onboard led. The argument can be either `LOW / 0` or `HIGH / 1`.
`void pixel(uint8_t red, uint8_t green, uint8_t blue);` Controls the onboard neoPixel color and intensity.. For highly-dynamic actions involving the neoPixel LED, avoid using this method, and instead use the methods from the Adafruit_Neopixel library directly, because the efficiency and speed are much better.
`void raiseError(uint8_t error);` Sets the value of the internal error flag.
`uint8_t readError();` Reads the value of the internal error flag. See the error code table on the last page.
`uint16_t getHardwareState();` Returns a 16-bit value, where each bit maps to the state of a hardware component.
`bool getHardwareStateOf(Component ComponentName);` Takes the enum-defined component name,
`bool getHardwareStateOf(uint8_t bitNumber);` Takes the bit number corresponding to a particular component,
Returns `true` if that component is active / on, otherwise it returns `false`.

Bit #	11	10	9	8	7	6	5	4	3	2	1	0
Component	SENSOR	LEDBLUE	LEDRED	PUMP2	PUMP1	OUTLET	INLET	PORT5	PORT4	PORT3	PORT2	PORT1

Software Stack



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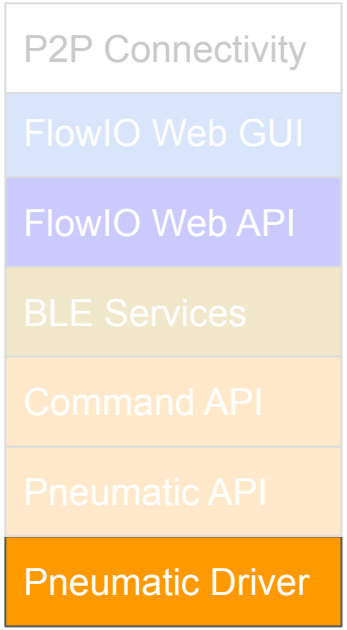
Pneumatic Driver



- Controls primitive tasks involving single pneumatic components
- C++ Library that is Arduino compatible.
- Representative functions include (not full list):
  - `void startPump(uint8_t pumpNumber,uint8_t pwmValue=255);`
  - `void stopPump(uint8_t pumpNumber);`
  - `void openInletValve();` *(right side)*
  - `void closeInletValve();`
  - `void openOutletValve();` *(left side)*
  - `void closeOutletValve();`
  - `void setPorts(uint8_t ports);`
  - `void openPorts(uint8_t ports);`
  - `void closePorts(uint8_t ports);`
  - `void powerOFF();`

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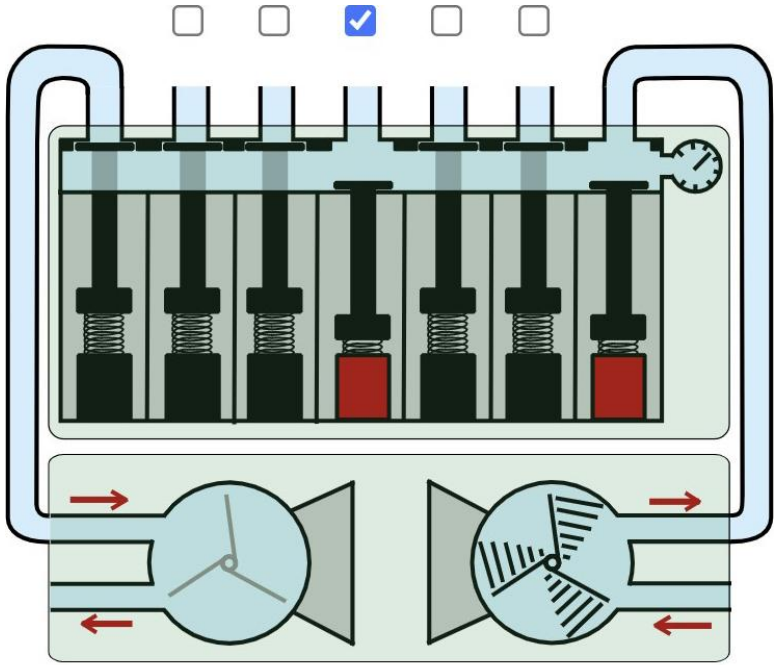

```
flowio.startPump(1,255);
flowio.openInletValve();
flowio.openPorts(0b00000100);
float p = flowio.getPressure()
    *
    *
    *
flowio.closePorts(0x04);
flowio.stopPump(1);
flowio.closeInletValve();
```


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Pneumatic API

- Controls entire activities involving combinations of components and multiple tasks done in the appropriate sequences.
- C++ Library that is Arduino compatible.
- Representative functions include (partial list):
  - `void startInflation(uint8_t ports,uint8_t pwmValue=255)`
  - `void startVacuum(uint8_t ports, uint8_t pwmValue=255)`
  - `void startRelease(uint8_t ports)`
  - `void stopAction(uint8_t ports)`
  - `uint16_t getHardwareState()`
  - `float getPressure(Unit pUnit)`

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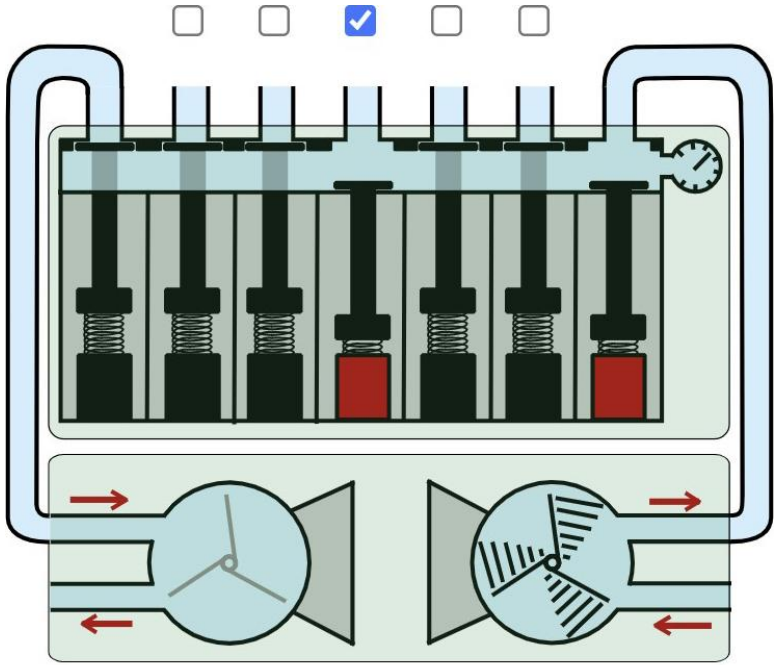

```
flowio.startInflation(0x04,255);
float p = flowio.getPressure()
    *
    *
    *
flowio.stopAction(0x04);
```


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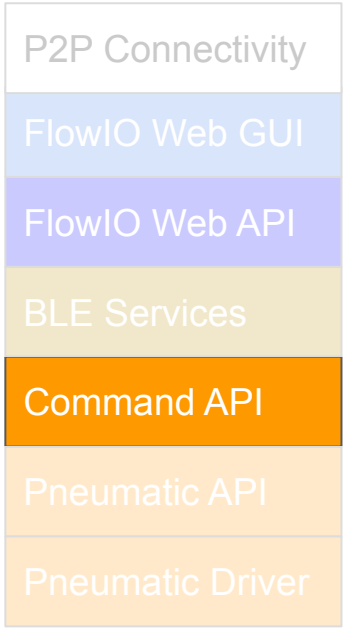
Command API



