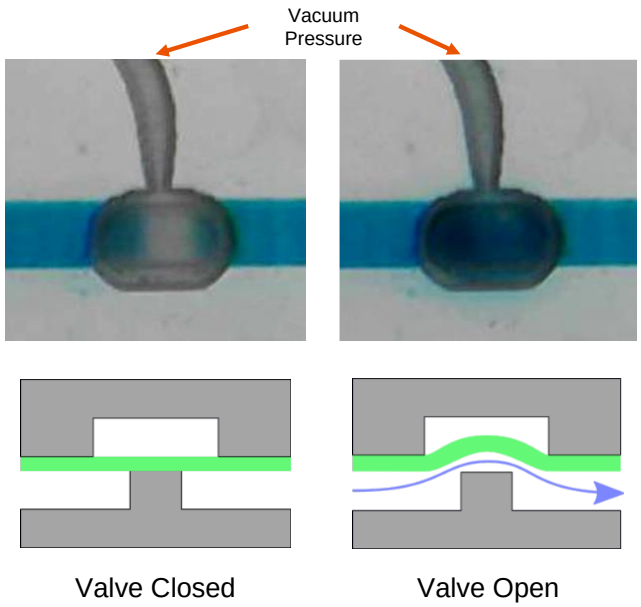
Microfluidics

I worked on microfluidic valves and circuits in the Hui Lab at UC Irvine. I took part in creating a **new valve design** for more consistent pumping to make monodisperse droplets. The valve consistency was measured through a **computer vision script** made in MATLAB and Processing (programming package). This work contributed to a paper published in Micromachines [***Micromachines*** (2022)].

New Valve Design – Truncated Valve Ceiling

Microfluidic valves operate by applying vacuum pressure to the top side of a chamber, allowing for an elastomer to deform into the chamber. This allows for the flow of liquid in the bottom channel. This operation is very similar to a transistor's operation. In fact, resistor-transistor logic circuits can be made with these valves, allowing for basic computation.

In the figure below, a ring oscillator is made from 3 of valves and is used to drive a peristaltic microfluidic pump, also made of 3 valves. When a valve is closed, the liquid in the top chamber is pushed out into the connecting channels. Directional pumping is achieved by using surrounding valves to close off one channel.



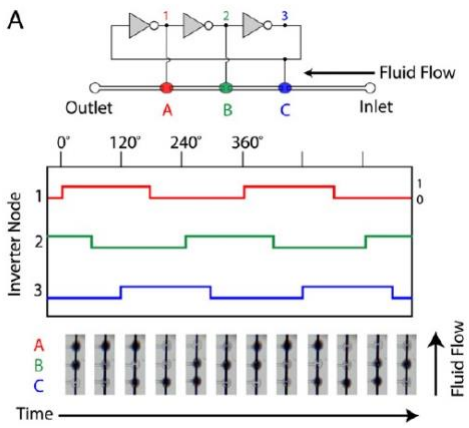


Fig 3.1 Peristaltic pumping using a ring oscillator and three pumps.
[Duncan, et al. (2013) *Pneumatic oscillator circuits for timing and control of integrated microfluidics*]

Figure 1: (Left) Close up of a closed and open microfluidic valve and a schematic of the cross-section. The valve consists of three layers: pneumatic (top layer), elastomer, liquid (bottom layer). A schematic of the peristaltic pumping configuration is shown (right), consisting of a ring oscillator and three pumping valves.

The magnitude of vacuum pressure applied to the valve determines the amount of deflection, and thus the amount of liquid pumped by each valve actuation. A consistent pumping volume is critical in making monodisperse droplets for accurate dosing of solutions. A lowered valve ceiling (among other strategies) can effectively control the volume of liquid pumped by the valve. Essentially, the valve is driven to saturation on each stroke, ensuring a consistent volume.

