Chemical Process Automation

Group 22

Jason Scislaw – EE

Anish Umashankar – EE

Amanda Gilliam – CPE

Ernel Reina – EE

Sponsored by:

HELICON CHEMICAL COMPANY

HELICON CHEMICAL COMPANY

- Small company making nanostructure composites
- Current focus in adding energy density to rocket fuel for aerospace partners

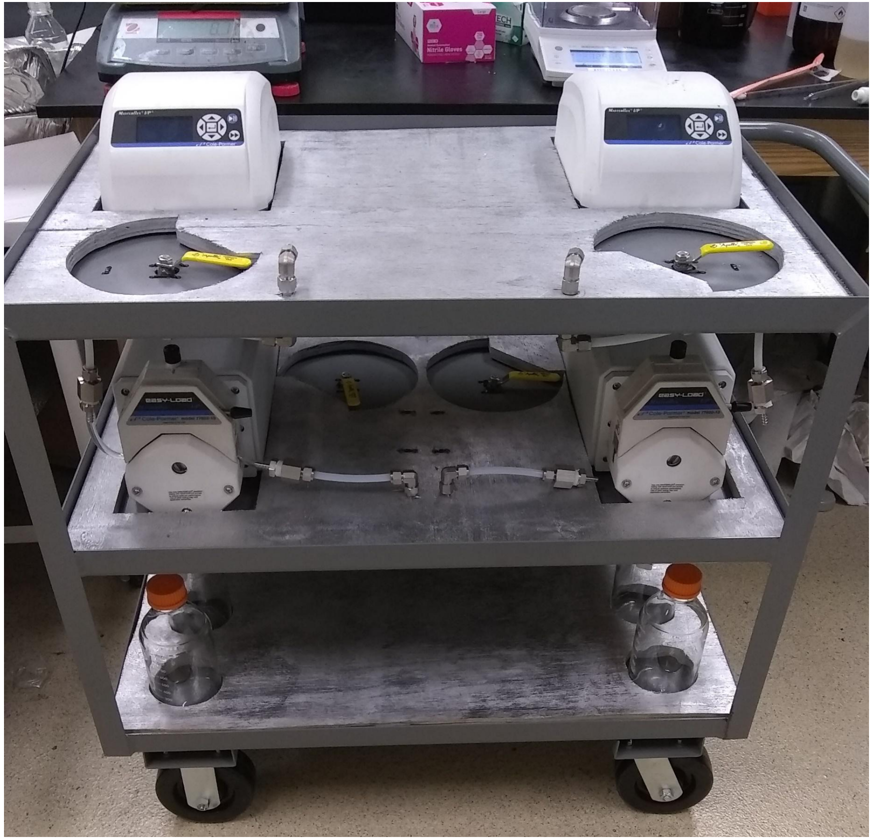
ARC

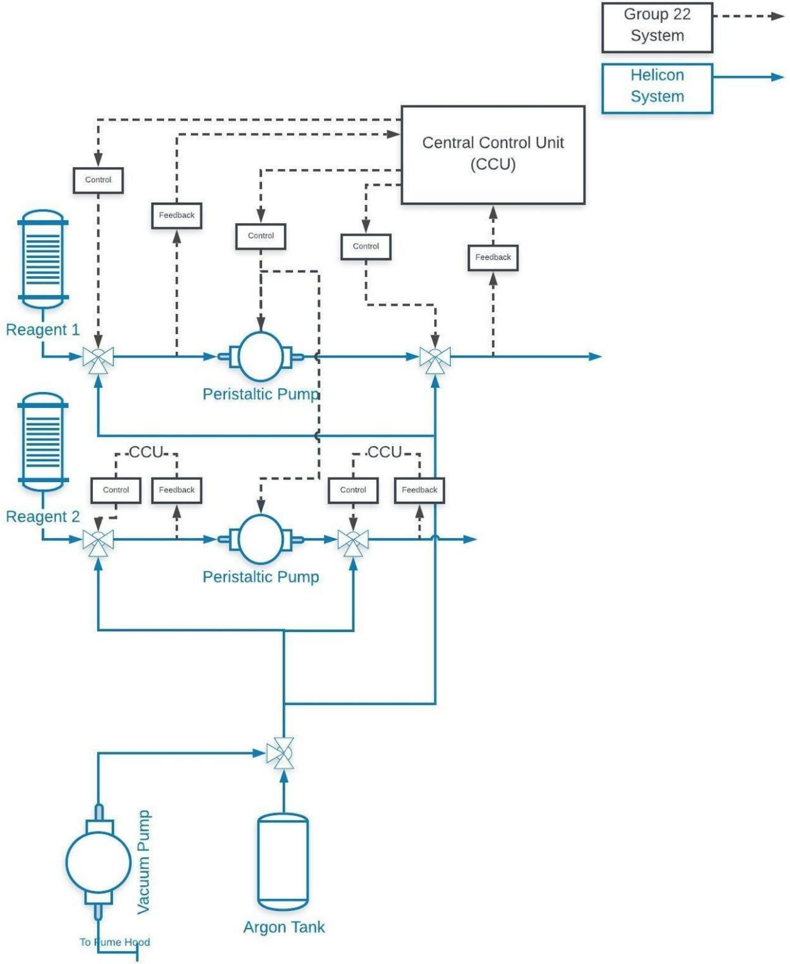
DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

TEES
Texas A&M Engineering
Experiment Station

NORTHROP GRUMMAN
Orbital ATK

PURDUE
UNIVERSITY


Nitrile Gloves


Group 22 System
Helicon System
Central Control Unit (CCU)
Control
Feedback
Control
Control
Feedback
Reagent 1
Peristaltic Pump
Reagent 2
CCU
CCU
Control
Feedback
Control
Feedback
Peristaltic Pump
Vacuum Pump
Argon Tank
To Fume Hood

Motivations

Theirs

- Rapid growth brings need for improved systems
- Free labor

Ours

- Unique opportunity to work with an industry partner
  - Cutting edge tech in an exciting field
  - Working with systems critical to company’s operations
- Unique Challenges
  - Soft skills

Project Objectives

Primary Objectives:

- Design and build a system that works - **MET**
- Meet the requirements of EEL4914 - **IN PROGRESS**
- Maintain compliance with regulations that Helicon are obligated to - **MET**
- Maintain secrecy of all of Helicon's proprietary information - **MET**

Secondary Objectives:

- Design and build a system that meets Helicon's objectives. - **MOSTLY MET**
- Implement our system into Helicon's process. -**UNMET**

Stretch Objectives:

- Develop a control loop to manage temperature - **MET**
- Develop profile system such that Helicon can update our project with new profiles if the manufacturing process grows or changes. - **UNMET**

Project Requirements

Important ones to note:

- System shall contain 4 valve control motors
- System should log data upon start, stop, variable set, and emergency shutdown within 5ms of event occurring

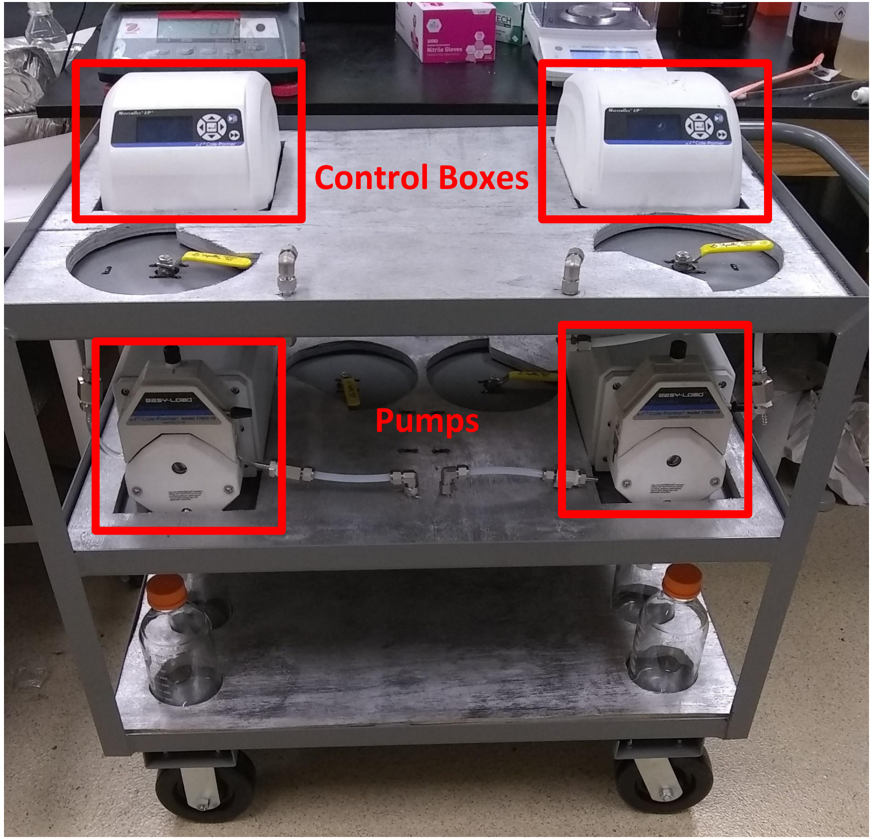
Requirement Specifications
The system shall contain two pumps, a control unit, and 4 valve control motors.
The system must be operable 90% of the year
The system shall have an emergency shutoff switch that safely powers the system off.
The system shall retain a complete record of the last chemical profile run.
The system shall provide the user with the ability to handle different chemical profiles.
The system shall utilize an LCD screen to display information to the user.
The system shall safely execute a chemical profile, or safely shut down.
The system shall be water resistant
The system shall evacuate lines with an inert gas before and after performing chemical manufacturing.
The system shall be able to handle 40mL to 2L batches of chemicals.
The microcontroller in the system must be able to control the 4 valve control motors.
The system shall be removable from Helicons components.
The system shall be able to be cleaned.
The system shall give an auditory warning in the case of a failure.
The system shall give a visual warning in the case of a non-critical malfunction.
The system shall be able to draw power from a standard US outlet.
The system shall be able to operate without user input after starting a chemical process.
The system must be able to safely shutdown in the event of a loss of power.