- A command-control interface for FlowIO.
- C++ Library that is Arduino compatible.
- 3-bytes that encode for **What**, **Where**, and **How**
- Returns the pressure value.
- Example: Start Vacuum on ports 3 and 4 with pwm of 50% duty cycle would be sent as the command : **('-', 0b00001100, 127)**

```
float command(uint8_t action, uint8_t ports, uint8_t pwmValue=255)
```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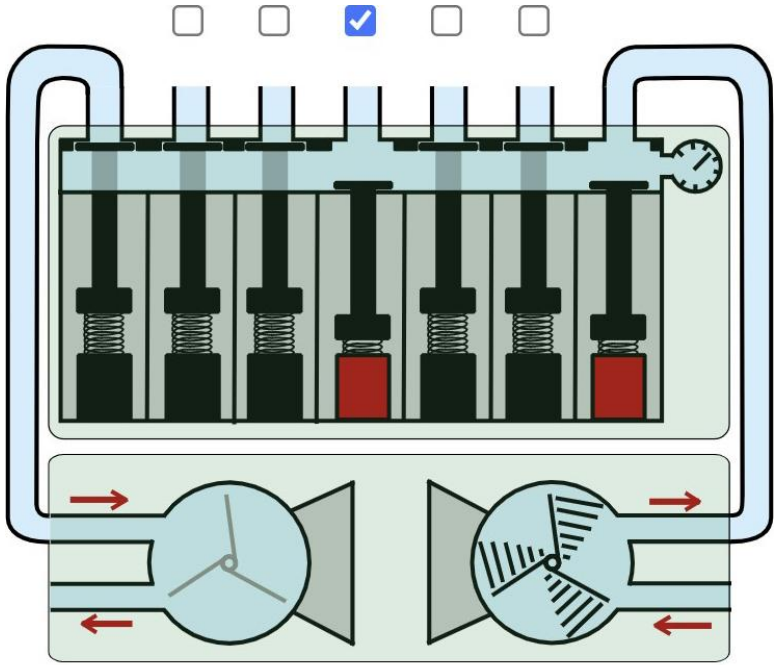

```
p = flowio.command('+', 0x04, 255)
    *
    *
    *
flowio.stopAction(0b00000100);
```


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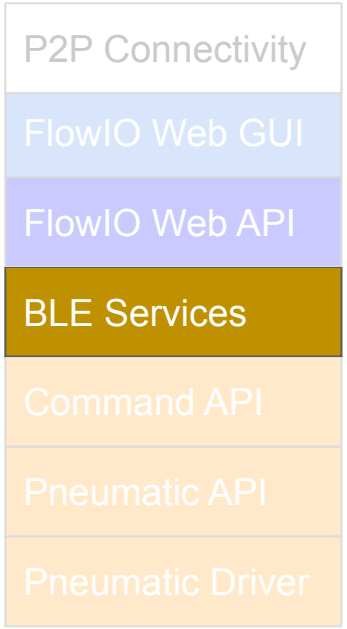
Bluetooth LE Services



- Firmware running on the FlowIO device
- 7 custom Bluetooth services with multiple characteristics:
  - **indicator Service**
  - **config Service**
  - **control Service**
  - **pressure Service**
  - **gpio Service**
  - **power Off Service**
  - **battery Service**
- This is the layer that enables you to control everything on FlowIO via Bluetooth Low Energy!

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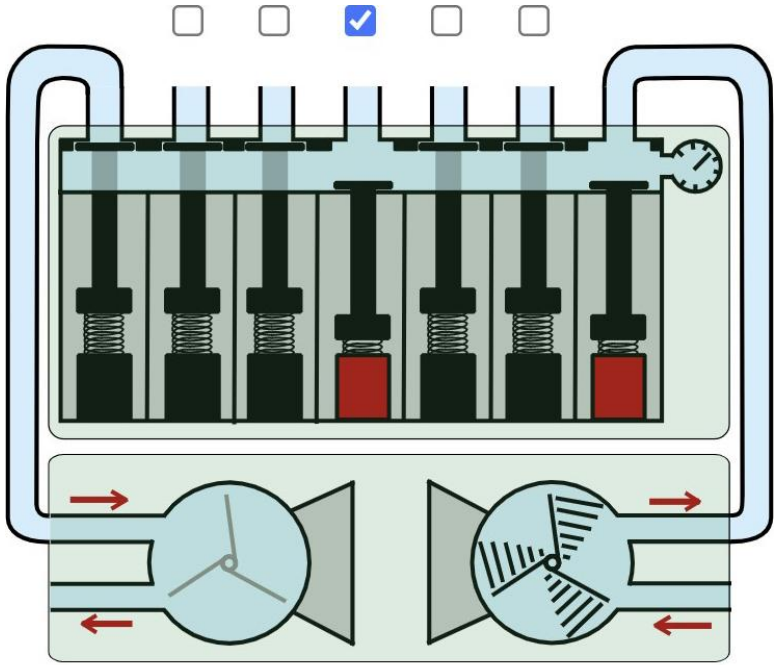

Control Service

Command Characteristic

+	0x04	255

Hardware Status Characteristic

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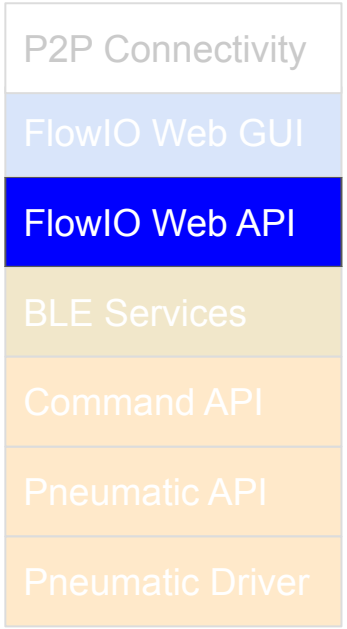
Web API



- An object-oriented JavaScript API
- Compatible with Google Chrome
- Based on Web-Bluetooth protocol
- Based entirely on the custom BLE services from the layer below.
- Runs in the web-browser, and is capable of executing computationally-heavy tasks.
- No software of drivers downloads needed to be installed.
- Requires only Google Chrome, making it compatible with just about any device and operating system.