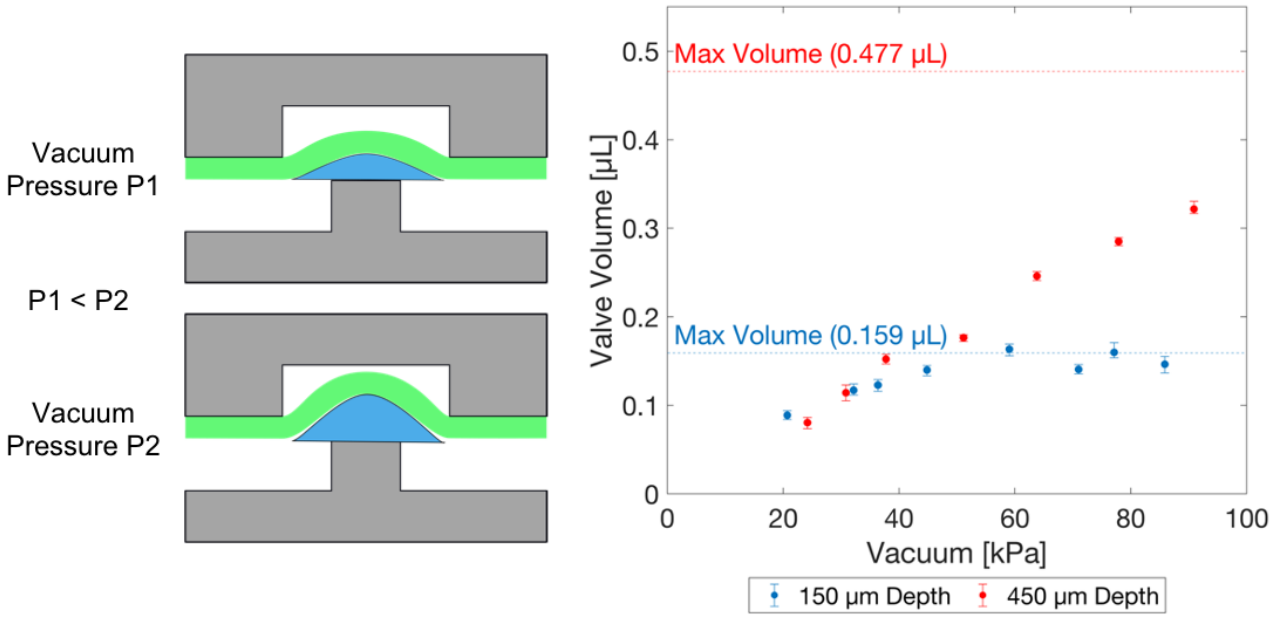
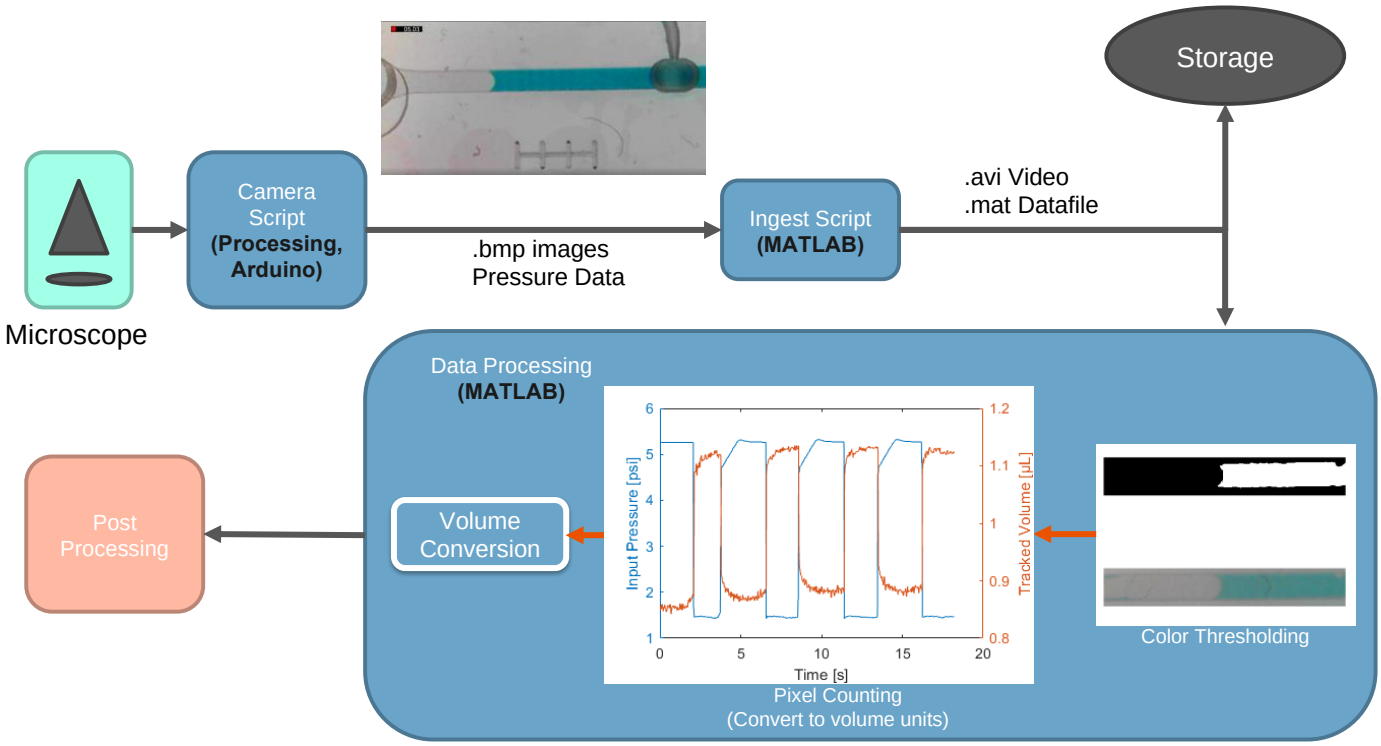


Figure 2: (Left) Schematic of how the vacuum pressure changes the volume of liquid pumped by a valve. (Right) Plot of a normal valve (450µm depth) and a truncated valve (150µm depth) actuated at different pressures.

