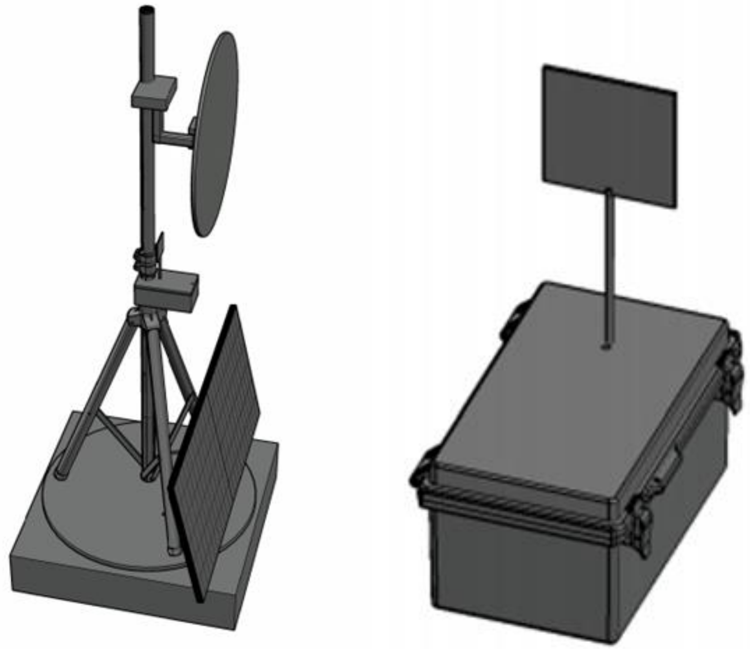
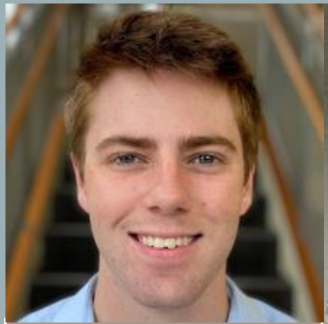
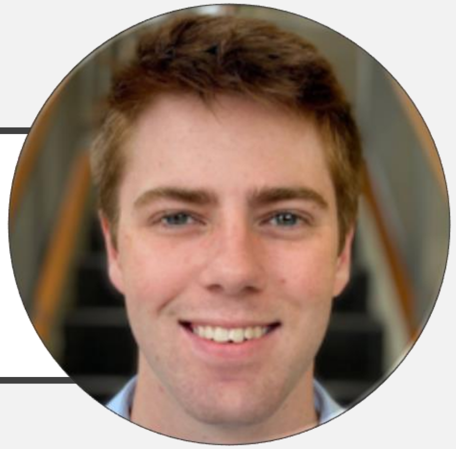


A.S.T.R.O.COM.

ADVANCED SOLAR TRACKING AND ROVER OBSERVATION COMMUNICATION

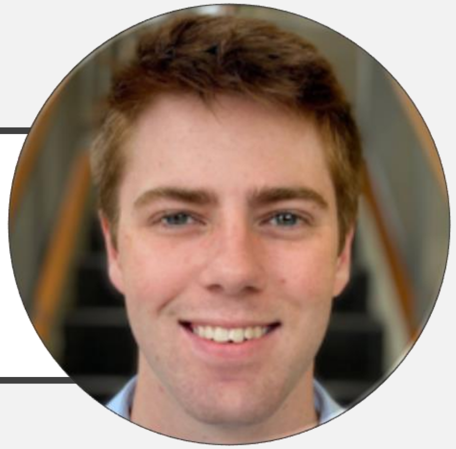
			
Alex Fiset	**Pedro Kasprzykowski**	**Stephen Martin**	**Binh Pham**
Electrical Engineering	Computer Engineering	Computer Engineering	Computer Engineering

MOTIVATION AND BACKGROUND



- South Pole of Moon is area of interest for researchers
- Lunar south pole has many craters that are in permanent darkness due to the sun's path across the lunar south pole's sky
- Approached by FSI to solve a few problems for lunar exploration:
  1. Permanently dark locations on the moon are difficult to explore
     - Lack of power infrastructure on the moon limits exploration
     - Permanently dark locations are a valuable location for research
  2. Communication on lunar surface is limited
     - Range of communication limits exploration of craters
     - Limited communication infrastructure on moon

MOTIVATION AND BACKGROUND



- Proposed Solution:
  1. A heliostat tower
     - To reflect light from the sun into permanently dark locations
     - Equipped with communication capabilities
  2. A smaller communication beacon
     - Carriable by rovers
     - Form a communication network with rovers

GOALS

Overall Goals (High Level)

- Build a tower to handle rover communication.
- Build a tower to handle sunlight diversion to targets.