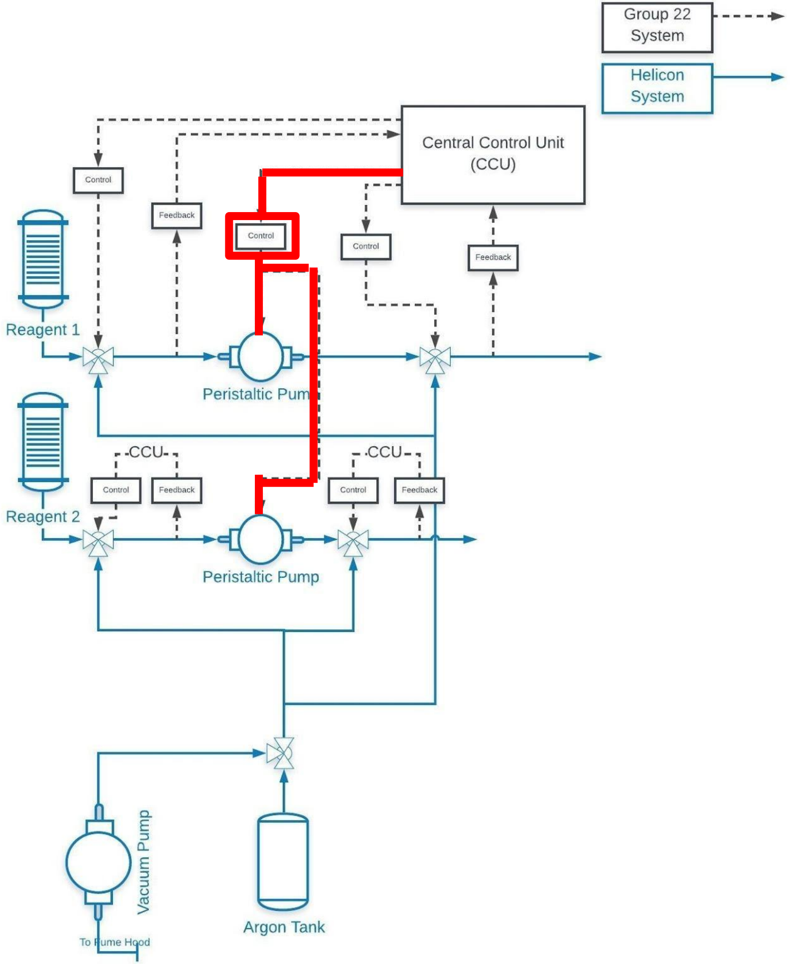
Project Constraints

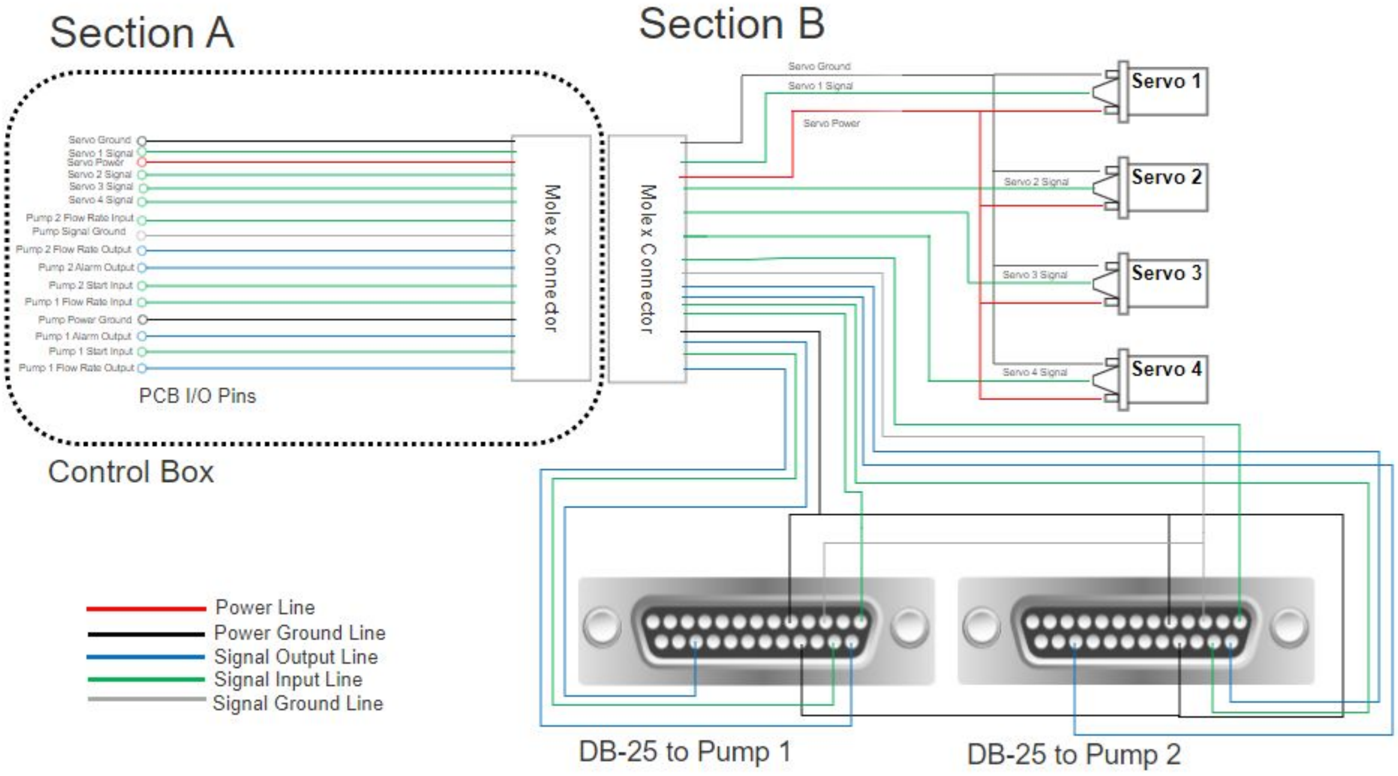
- Work with existing hardware - **MET**
- Easily removable - **MET**
- Reliability - **UNMET**
- Modularity - **MET**
- Chemically resistant - **MET**
- Reasonable cost - **MET**

Related Standards

- IEEE Standards
  - Hardware and Software testing (IEEE 829)
  - IEEE Power Switchgear,Circuits, & Fuse (IEE C37.59-2018)
- NEMA Standards
  - Enclosure is chemically resistant
  - Enclosure is capable of withstanding accidents
- UCF Health and Safety Standards
  - Helicon is on UCF property (BIC)
  - Ensure our electronics are properly enclosed and fault protected


Control Boxes
Pumps

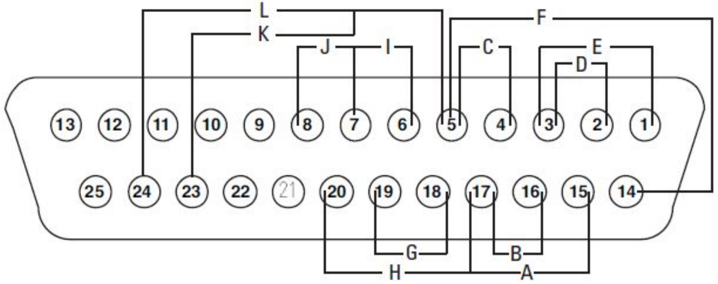

Group 22 System
Helicon System
Central Control Unit (CCU)
Control
Feedback
Control
Control
Feedback
Reagent 1
Peristaltic Pum
CCU
CCU
Control
Feedback
Control
Feedback
Reagent 2
Peristaltic Pump
Vacuum Pump
Argon Tank
To Fume Hood



	DRAWN BY	CHECKED	DATE	SCALE	SHEET NO.
WIRING HARNESS DIAGRAM For Control Box - Cart Interface	Jason	N/A	Nov - 2019	N/A	N/A

Pump Interface

Contact Arrangements



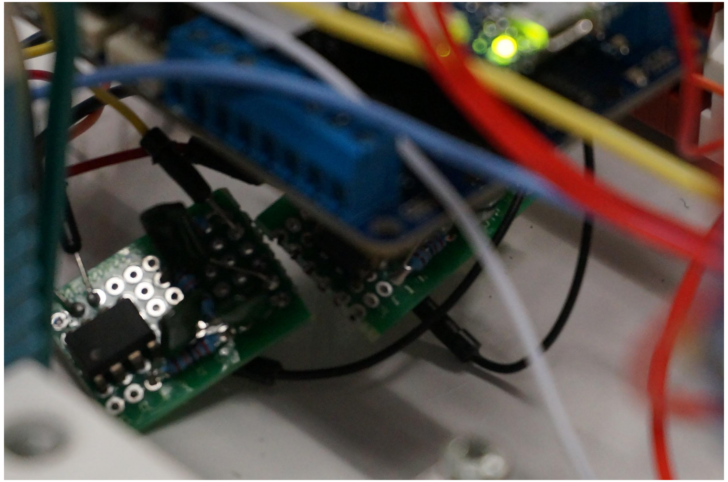
A. START/STOP
B. CW/CCW
C. OUTPUT 0-20mA; 4-20mA
D. INPUT 0-20mA; 4-20mA
E. INPUT 0-10V
F. OUTPUT 0-10V
G. TACH OUTPUT
H. PRIME
I. MOTOR RUNNING N.O. CONTACT (1A @ 24 V)
J. MOTOR RUNNING N.C. CONTACT (1A @ 24 V)
K. General Alarm
L. Local.Remote Indicator