Computer Vision Workflow



To measure the small volume of liquid (<1 µL) pumped by these microfluidic valves, a digital microscope was used to record the movement of liquid through a channel as the valve was actuated on and off. The applied pressure on the valve was concurrently recorded. The data acquisition has the following requirements:

- Speed is critical in real time operation. A higher framerate allows more temporal detail to track the volume change over time.

- After recording, storage space is a concern because we would like to save the video streams of many experiments.

Uncompressed .bmp images were saved because the compression from saving as .png or a video format significantly decreased the recording framerate. Although .bmp images take up a lot of space, we only have 1 video stream at a time, so the amount of memory storage is not a concern. The .bmp images were then ingested by a MATLAB script for storage as a .avi file and .mat file to save space.

Color thresholding on each of the video frames was done to find where the liquid is in each frame and the area was integrated to find the volume of liquid in the frame. As the valve is actuated, the liquid in the channel moves left and right, increasing and decreasing the number of “water pixels” are in the frame. This allows us to find the volume of liquid pumped by the valve.

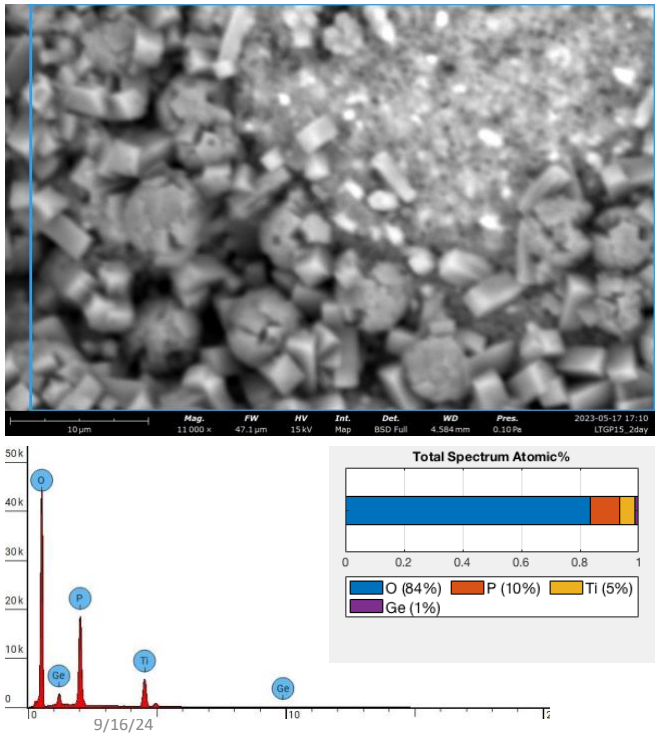
Automatic SEM Processing

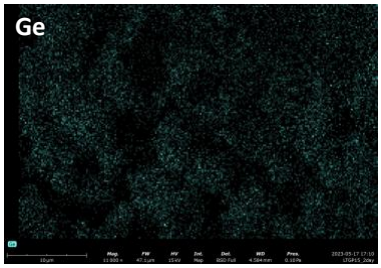
Scanning Electron Microscopy paired with Energy Dispersive Spectroscopy (SEM/EDS) images enable high magnification analysis of a sample's morphology and chemical composition. The analysis of SEM/EDS images often involves comparing multiple scans at the same time. In my case, I wanted to compare the results of 5 different samples over 5 time-steps, with each time step having upwards of 10 scans each (**>250 scans!**). I chose to organize this data into an **automatically generated PowerPoint presentation** since each image set (SEM image + elemental maps) can be grouped into a slide, and each imaging session grouped into a PowerPoint presentation. The data is also usually directly presented in PowerPoints, so this conversion also saves time making slides.

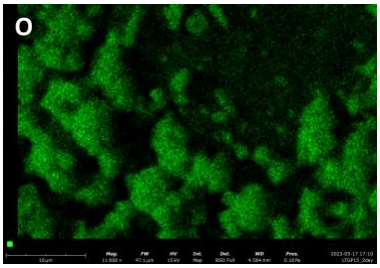
When running the script, the directory containing all the scans is given as input, and the subdirectories containing each scan are iterated to generate individual slides. There are four imaging modes, and each should be laid out differently. Example generated slides for each are shown below. The map, region, and spot analysis modes all are processed similarly, with a barplot of the total composition generated and all the data neatly laid out on the slide.