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P2P Connectivity

FlowIO Web GUI

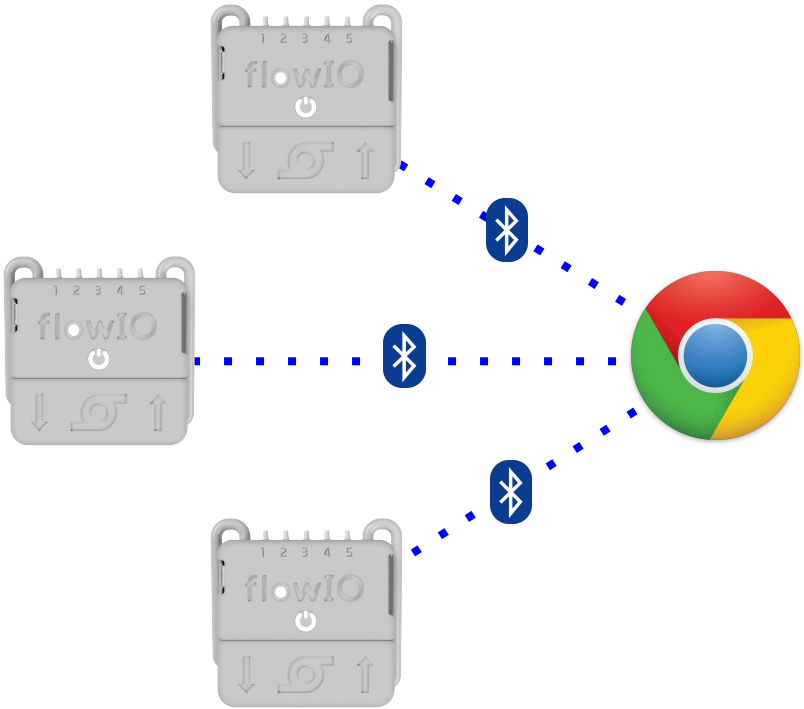
FlowIO Web API

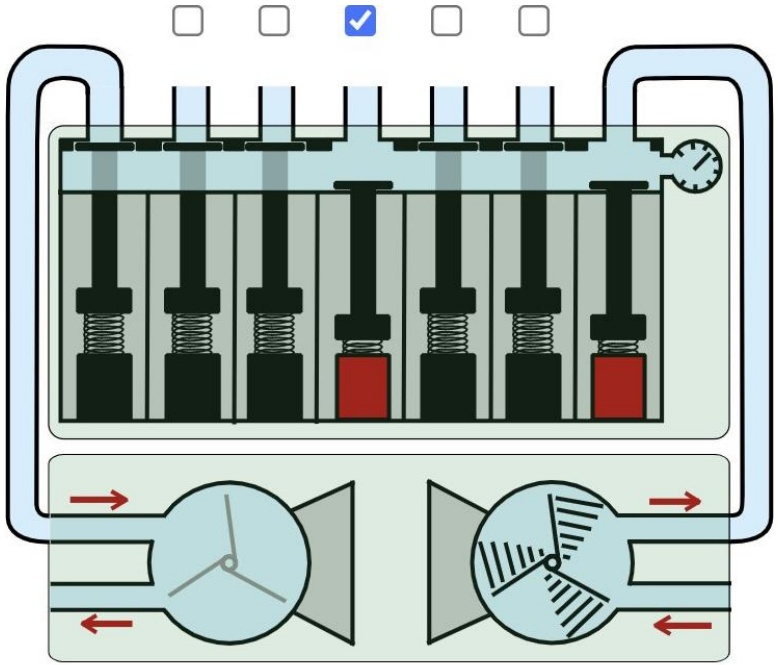
BLE Services

Command API

Pneumatic API

Pneumatic Driver





```
p = flowios[0].command('+', 0x04, 255)
    *
    *
flowios[0].stopAction(0x04)
```

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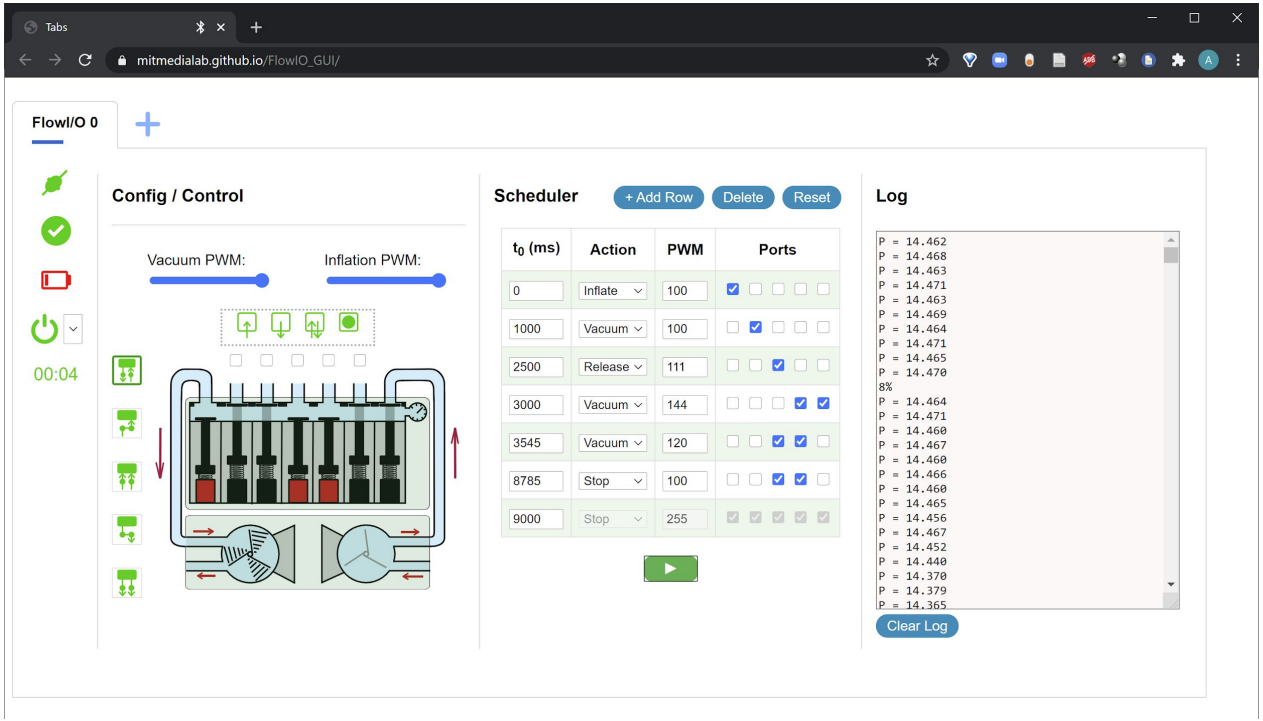
Web GUI

- P2P Connectivity
- **FlowIO Web GUI**
- FlowIO Web API
- BLE Services
- Command API
- Pneumatic API
- Pneumatic Driver



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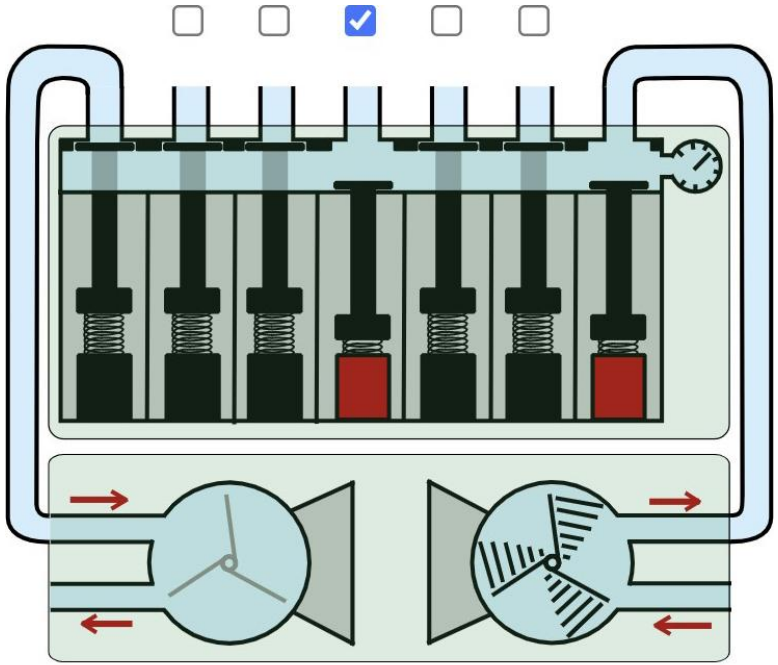