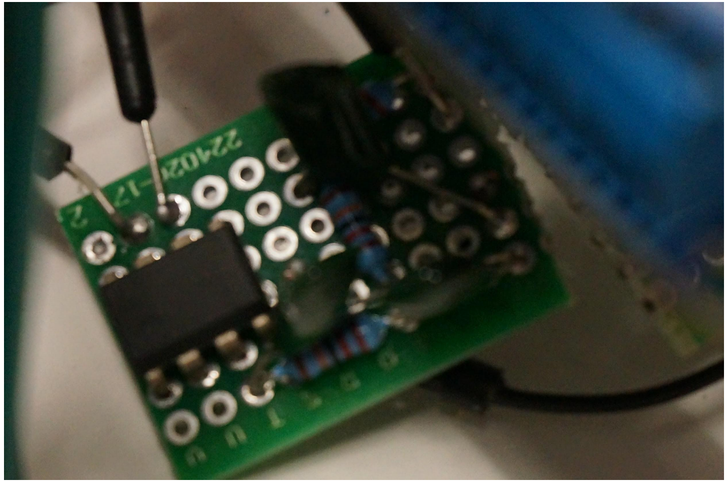
Figure 3-13. DB-25 Pin Configuration

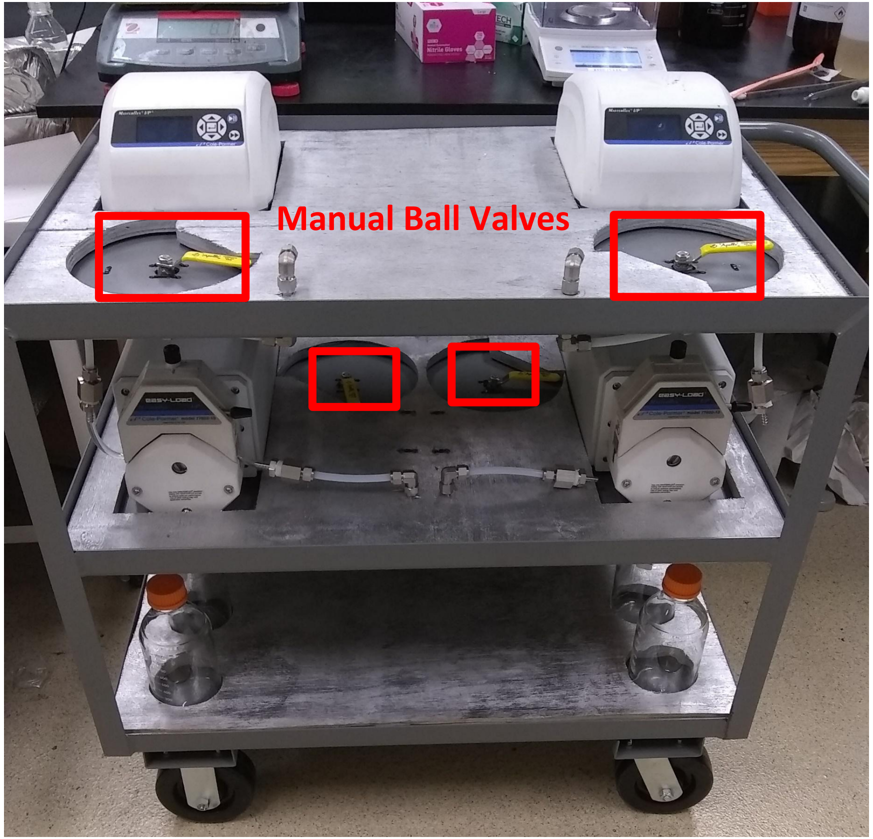
Pin No. DB-25	Description
1	Speed Control Voltage Input (0-10 V)
2	Speed Control Current Input (0-20 mA)
3	Speed Control Input Ground Return
4	Speed Signal Current Output (0-20 mA)
5	Speed Signal Output Ground Reference
6	(Motor Running N.O. Default) 1A @24 V (Relay)
7	COM (Motor Running)
8	(Motor Running N.C. Default) 1A @24 V (Relay)
14	Speed Signal Voltage Output (0-10 V)
15	Remote Start/Stop Input
16	Remote CW/CCW Input
17	Remote Start/Stop, CW/CCW, Prime Grnd Ref.
18	Tach Ground Reference
19	Tach Output (open collector)
20	Remote Prime Input
9	Reserved – Not Used
10	Reserved – Not Used
11	Reserved – Not Used
12	Reserved – Not Used
21	Reserved – Not Used
22	Reserved – Not Used
23	General Alarm (Open Collector)
24	Local.Remote Indicator (Open Collector)
25	Aux 24V+ (150mA)
13	Aux 24V- (150mA)

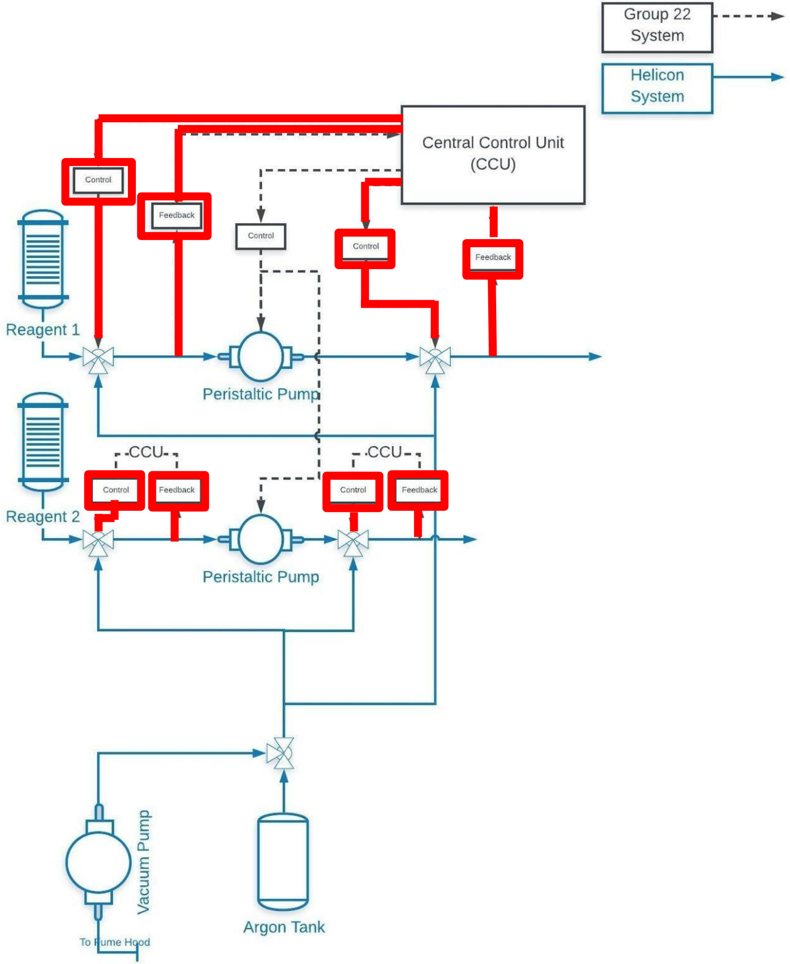
Pump Interface

Lost in Translation





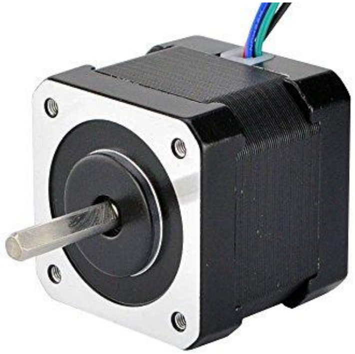

Manual Ball Valves


Group 22
System
Helicon
System
Central Control Unit
(CCU)
Control
Feedback
Control
Control
Feedback
Reagent 1
Peristaltic Pump
CCU
CCU
Control
Feedback
Control
Feedback
Reagent 2
Peristaltic Pump
Vacuum Pump
To Fume Hood
Argon Tank

Stepper Vs Servo

Stepper

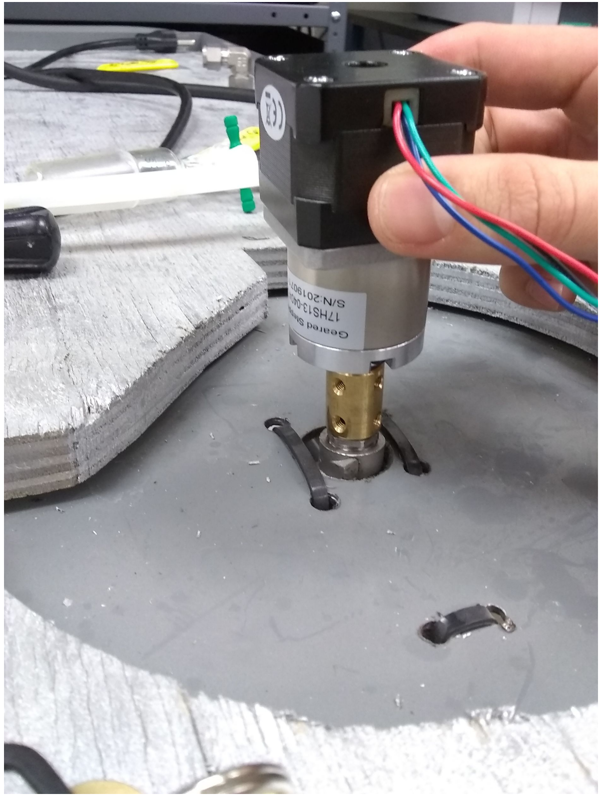
+ Good for holding torque
+ Multiple options for our needs at good prices
- Lower torque (0.33 lb-ft)
- No built-in feedback



Servo

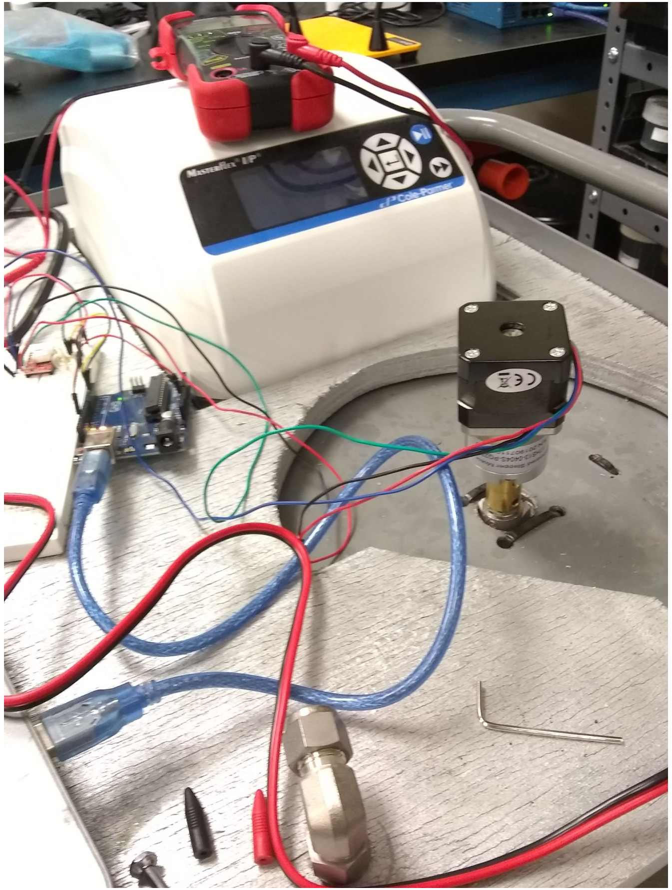
+ Built-in position feedback
+ Compatible with current PCB design
+ Higher torque (1.81 lb-ft)
- Accessible motor has not been tested

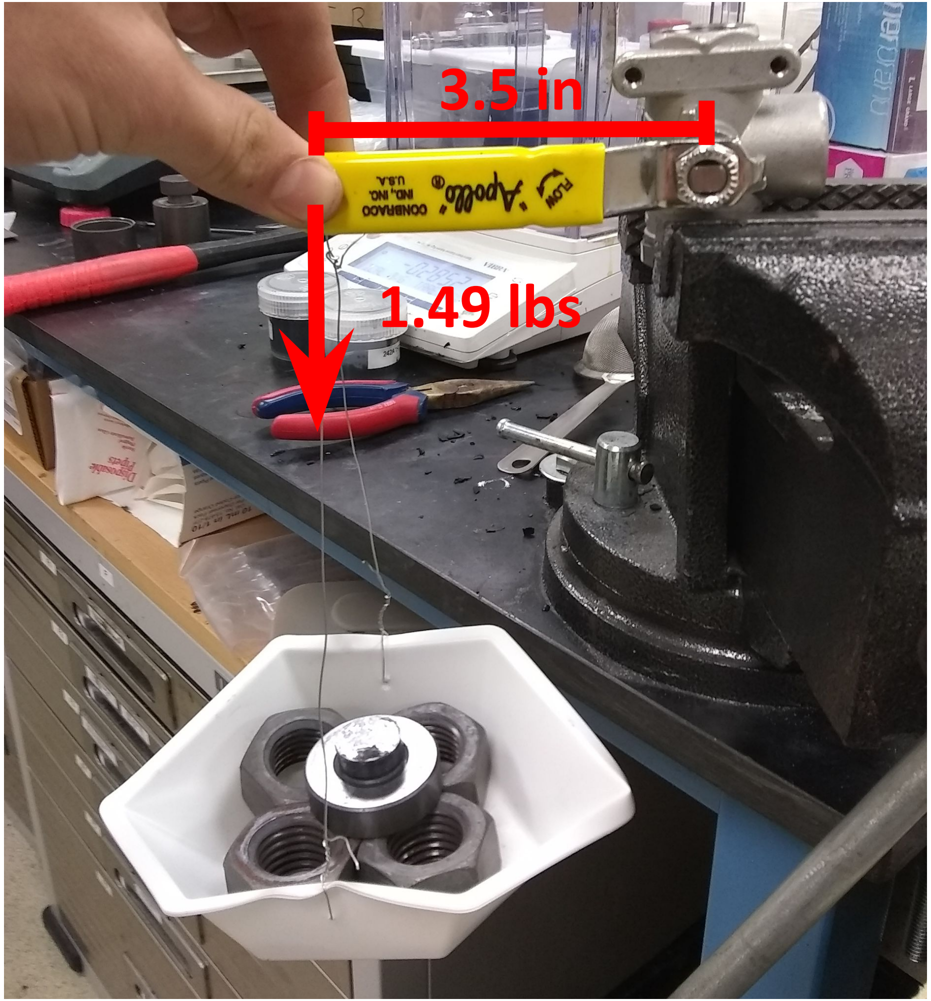
Motor Coupling (Stepper Example)