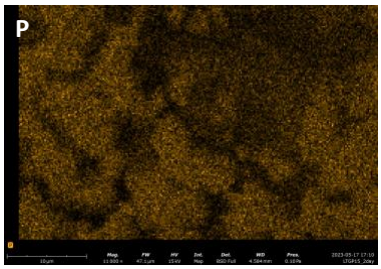
The linescan imaging mode takes more processing. This mode enables the elemental composition to be tracked over a line. The main benefit of this mode is the ability to see the quantitative breakdown of the composition, which is not easily displayed in a map scan. The line may be at any angle and length, so a **Hough Transform** is used to identify where the linescan is and the direction of the arrow, then the image is cropped and rotated so the scan can be read left to right. The cropped images are then displayed alongside a plot of the composition.

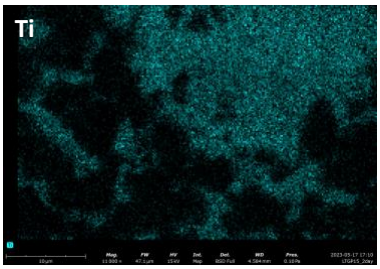
LTGP15_2day Image 1_analysis_1_map











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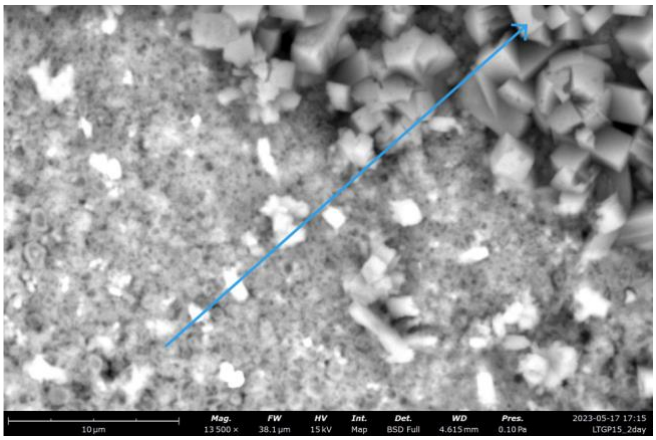
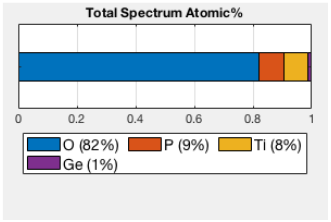
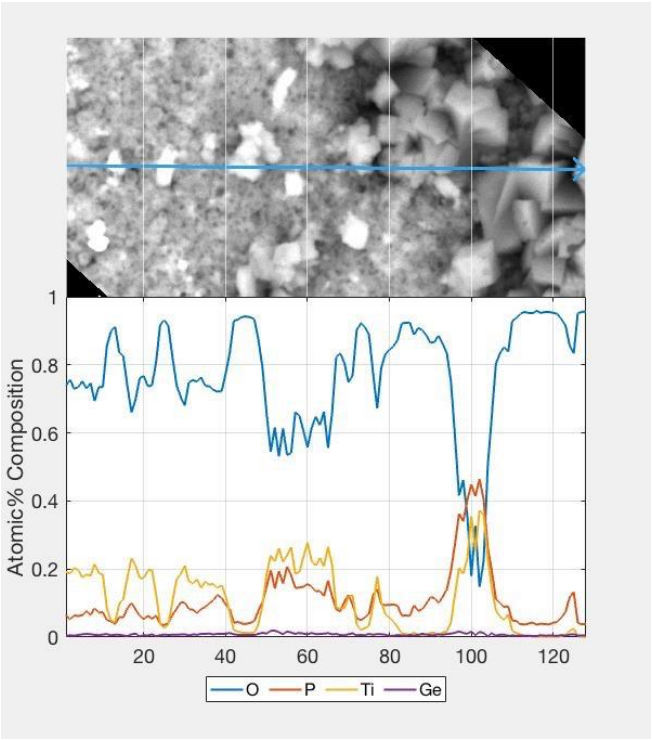
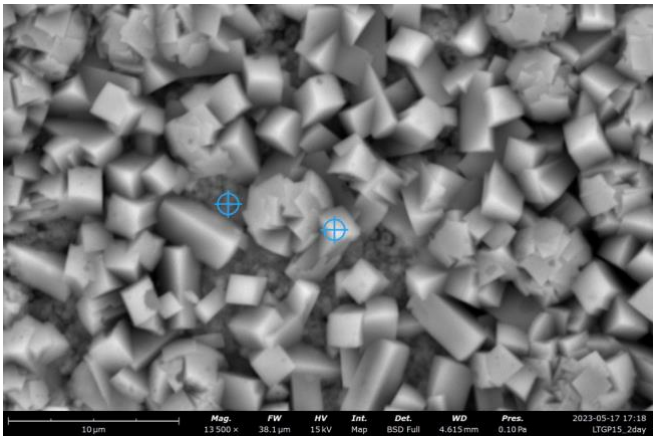
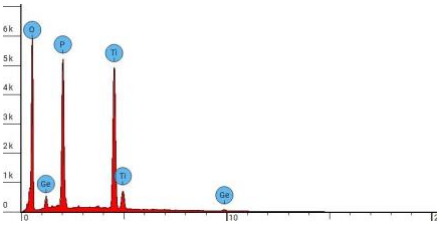