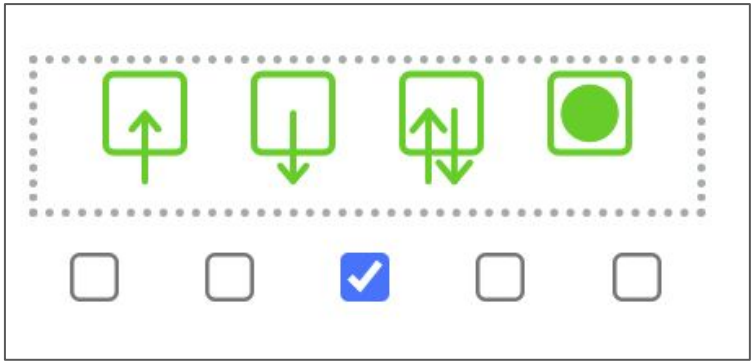

Scheduler + Add Row | Delete | Reset

t_0 (ms)	Action	PWM	Ports
0	Inflate	255	☐ ☐ ☑ ☐ ☐
2000	Stop	255	☑ ☑ ☑ ☑ ☑

▶

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Peer-to-Peer Networking

P2P Networking

FlowIO Web GUI

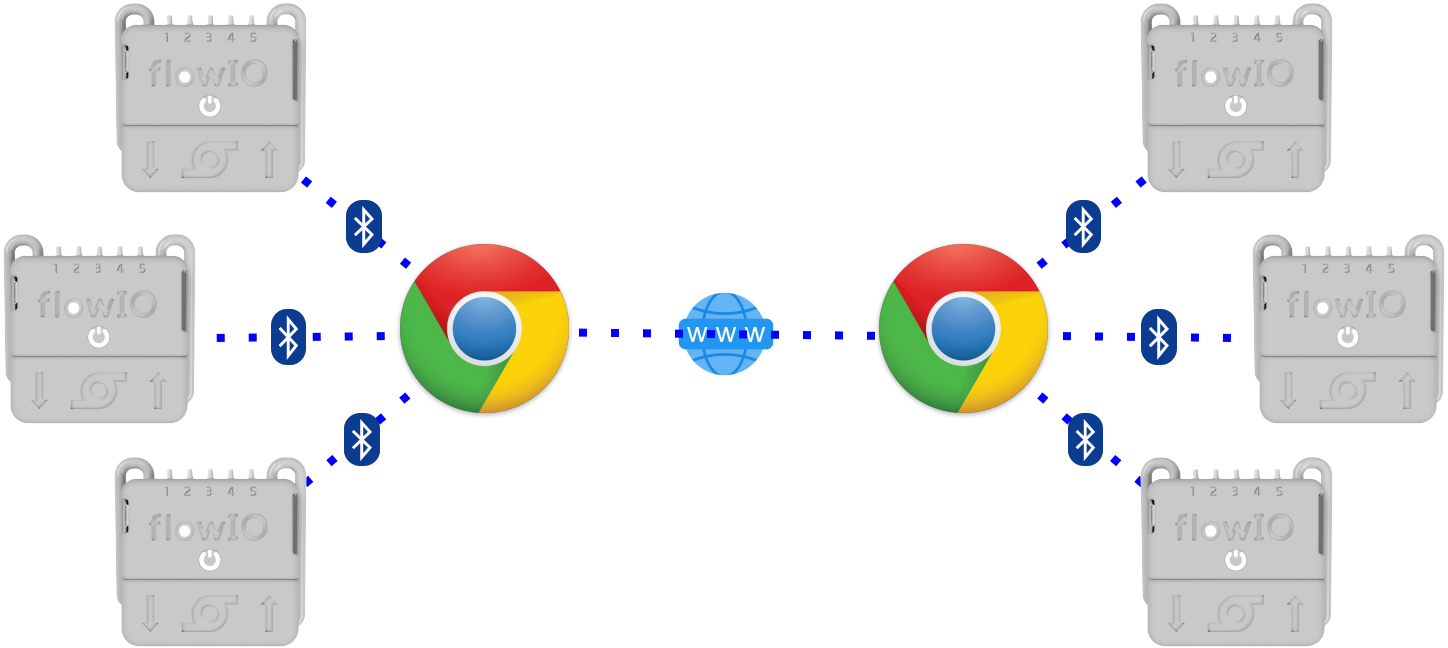
FlowIO Web API

BLE Services

Command API

Pneumatic API

Pneumatic Driver



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Other Notable Features

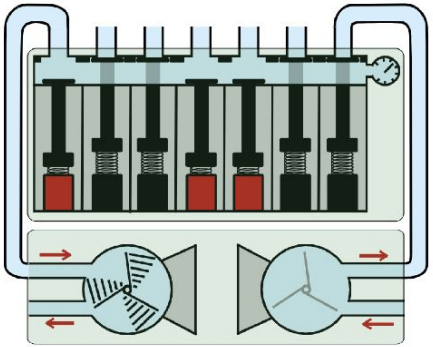
Auto-Off Timer

00:04

Battery Level Indicator

Configuration Selector

Real-Time Hardware Feedback



Pressure Indicators

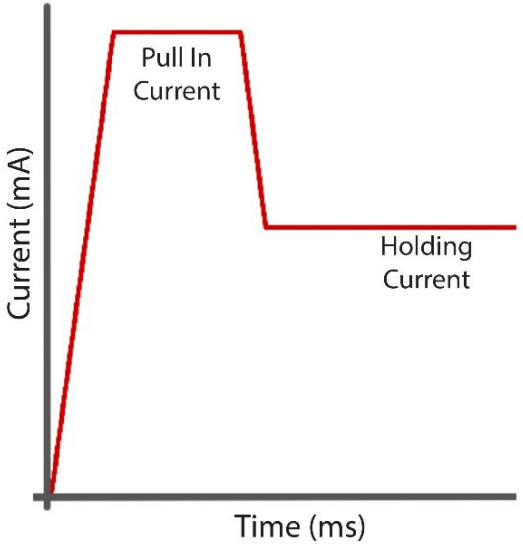
PWM Flow Control

Vacuum PWM:

Inflation PWM:

Hardware Status & Error Detection

Power Saving Algorithms



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HARDWARE

Controller

Main Module
(59 x 33 x 28) mm

Pumps

Small
(59 x 22 x 28) mm

Medium
(60 x 51 x 28) mm

Large
(70 x 66 x 64) mm

Expansion Modules

Sensors++

Expansion Breakout

16-pin Analog Input

Accessories

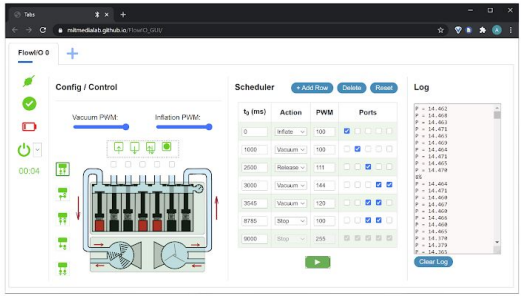
Wrist Strap

Auxiliary Tube

Lego Base

SOFTWARE

Web-GUI



APIs & Libraries

ARDUINO

Compatibility

ANDROID

iOS

COMMUNITY

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HARDWARE

Controller

Main Module
(59 x 33 x 28) mm

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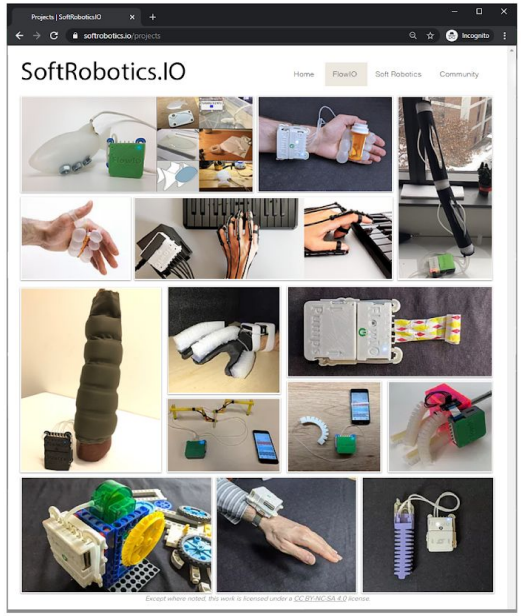
COMMUNITY