Stepper Prototyping

- Using A488 breakout driver
- Current PCB design uses ROB-12779
- Not enough torque



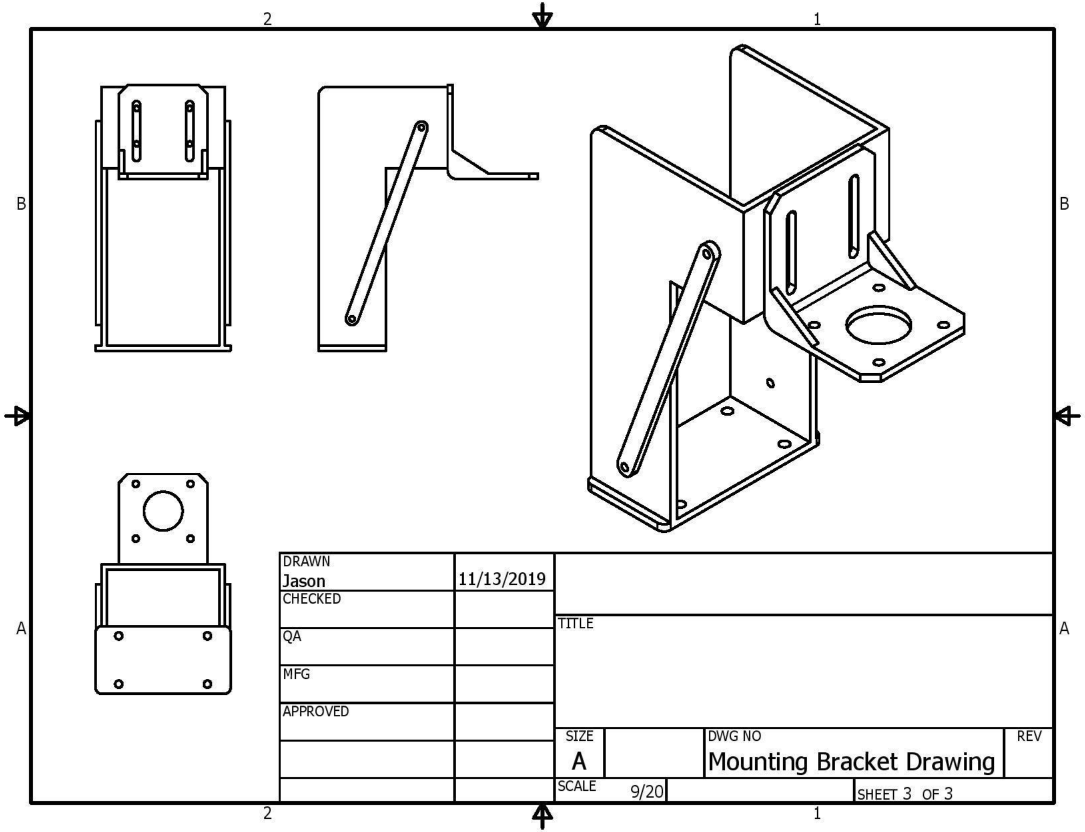


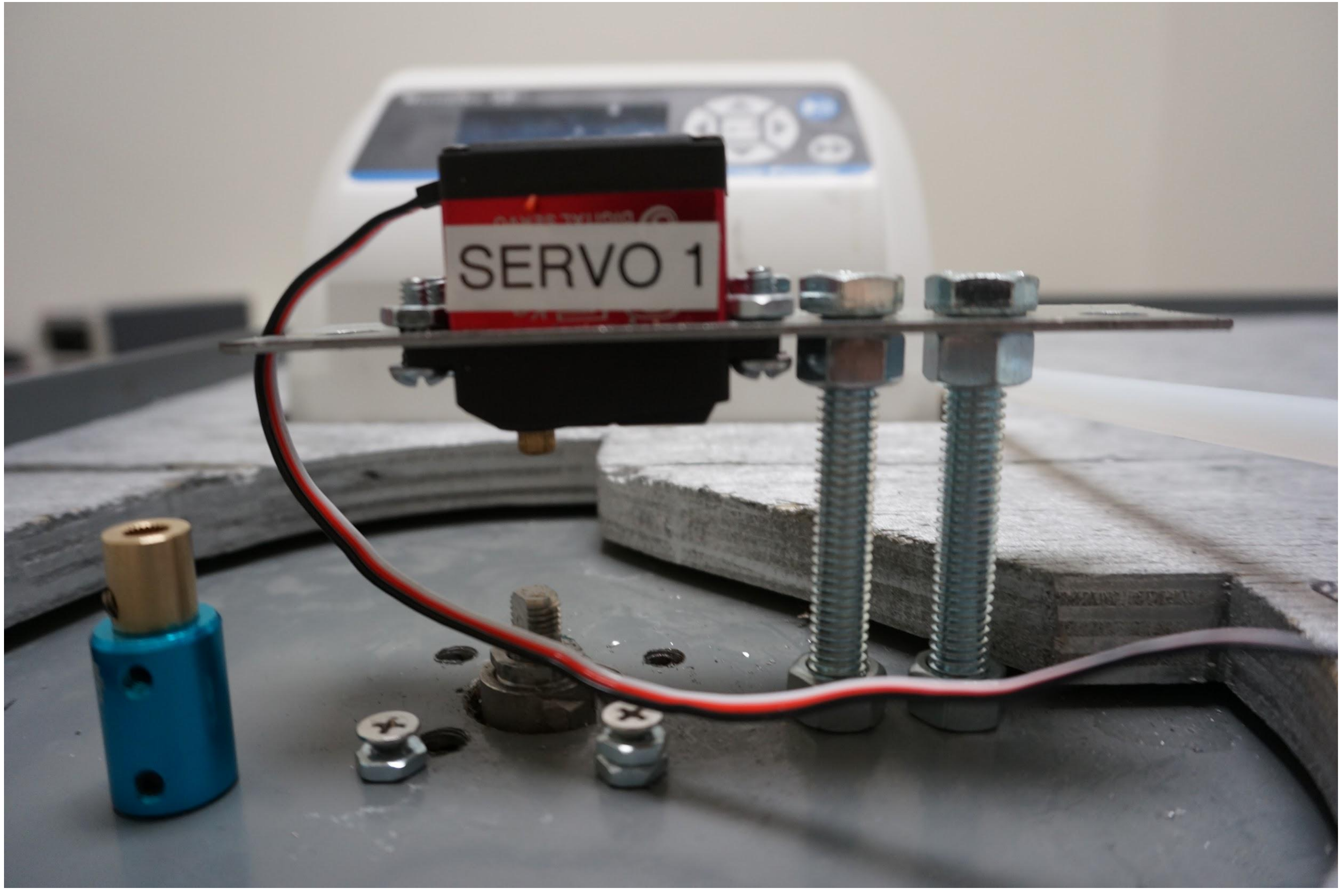
Torque Measurement

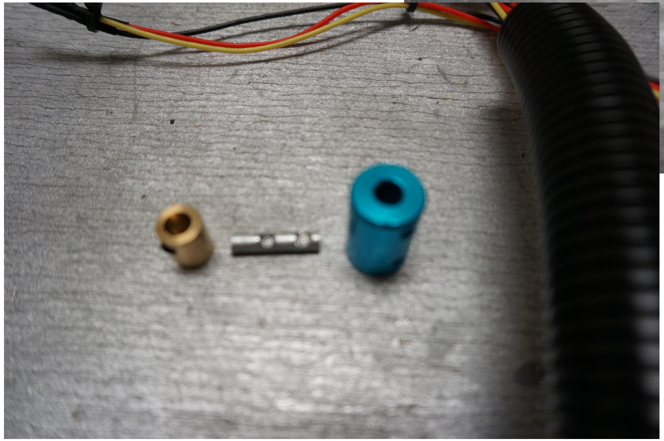
3.5 in * 1.49 lbs = 5.215 in-lb

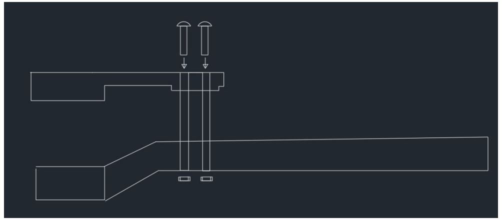
Converts to ~ **0.435 ft-lb**

Motor Mounting




SERVO 1



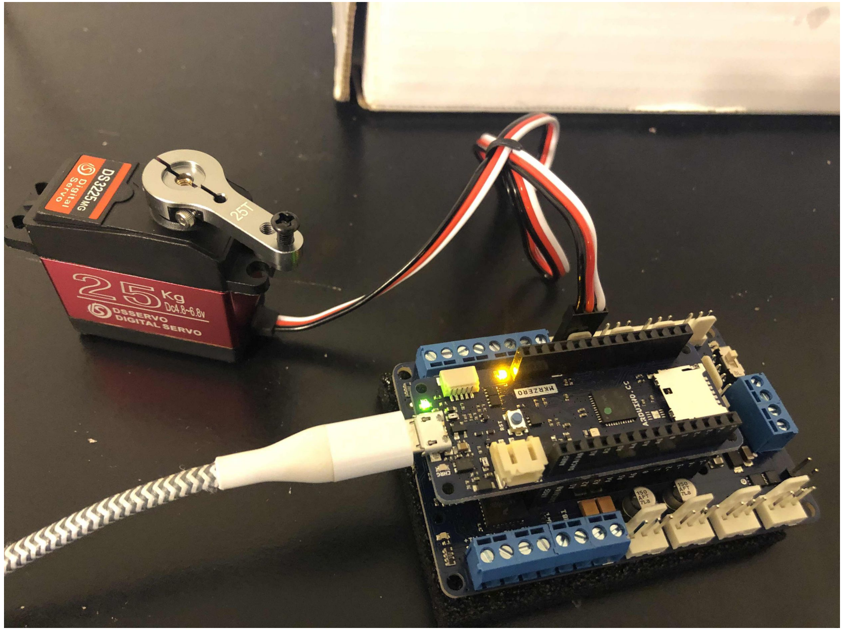


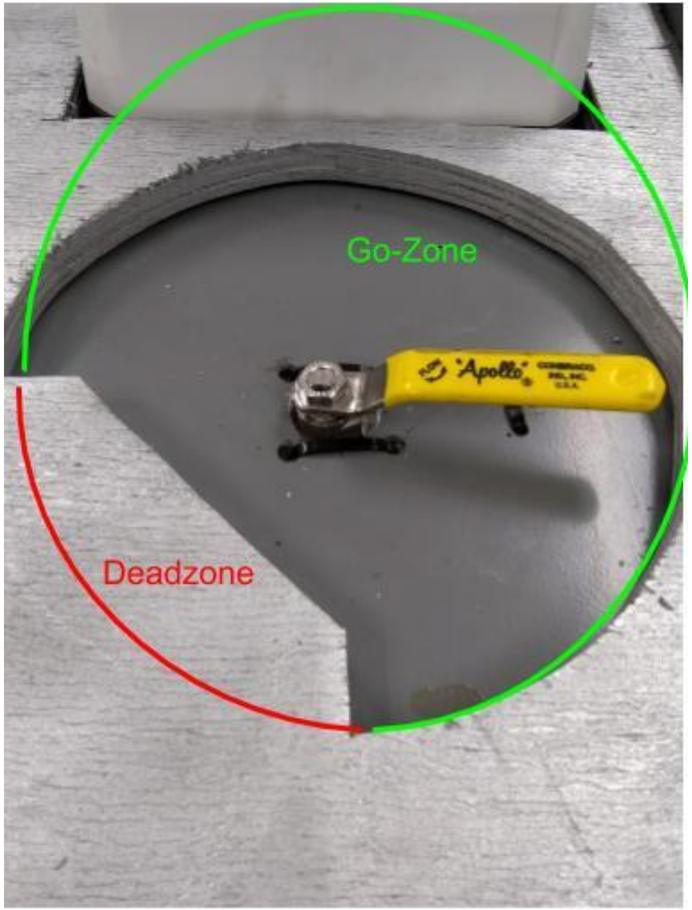
Servo Coupling

- We had to use 2 different couplers
- One connected to the gear on the servo and the other connected to the first and the valve.
- This ended up being a better design than our original idea of using the servo “horn”

Servo Motor Prototyping

- The job requires each motor to rotate to and hold one of three positions and our Servo goes from 0-270 degrees which makes it easy to program.
- Built into the servo is an encoder to provide feedback to the controller in case of any deviation from the set point.
- We have our prototype board the MKzero with its accompanying motor carrier
- Strong even though its small 1.8 ft-lb





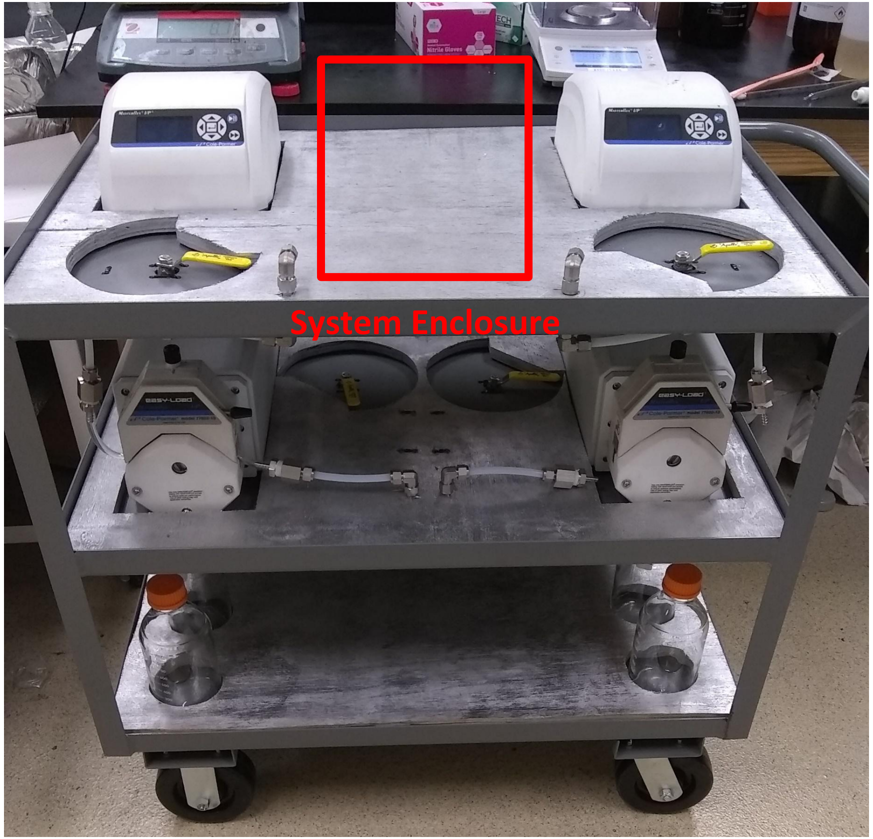
Valve Deadzone

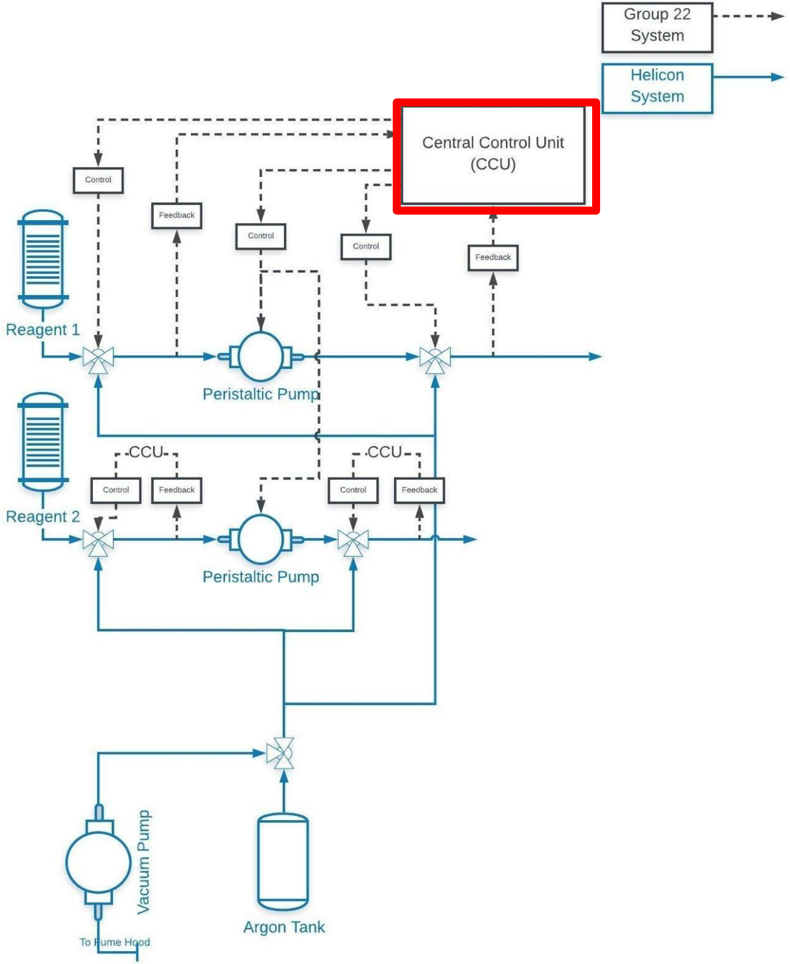
- 90 degree zone where valve connects all three lines