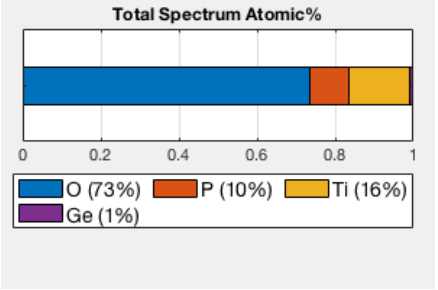




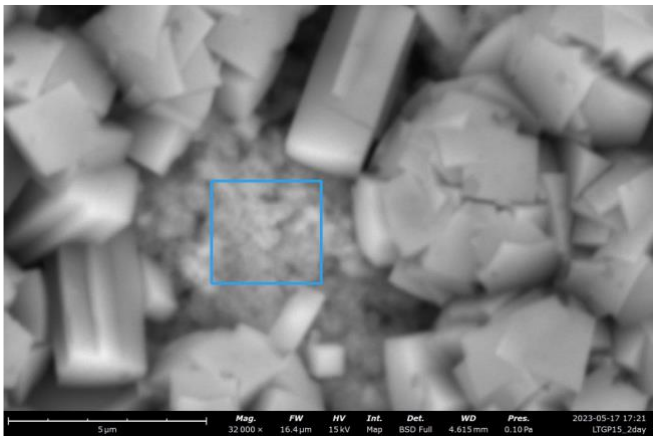
LTGP15_2day Image 5_analysis_1_spot







LTGP15_2day Image 7_analysis_1_region



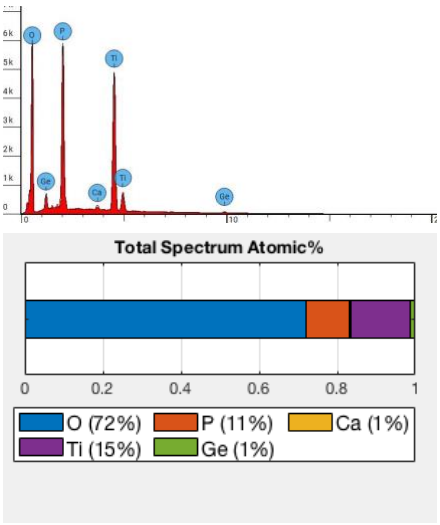
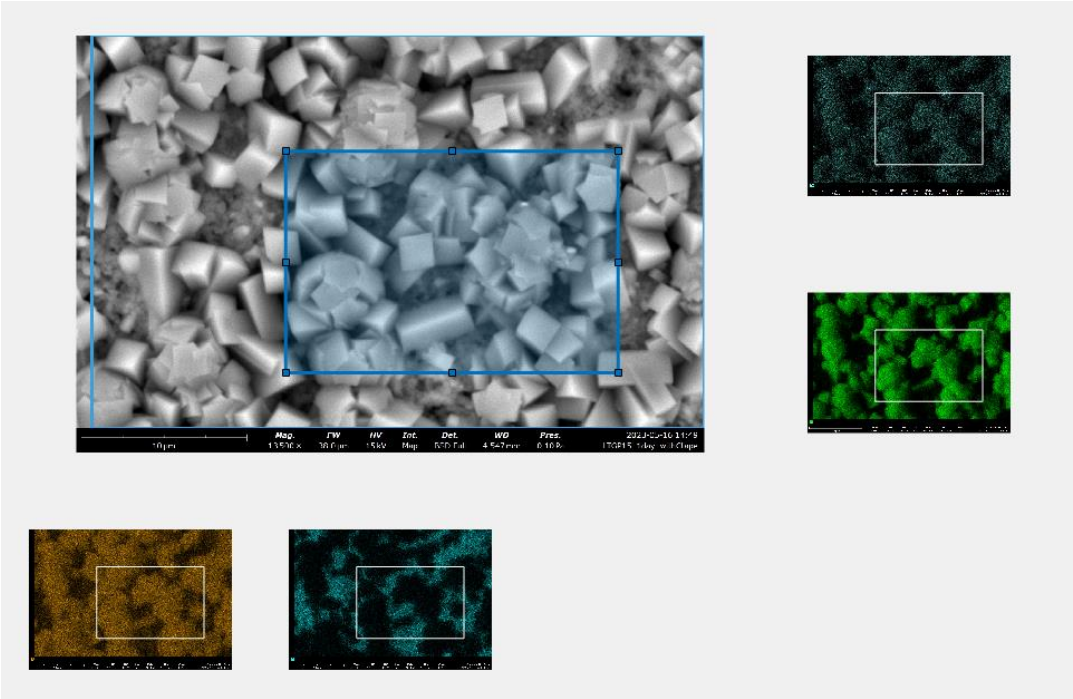