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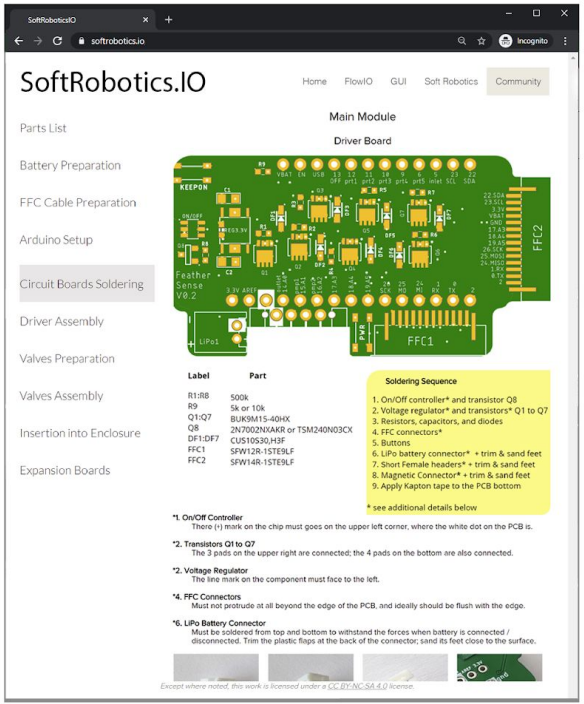
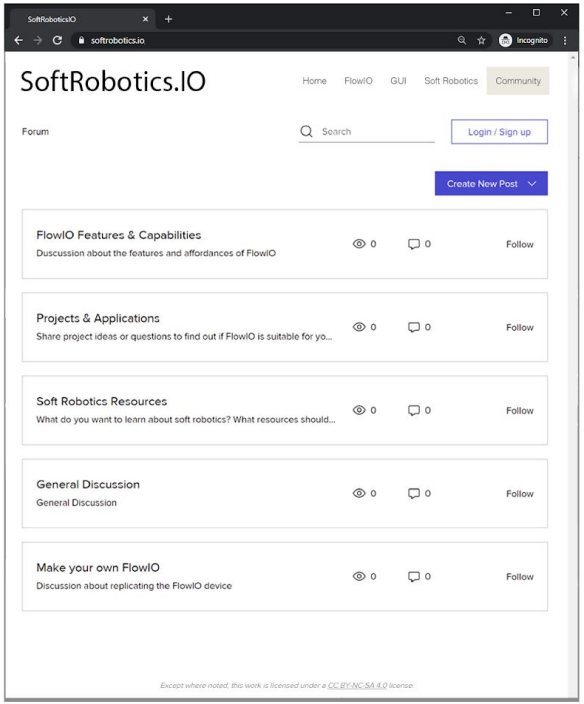
COMMUNITY

Projects

Documentation



Forums



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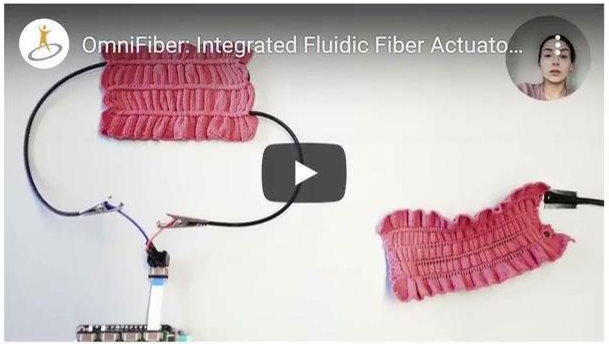
Robotic fibers can make breath-monitoring ...


OmniFiber: Integrated Fluidic Fiber Actuato...


FlowIO


Turbidity: 0.2 NTU

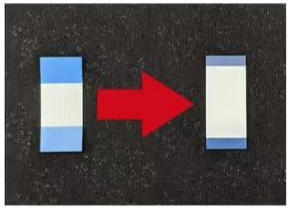

Application: Piano Skill Glove


Application: Tangible Message


Application: Larynx Actuation

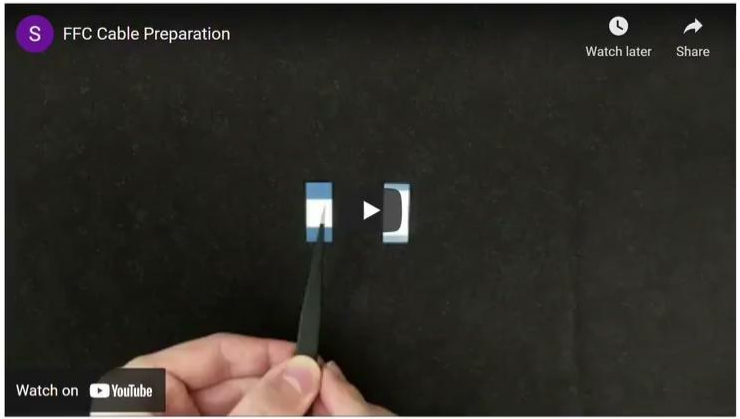

Application: Robotic Toy

FFC Cable Preparation



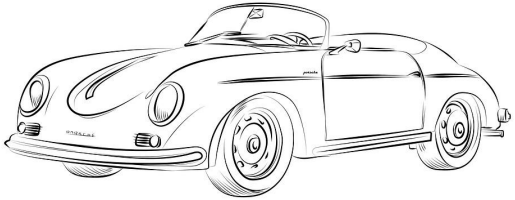
We will prepare the 12-pin FFC cable now in the form needed for the final assembly. We will simply need to trim some of the blue plastic on both sides, so that we can bend the cable where we need. We will need the following items:

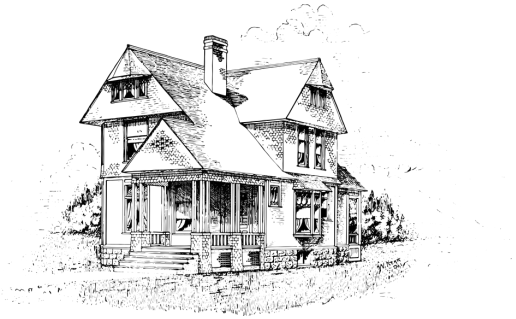
- 12-pin FFC cable
- Hot-air gun
- 12-pin FFC connector
- Knife

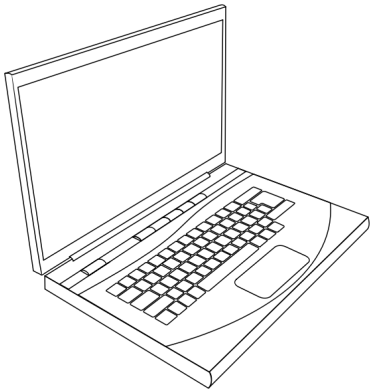


There is much more documentation, tutorials, project videos, and other content that is slowly being added to this website. If interested in helping with any of these or other tasks, please consider volunteering.