- Can result in equipment damage

Expectations vs Reality

- Supply chain issues led to concessions regarding the deadzone
- Solution leaves more work for Helicon’s operators, but the system still operates as needed.


System Enclosure

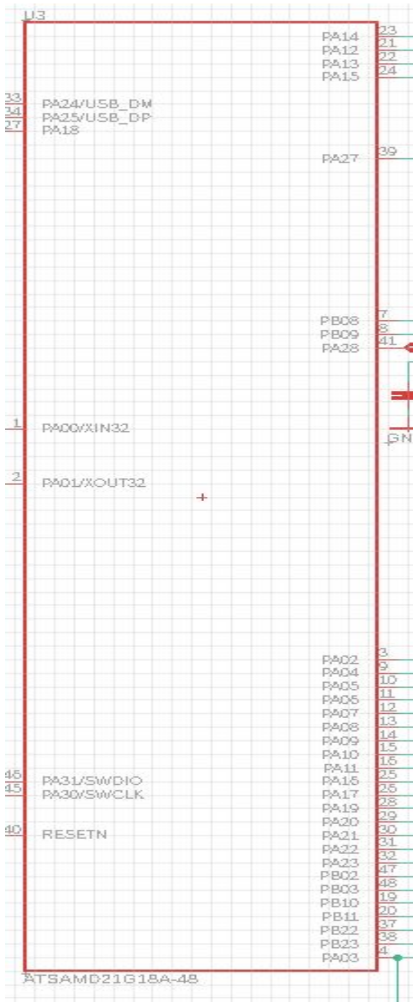

Group 22 System
Helicon System
Central Control Unit (CCU)
Control
Feedback
Control
Control
Feedback
Reagent 1
Peristaltic Pump
CCU
CCU
Control
Feedback
Control
Feedback
Reagent 2
Peristaltic Pump
Vacuum Pump
Argon Tank
To Fume Hood

Microcontroller Comparison

	Mem.	I/O	Freq.	Comm.	Cost	Pwr.
ATmega328	2KB SRAM	23	20 MHz	USART	$1.90	1.8V-5.5V
ATmega128	4KB SRAM	64	16 MHz	UART, SPI, I2C	$11.35	2.7- 5.5V
MSP430FG4618	8KB RAM	80	16 MHz	USART, UART	$15.43	1.8-3.6V
MSP430F67671	32KB RAM	90	25 MHz	USART	$8.80	1.8-3.6V
TMS32F28378S	132KB RAM	169	200 MHz	USB, CAN	$18	1.8-3.3V
EFM32WG990f256	32KB RAM	87	48 MHz	UART, USB	$5.26	1.98-3.8V
ATSAMD21G18A	32KB SRAM	34	48 MHz	SPI, I2C UART	$3.00	1.62-3.63V
ATSAMD11	4KB SRAM	19	48 MHz	SPI, I2C UART	$1.26	1.62-3.63V

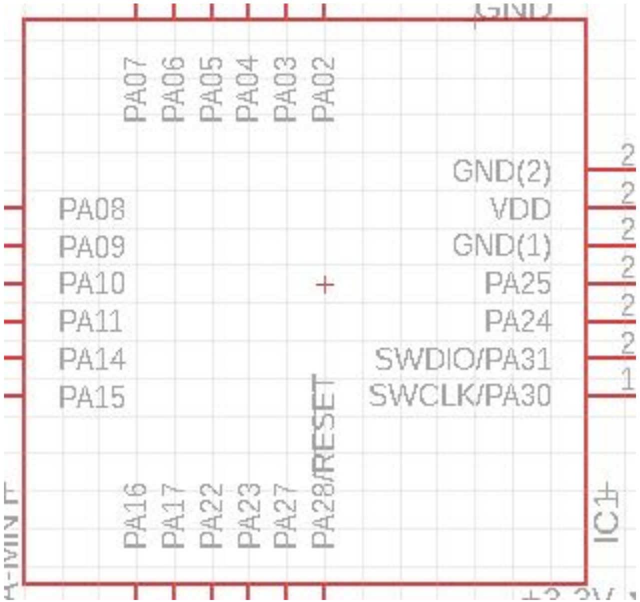
ATSAMD21G18A

- 34 Pins to work with
  - 10 Analog Pins
  - 24 Digital Pins
- Low power
- Speed for price (48 MHz for $3)
- Used in MKR Zero development board