Stretch Goals

- P2P Networking for communication and mirror tower with rovers.
- Wireless charging and/or docking station for communication tower.

OBJECTIVES

Mirror Tower Objectives (Lower Level)

- Identify optimal sun location based on lux value from sensor.
- Receive requests from communication tower using protocols.
- Create a heliostat algorithm to orient towards the target with motors.
- Create a self-sustainable power supply using solar and battery power.

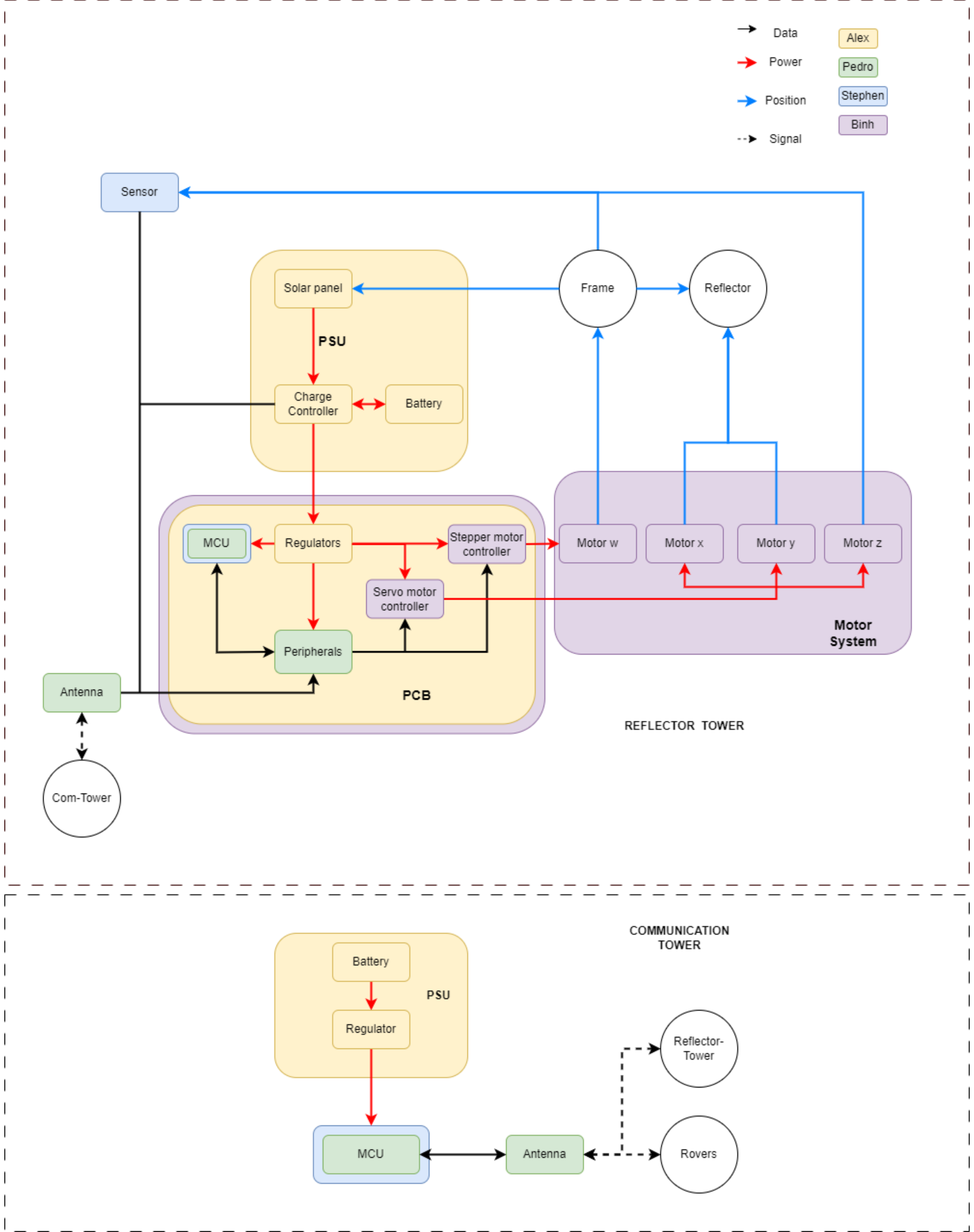
Communication Beacon Objectives (Lower Level)

- Receive requests from target through mesh network protocols.
- Relay requests to mirror tower using communication protocols.
- Create a small and portable tower that can be moved by rovers.