Get Involved
Find out how you can help







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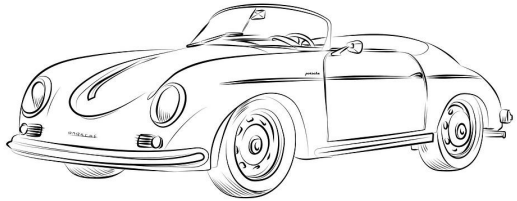

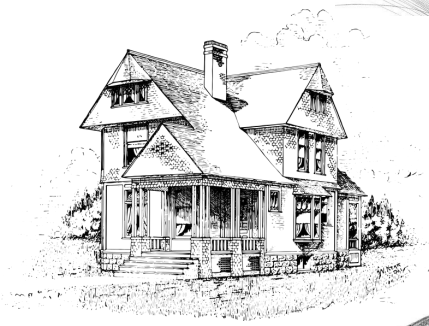

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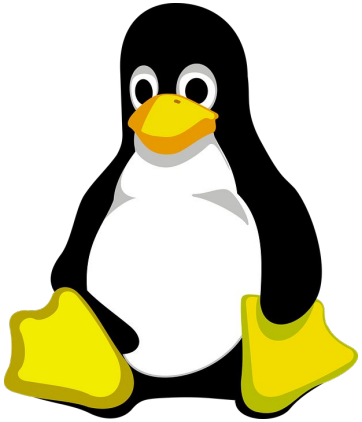

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FlowIO is Creative Commons Hardware…

…and is provided FREE of charge to approved users

Forums
Workshop Intro
Workshop MSRs
Projects
Institutions
Review Articles

Soft Robotics Workshop
How To Make (Almost) Anything, Fall 2019

Ali Shtarbanov
MIT Media Lab
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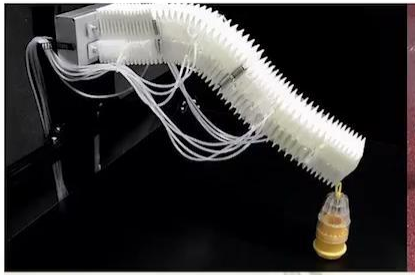
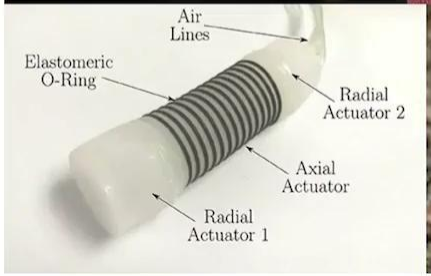
Soft Robots

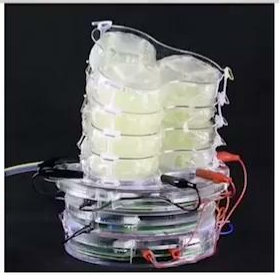
Systems built from highly-compliant materials with mechanical properties similar to those found in living tissues. Many kinds of soft robots exist, but in this workshop we will focus primarily on pneumatically actuated soft robots.



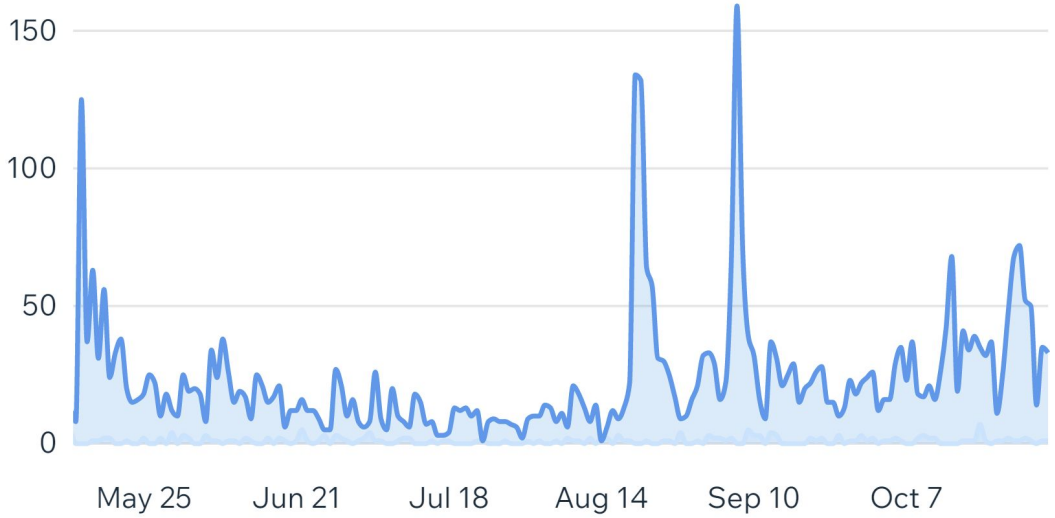




SoftRobotics.IO Analytics



Monthly Visitors: 1000+

Site Members: 260+

FlowIO Request Proposals: 65

FlowIO Devices Given: 18

Volunteers: 15

Donors: 14

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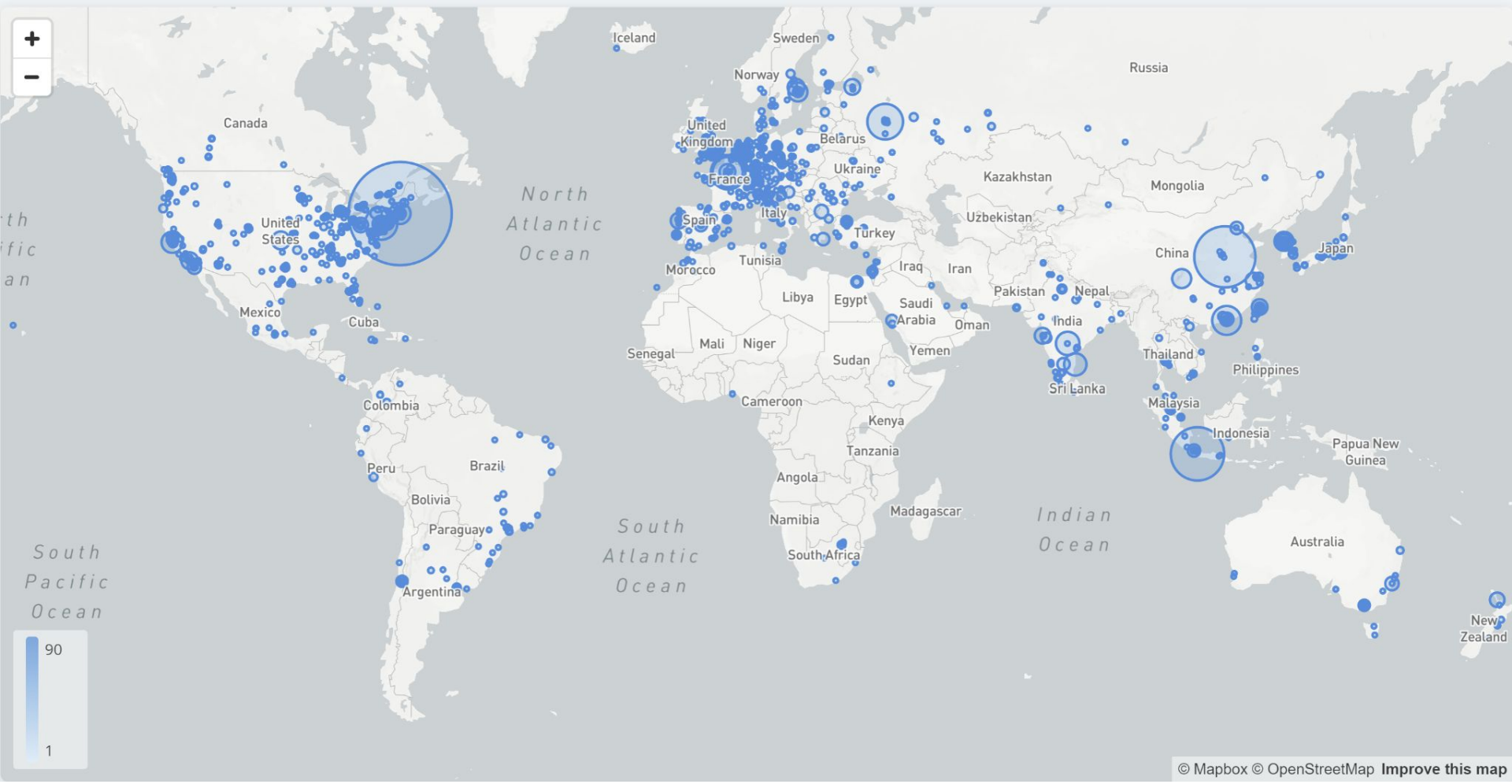
FLOWIO TAKES TOP HONORS IN THE 2021 HACKADAY PRIZE