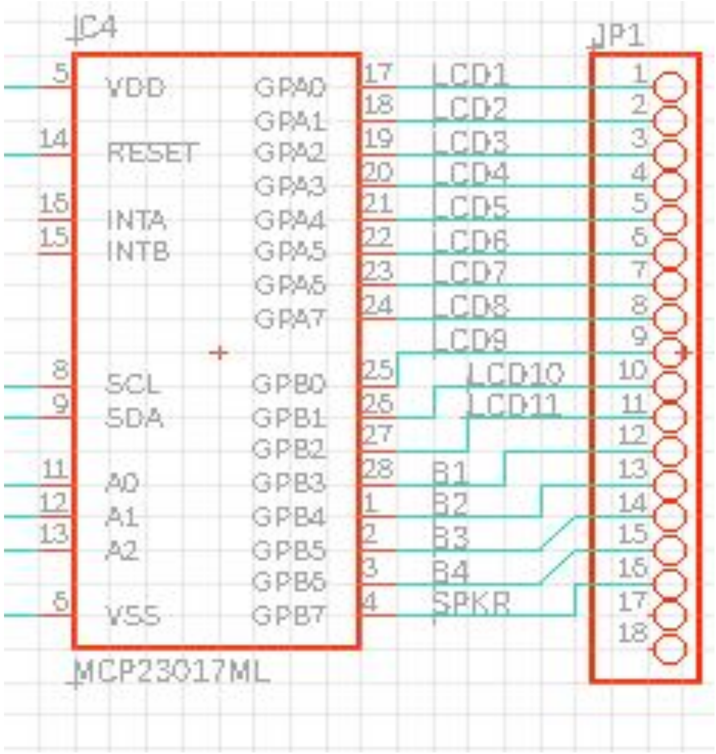
ATSAMD11

- 19 Pins to work with
  - 6 Analog Pins
  - 13 Digital Pins
- Low power
- Compatible with ATSAMD21 in M/S format
- Used in MKR Motor Carrier board



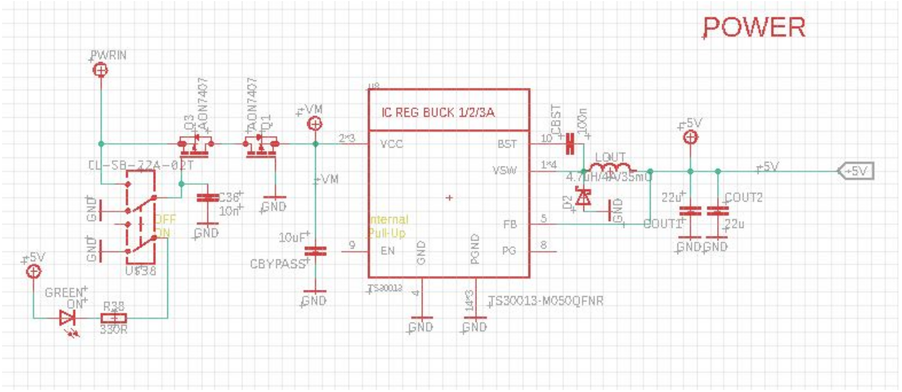
Port expander

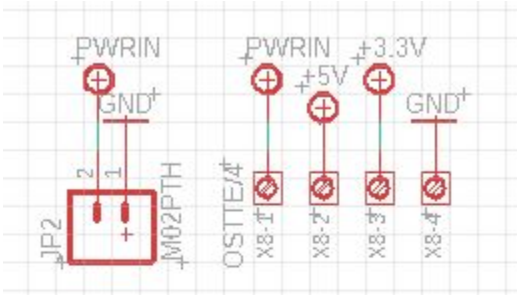
- Added to our schematic to add additional digital ports.
- Needed for addition peripherals needed by helicon.
- Connected via I2C or SPI
- 3 Address pins that allow up to 8 devices on the bus
- Cheap @ $1.20



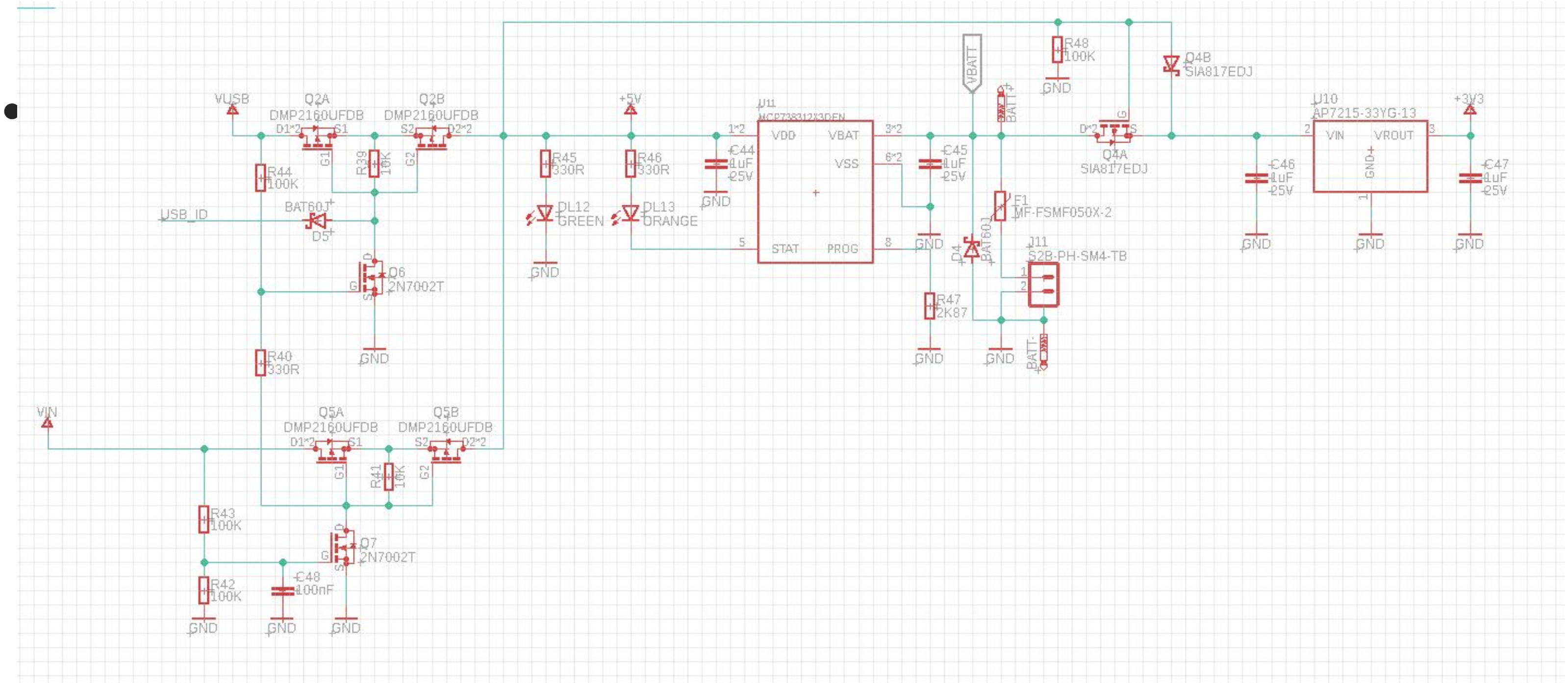
Power module 1

- Reset switch
- Designed by Arduino
- Two key power inputs (+5V coming from Micro USB or PWRN coming from optional LiPo battery)
- Two P-MOSFET for reverse current protection.
- Full fault protection in DC-DC regulator
- DC-DC Switching regulator is cheap @ $1.40



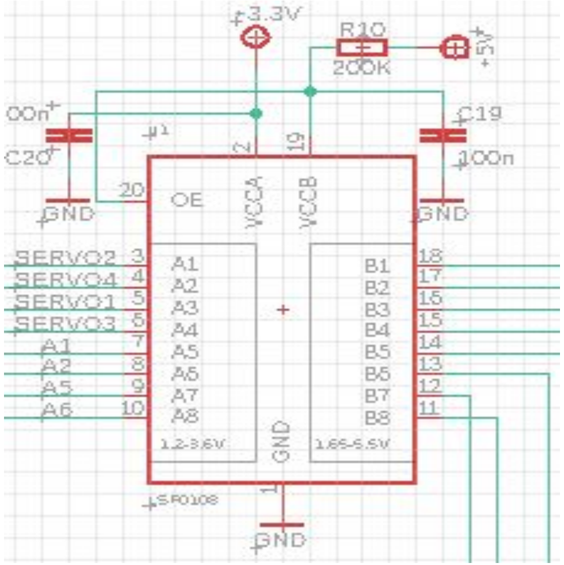


Power Module 2



Voltage Level Translator

- Pins on both microcontrollers operate at maximum 3.3V.
- Servos and motors operate at 5V.
- Serves as a way to connect the pin from the microcontrollers to the connectors for the servos and motors.
- Another means of fault protection.
- Cheap @ $1.73

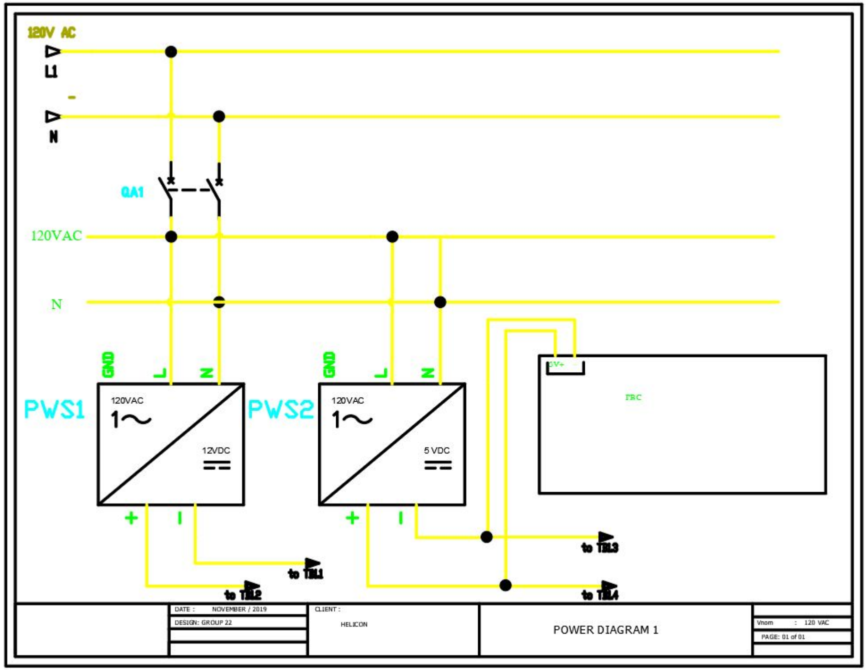


PCB Issues

- Bootloader
  - Currently using the ATMEL ICE kit
  - Board contains a 10-pin JTAG connector which connects to the bootloading kit.
  - Board is not communicating with bootloader. Upon connection, the green LED indicating bootloader connection to target board does not turn on.
  - Issue may lie in ATMEL ICE kit as board does have sufficient power (as indicated by LEDS) and contains proper JTAG pin configuration.