Image Cropping

The magnification of SEM/EDS images may not all the be same sample-to-sample, so in order to compare them, we would like to crop them to all the same scale so sizes may be compared. A list of scans can be uploaded to this script, and in each:

1. The scale bar is identified, and the user is prompted to input the length of the scale bar. The program automatically counts the pixel length to determine the proper scale

2. The user-defined window dimensions is overlayed over the SEM image and corresponding EDS images to indicate the cropping area.



One improvement may be to use OCR (optical character recognition) to read the scalebar and determine the scalebar automatically. I decided against this because the prompt to enter the length of the scalebar also serves as a way for the user to check that the program is properly identifying the length of the scalebar. Although my method for scalebar identification has been very reliable so far, it is nice to keep track of exactly what the program is doing, especially since these images will be used for publications and presentations.

Microfluidics PCB

I developed an Arduino Mega shield with the ability to control up to 32 solenoids and record from 4 pressure sensors for microfluidics testing. The board takes 24V input and includes a buck converter to step down the power to 12V for the Arduino. A CANBUS module is also installed as an option for external communication. This was designed in EasyEDA [Link to project].

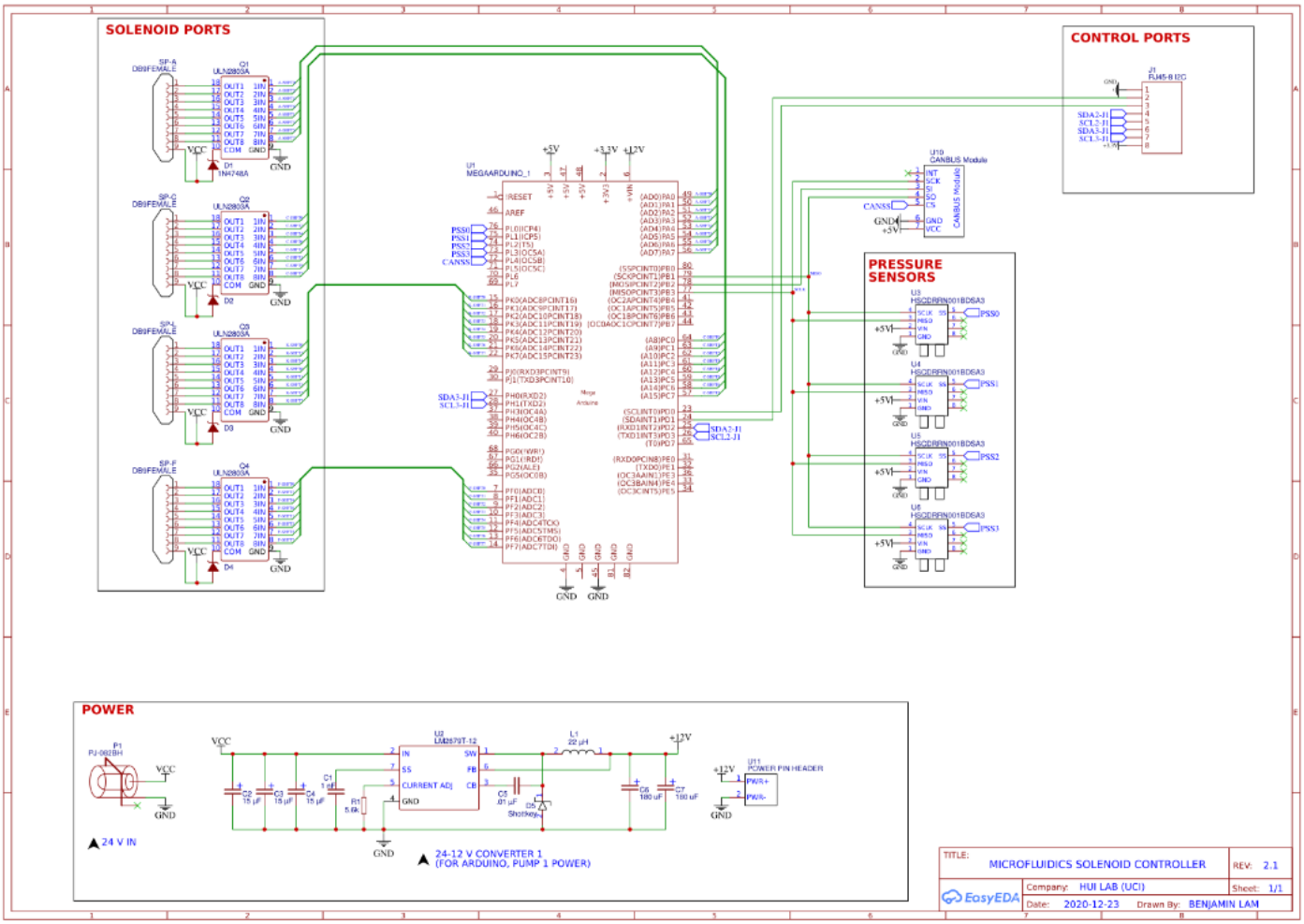


Figure 1: Schematic of the board.

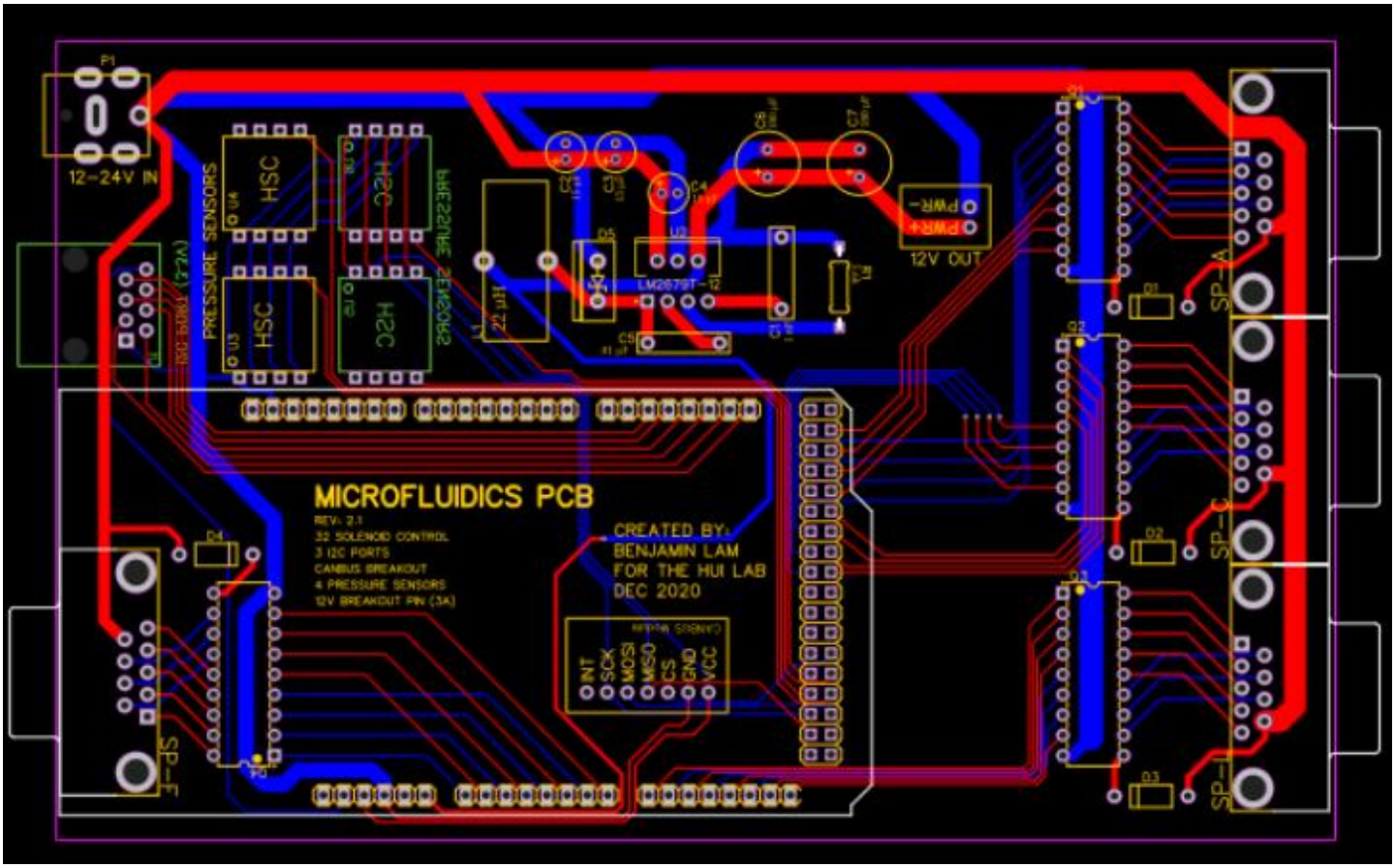


Figure 2: Layout view of the board.