by: Dan Maloney

7 Comments

November 20, 2021



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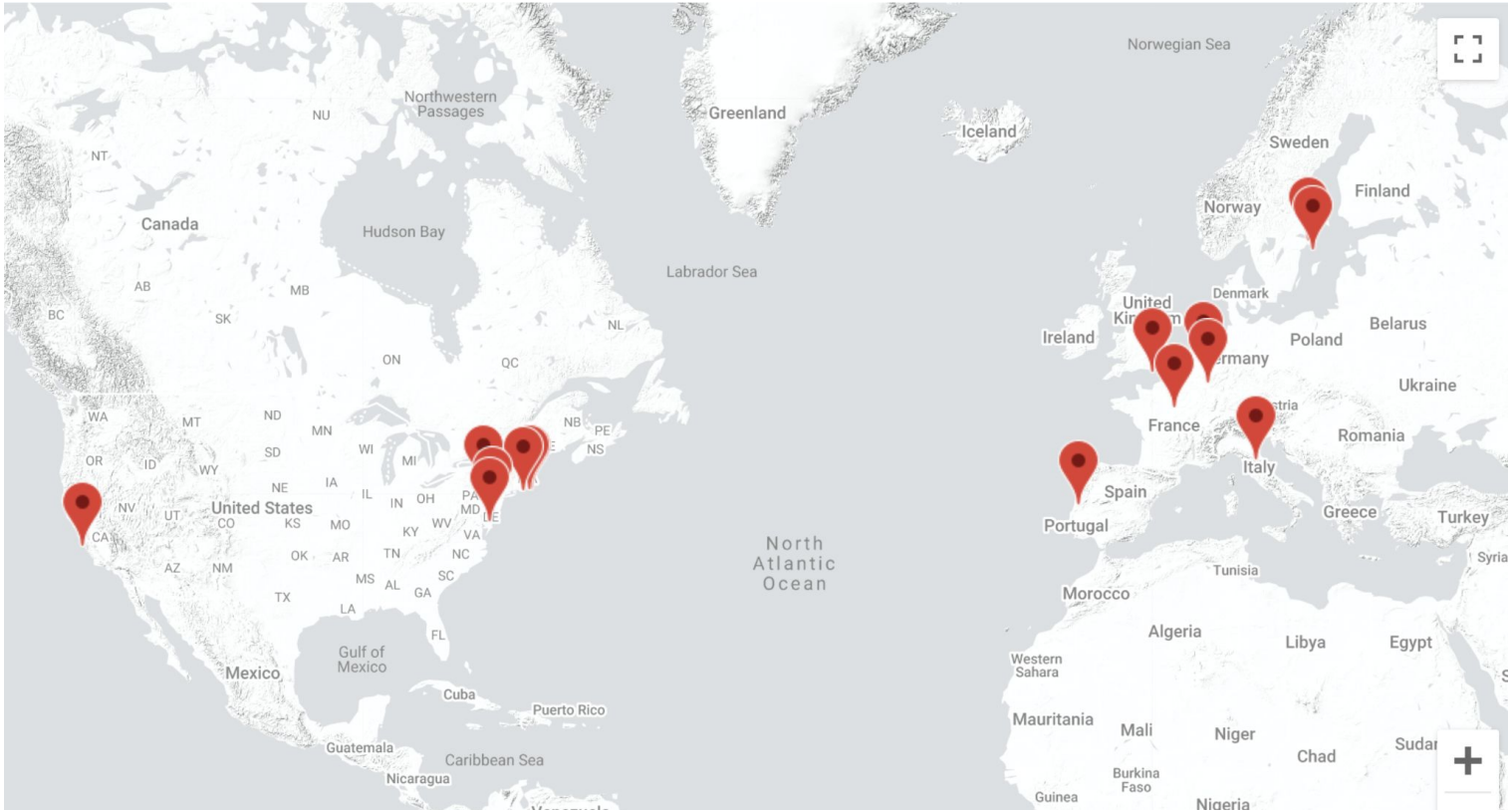
18 FlowIO Devices Given to Date



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Awards for FlowIO

SUPPLYFRAME DESIGNLAB
HACKADAY PRIZE 2021

STUDENT
RESEARCH
COMPETITION

INTERNATIONAL
DESIGN
EXCELLENCE
AWARDS

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Donations

Alive Leyang Xiao
Brad Holschuh
David Saldana
Ed Moriarty
Francesco Bondesani
Hyejun Youn
Irmandy Wicaksono
Karthik Chandrasekaran
Markus Nemitz
Muhammed Oguz Yildiz
Neil Gershenfeld
Ozgun Afsar
Thrishantha Nanayakkara
Wanhui Li

Applications

Ali Shtarbanov
Bai Li
Francesco Bondesani
Hyejun Youn
Irmandy Wicaksono
Michael Bell
Ozgun Afsar
Xinlei Zhang

Graphics

Ali Shtarbanov
Hyejun Youn
Ozgun Afsar

Content

Ali Shtarbanov
Hyejun Youn
Layal Barakat

Advice

Joseph Paradiso
Jie Qi
Ed Moriarty
Michael Bell

GUI

Ali Shtarbanov
Alisha Fong
Yoav Luft

Electronics

Ali Shtarbanov

Mechanical Design

Ali Shtarbanov

Software Stack

Ali Shtarbanov

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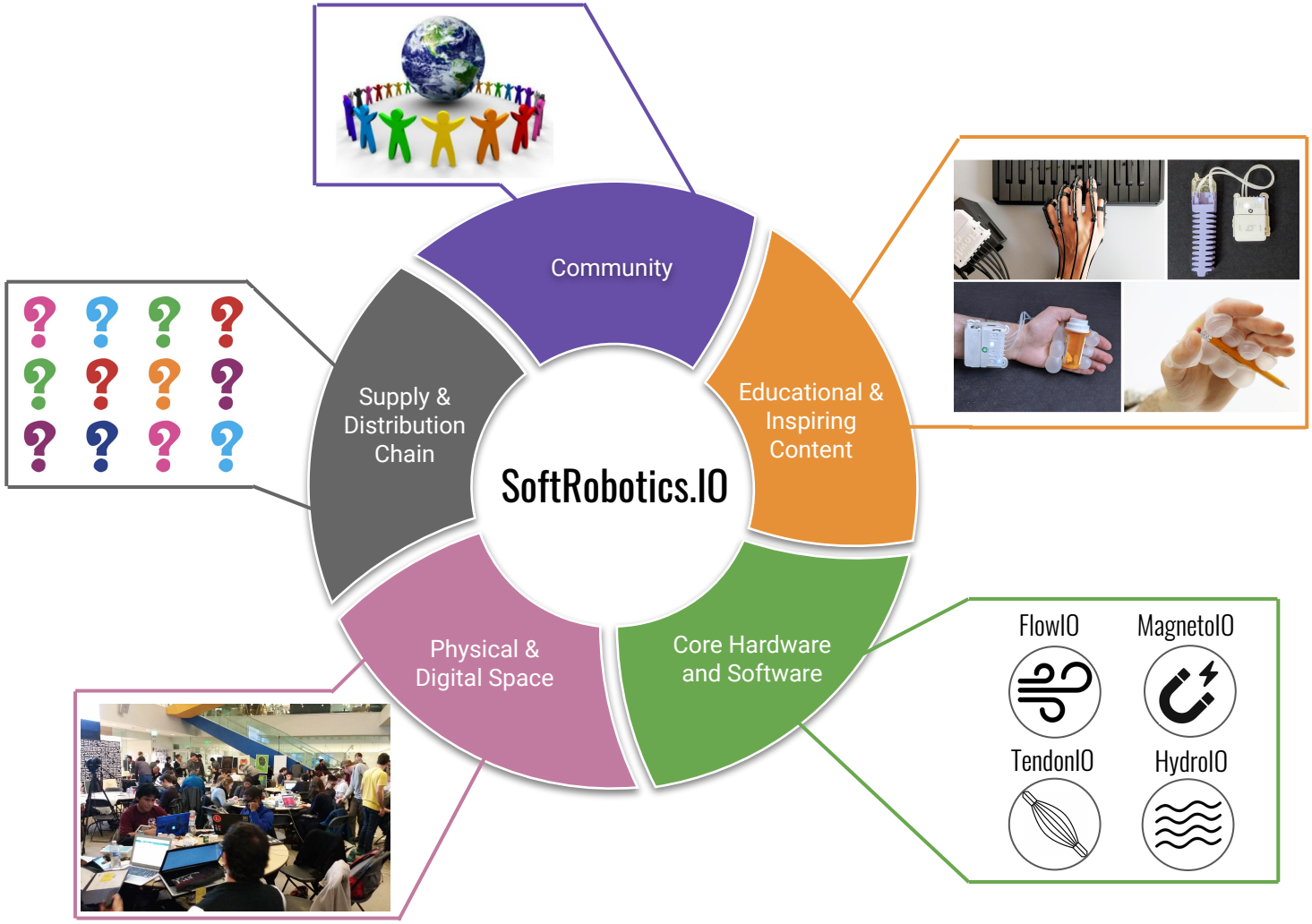