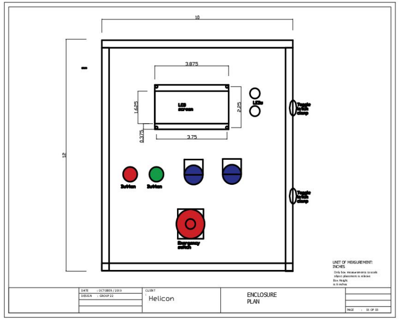
Power

- Power will be handled separately from the PCB for replace-ability
- First Power will enter a very typical 120V AC power cord and make its way into the enclosure.
- A small circuit breaker will be put into place before the power supply. This breaker will protect the other components from a current overload which could damage them.
- Then a 5V source will be used to power the PCB which in turn powers the motors if servos prove best
- We will be using a MEAN WELL MDR-50-5 AC to DC DIN-Rail Power Supply 5V 10 Amp 50W (PWS2)
- Familiarity with the product and relatively low cost
- The board should need under 1 Amp to operate and the motors should require about 2.5 at maximum load but testing still pending.
- The 12VDC source (PWS1) is Illustrated here to show how the design would have been with stepper motors.



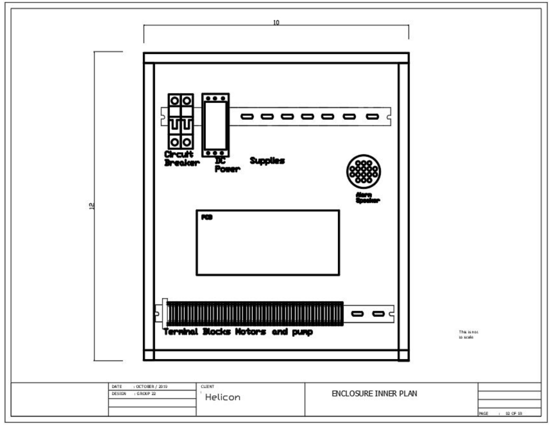
User Interface

- LCD readout (include prototype pic if its good)
- - 8pin vs 16 pin
- Basic interface consists of:
  - 2 Buttons
  - 2 Knobs, to set values for the pumps
  - LCD screen for menu
  - LEDs for Amanda
  - And a Big Red “oh no” button



Enclosure

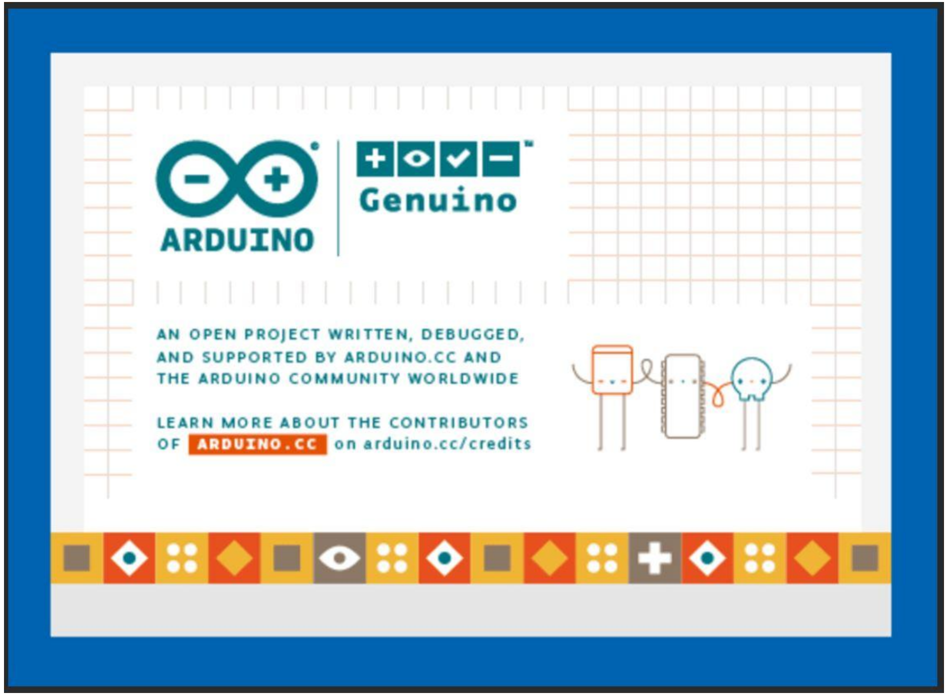
- Following some standardized practices we used an electrical enclosure
- To meet Helicon's requests the enclosure is Nema 4x which indicates it is splash proof, corrosion resistant and fire resistant.
- It is be openable with relative ease Terminal blocks to allow for good organization practices and easy unimpeded access to the SD card.



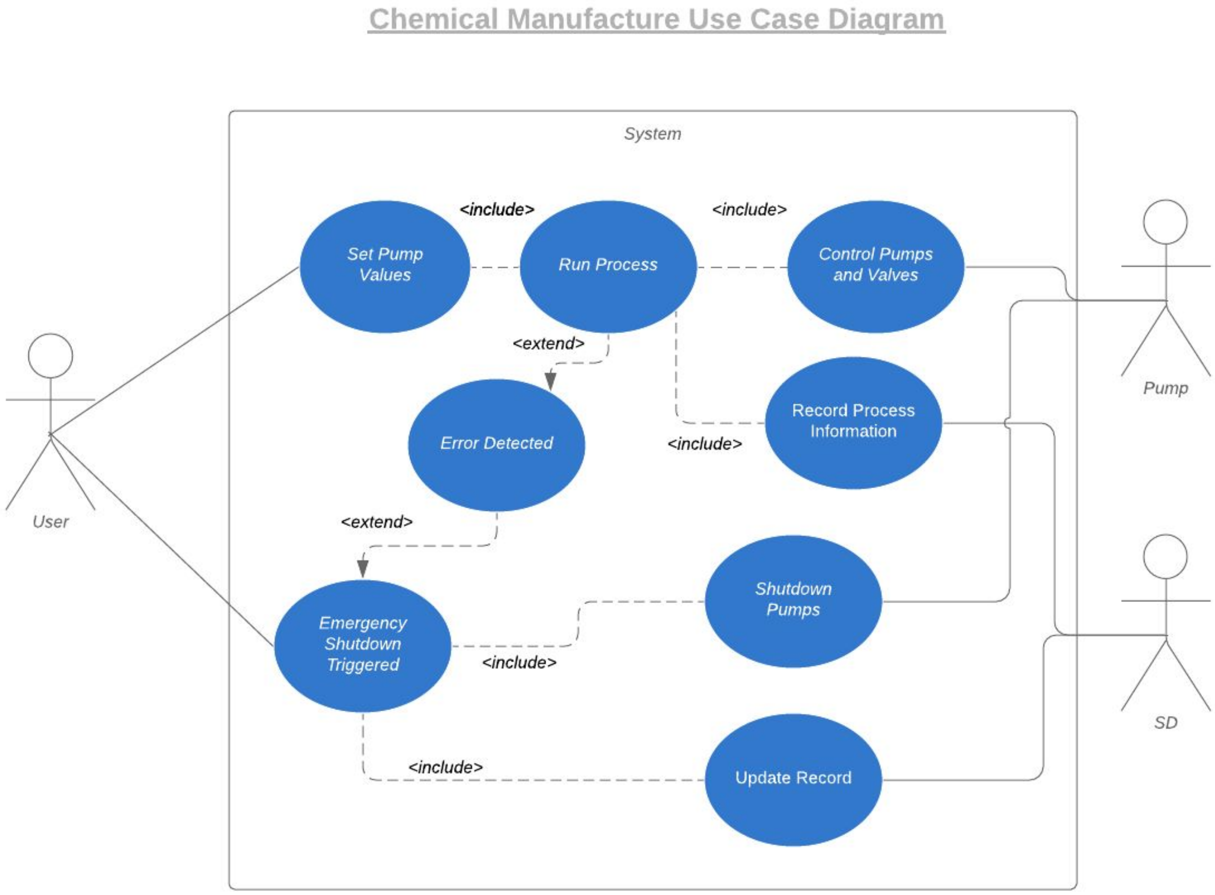
Software

IDE: Arduino v1.8.10
Language: C++

+Lots of helpful libraries
+Robust community support
-harder to debug
-mostly just a text editor



Use Case



Chemical Manufacture Use Case Diagram
System
Set Pump Values
<include>
Run Process
<include>
Control Pumps and Valves
<extend>
Error Detected
Record Process Information
<include>
<extend>
Emergency Shutdown Triggered
Shutdown Pumps
<include>
<include>
Update Record
User
Pump
SD