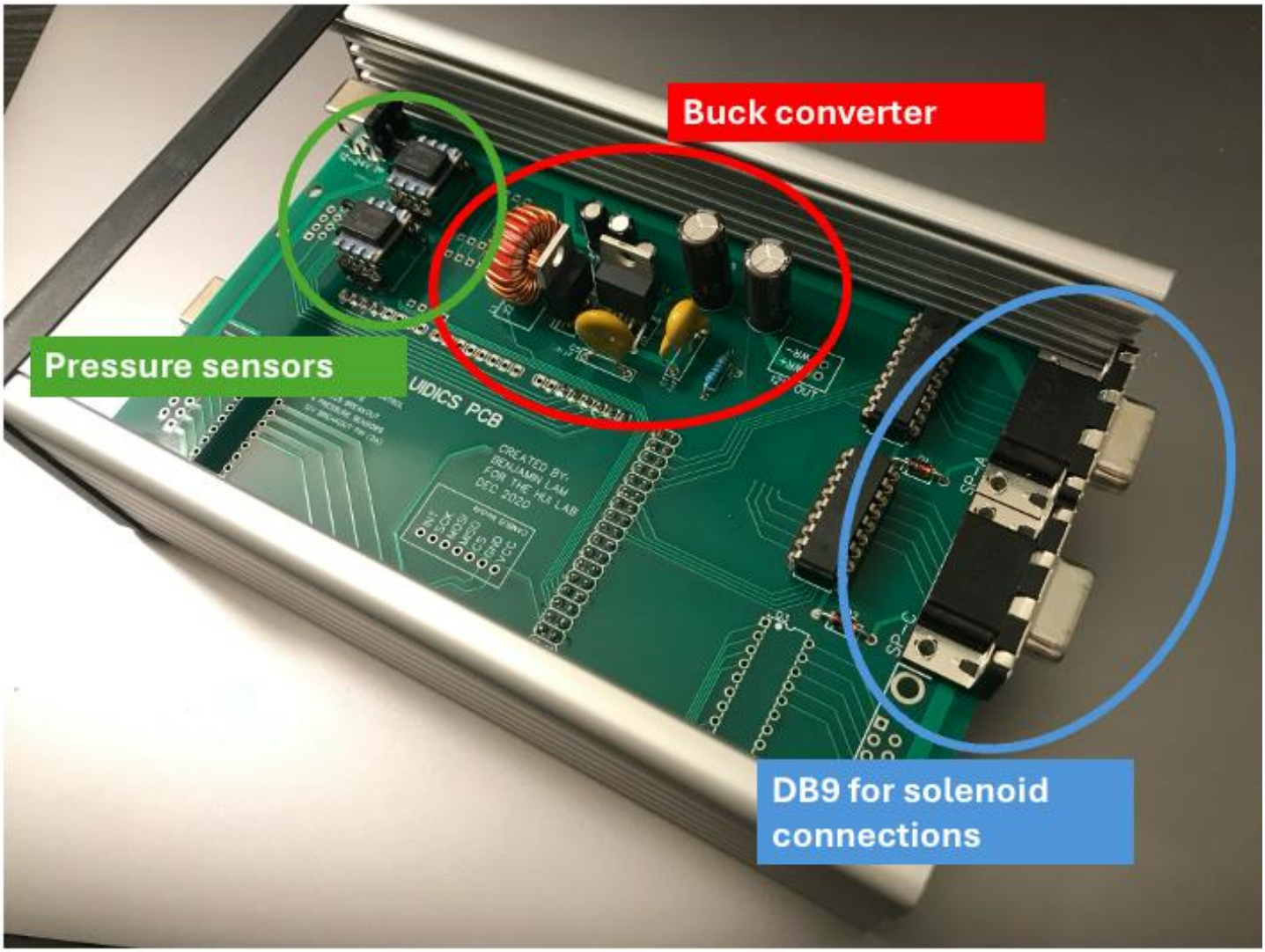


Figure 3: Real board inside enclosure. The board is modular and does not require all components to be installed. In this case, only 16 solenoid outputs were needed, so only 2 DB9 connectors were installed.