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I want to create a world...

- ...where creative opportunities are not restricted to only those who can afford them.
- ...where the objects around us are programmable and reconfigurable.
- ...where disabled individuals can create by themselves the unique solutions they need.
- ...where building a prototype takes just days or weeks instead of months or years.
- ...where the tools for prototyping and innovation are very powerful yet very simple to use.
- ...where people don’t have to give up on an amazing idea just because it’s too complex to build.
- ...where people are motivated, inspired, and have the means to make the world better themselves.

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To democratize and enable rapid prototyping and innovation opportunities in emerging fields for researchers, designers, artists, and makers from all technical and socioeconomic backgrounds

through development and **deployment** of enabling platforms that are highly versatile, general purpose, and simple to use by anyone.

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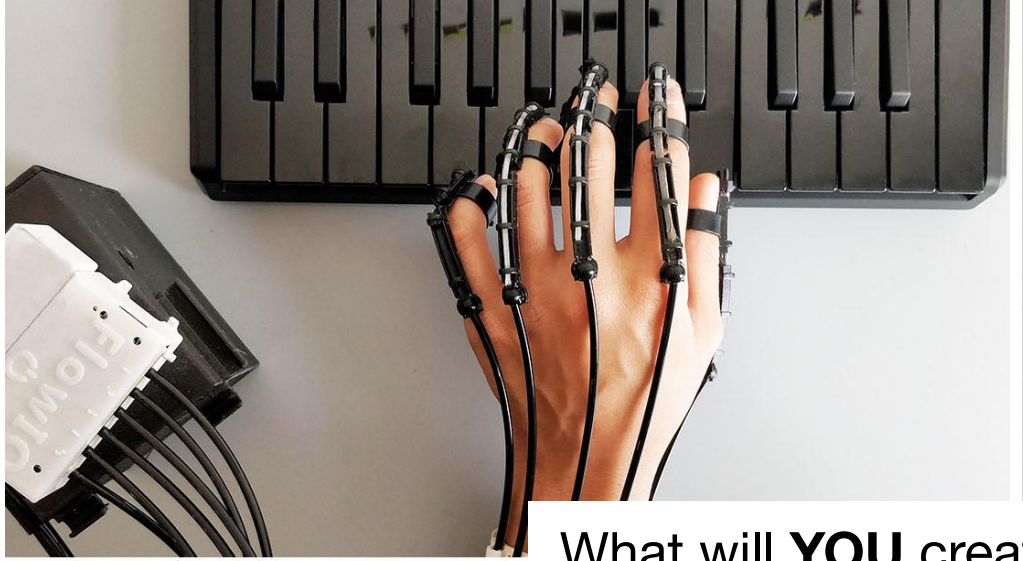
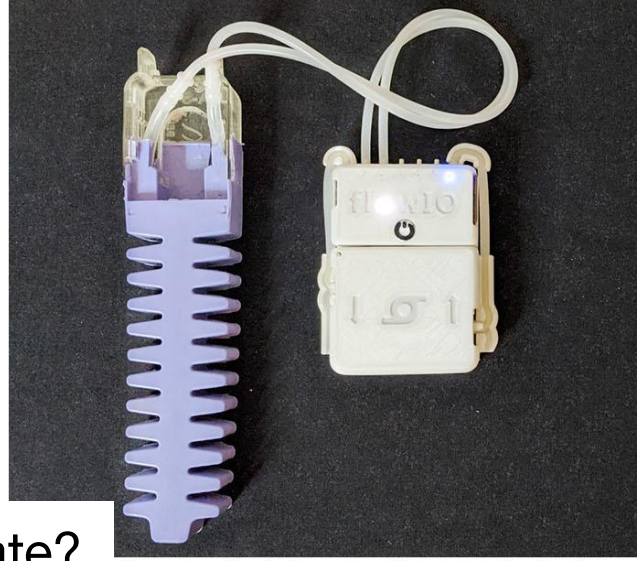
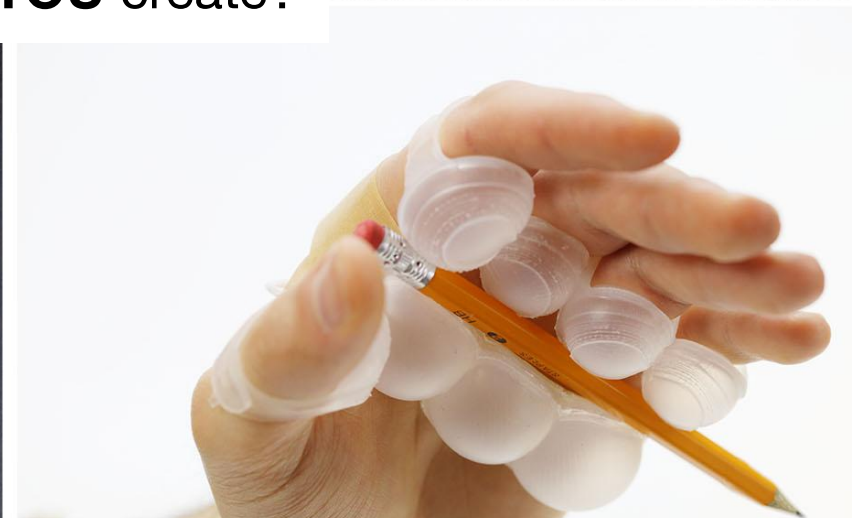




What will **YOU** create?



Software Stack Details

Make a slide about the web-connectivity layer and discuss the webrtc p2p protocol.

Pros and Cons

Cost to make is high but is free to obtain

Making FlowIO is very challenging and requires lots of modifications to parts.

Project is still far from complete - both hardware and software-wise.

More Documentation is still needed

More examples are needed

Graphical User Interface needs more work.

Notable Projects Made with FlowIO

Peristaltic Suit

Omnifiber

The Power of Modularity

Extendable and ability to make new modules in the future.

Others can design their own modules for FlowIO

List all other benefits or modularity from my general exam talk.

Sensors in Flowio

Alternative microcontrollers possible

People from all around the world have contacted me and got many invites to give talks and visit places

A great way to form new collaborations

Wearable first design approach

Include some slides about the evaluation with users.