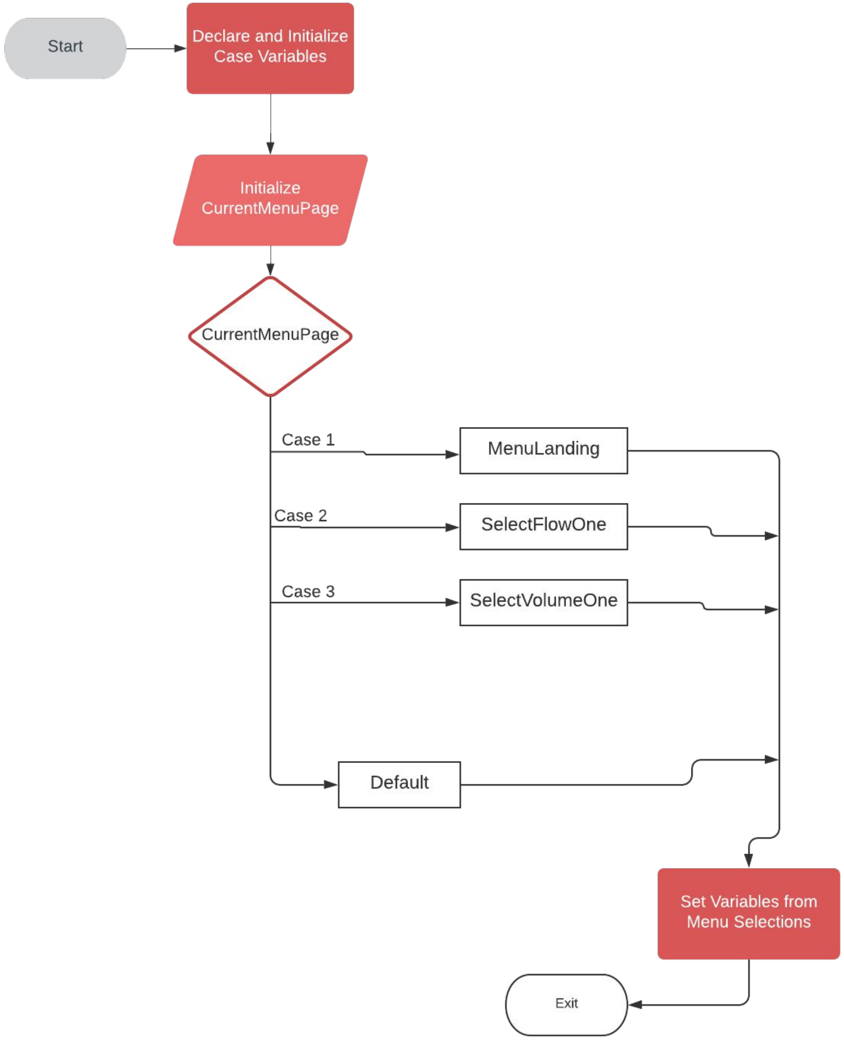
User Interface

-Sync user inputs to LCD display

-Timing is important

-Focus is on being user friendly

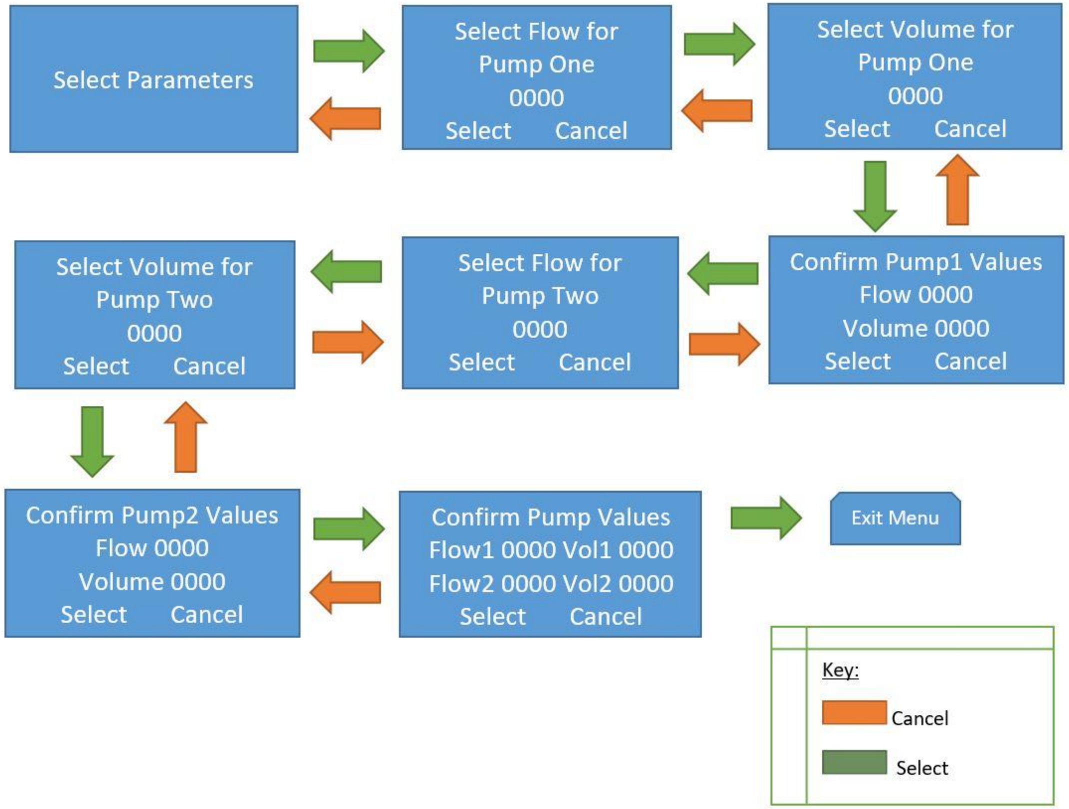
-Code structured to be easily extended using a switch statement



User Interface

-20x4 is less space than it seems.

+Button options labeled via UI



Datalogging

Feature is a specific request from Helicon.

-Using an SD card for data storage.
-Records important info such as volume, flow, date, time, etc.
-Records emergency shutdowns.

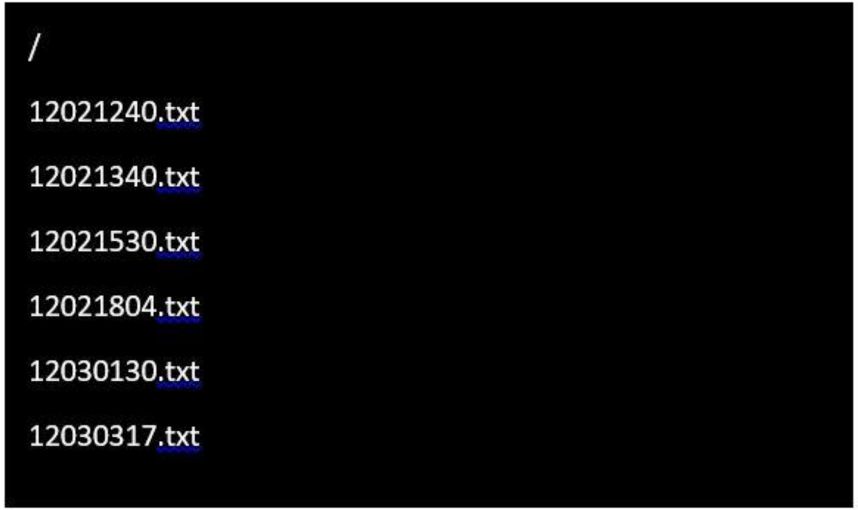
Image frome https://tinycircuits.com/products/tiny-arcade-preloaded-microsd-card

Datalogging

SD library

+Supports fat16 or fat32 file systems for standard SD cards

-Uses 8.3 naming convention, limiting file names to at most 8 characters



Software Challenges

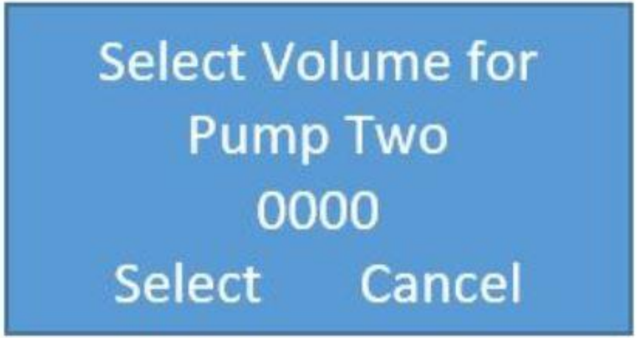
- Architecting System
  - Best solution for requirements
- Emergency Shutdown
  - Handled via Interrupt
- Debouncing Inputs
  - Getting the ‘real’ input
- Resolutions
  - Calibrating analog outputs to correct pump speed setting

Issues/Bugs

- Upon upload of code, the pumps would automatically be set to a speed without being prompted.

- LCD did not display actual number selected by user

Testing



Joint software and hardware effort

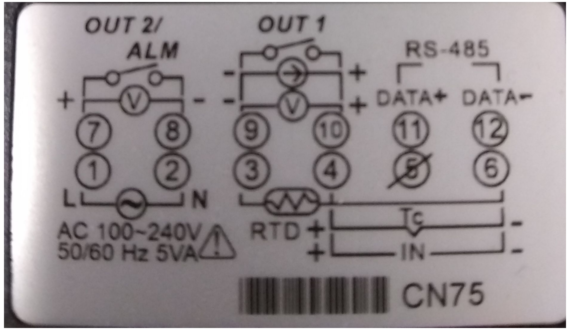
-Great for fine tuning things

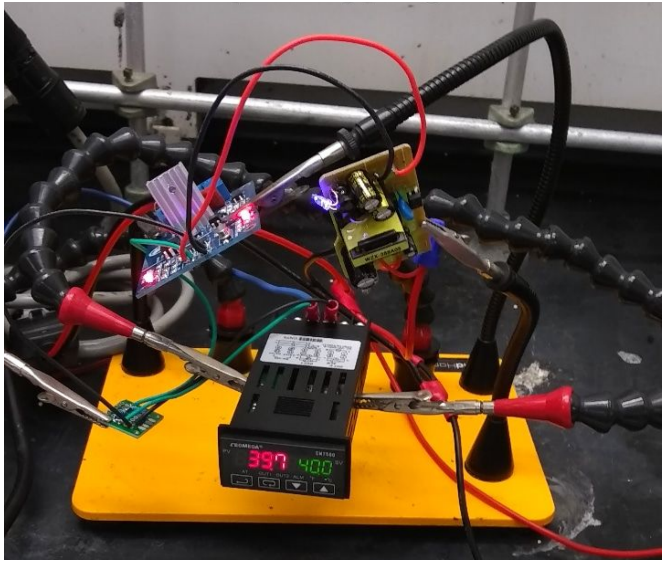
Have someone who didn't write the code test for bugs.

-Found an error in UI this way

Stretch Goal - Temperature Control

- Designed to be a stand-alone system
- Components
  - Omega CN7500 controller
  - Triac breakout circuit
  - Wall wart
  - Signal voltage divider





Design Hiccups

- Scrapping the sensors
- Stepper vs Servo and related PCB design woes
- GPIO Issues
  - Port Expander

Name	PCB Design	Motor programming	Enclosure construction	Power	Pump programing	UI programing
Amanda		Tertiary			**Primary**	**Primary**
Anish	**Primary**	Secondary		Secondary		
Ernel			**Primary**	**Primary**		Secondary
Jason	Secondary	**Primary**	Secondary		Secondary	

Work Distribution

Budget/Financing

	Inc. in Final Design?	Price	Quantity	Total	Purchased?	Initials of Purchaser	Billed to Helicon?	Amt. Billed to Helicon
PCB/Components	1	$ 75.00	1	$ 75.00	Y	AU	1	$ 75.00
Sensors		Too much		$ -				$ -
Valves		$ 75.00	4	$ -				$ -
Pumps		$ 3,000.00	2	$ -				$ -
Power supplies	1	$ 25.00	1	$ 25.00	Y	ER	1	$ 25.00
Enclosure	1	$ 60.00	1	$ 60.00	Y	ER	1	$ 60.00
Din Rails	1	$ 15.00	2	$ 30.00	Y	ER	1	$ 30.00
Backplane	1	$ 30.00	1	$ 30.00	Y	ER	1	$ 30.00
LCD Display	1	$ 8.00	1	$ 8.00	Y	AG	1	$ 8.00
Motors	1	$ 21.00	4	$ 84.00	Y	JS	1	$ 84.00
Motor Mounts	1	$ 14.25	4	$ 57.00	Y	JS	1	$ 57.00
MRKZero for Prototyping	1	$ 60.00	1	$ 60.00	Y	AG		$ -
MRKZero for Prototyping	1	$ 60.00	1	$ 60.00	Y	AU		$ -
Motor Carrier for Proto.	1	$ 30.00	1	$ 30.00	Y	AG		$ -
Motor Carrier for Proto.	1	$ 30.00	1	$ 30.00	Y	AU		$ -
Pump Interface Supplies	1	$ 35.00	1	$ 35.00	Y	JS	1	$ 35.00
ATMEL-ICE Programmer	1	$ 61.00	1	$ 61.00	Y	JS	1	$ 61.00
Miscellaneous	1	$ 42.00	1	$ 42.00	Y	JS	1	$ 42.00
Total				$ 687.00				$ 507.00
Expected Total Cost				$ 687.00				

Total spent by group member	
Amanda	$ 98.00
Anish	$ 165.00
Ernel	$ 145.00
Jason	$ 176.00
Total projected project cost	$ 687.00
Helicon Total Cost	$ 507.00
Total cost to us	$ 180.00

Progress Visualization