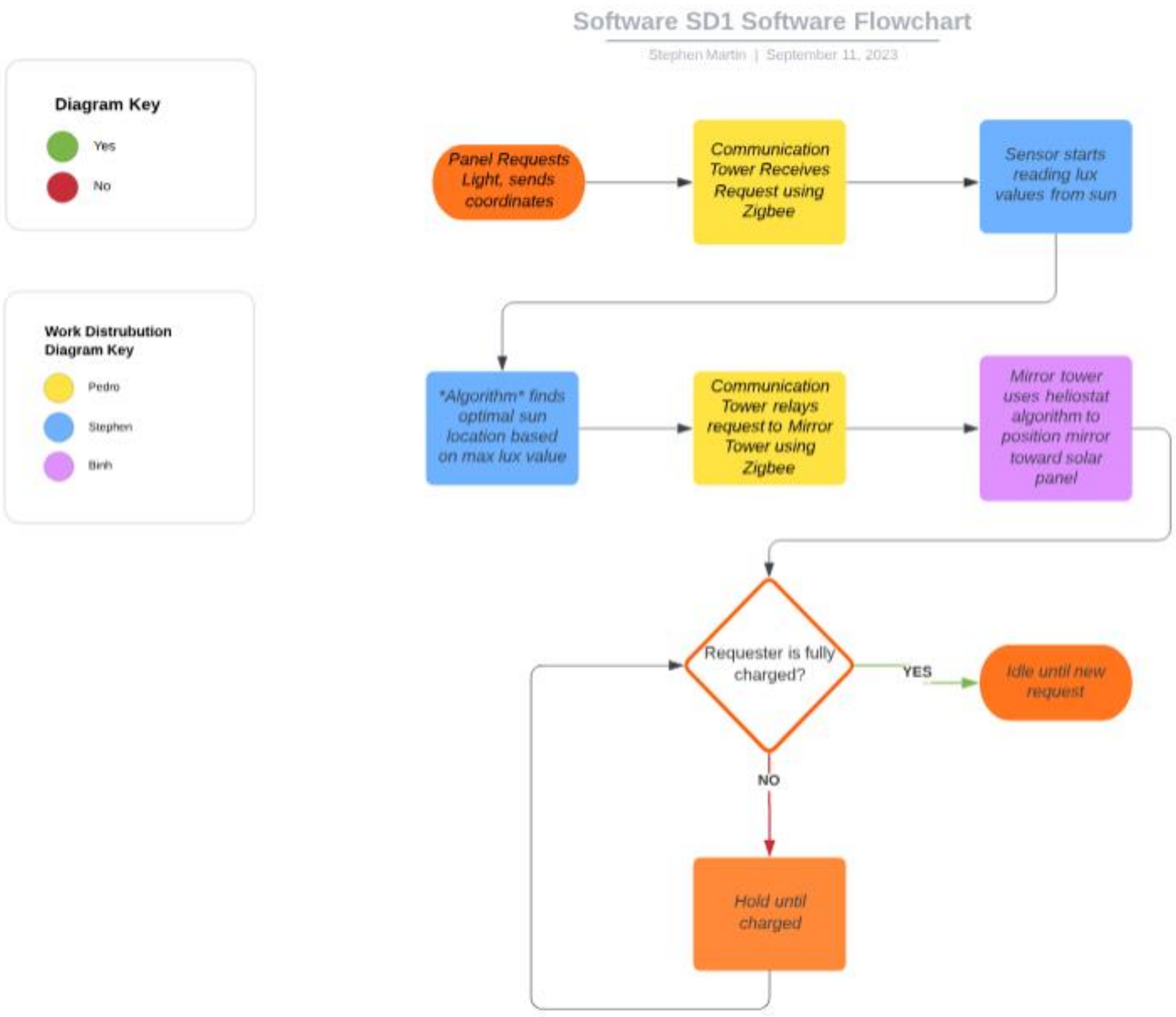
SPECIFICATIONS TABLE

Heliostat Tower	
Minimum Temperature	-40°C
Reflector	
Minimum size	1ft diameter
Maximum size	5ft diameter
Maximum Weight	9kgs
Minimum Reflectivity	90%
Response Time	3 minutes
Tower Frame	
Maximum total weight	27kgs
Minimum Weight Capacity	10kgs
Solar Panel	
Minimum Power	30W during sunlight hours
Maximum Voltage	24V
Battery	
Minimum Lifespan	2 weeks without sun

Communication Tower	
Minimum Enclosure Volume	6.5"x6.5"x5"
Maximum Weight	2kg
Minimum Network Range	20m
Communication Rate	2400MHz
Voltage input	3.3V or 5V
Maximum Current Draw	500mA
Minimum Temperature	-40°C
Latency	1 second
Maximum Power	5W



HARDWARE BLOCK DIAGRAM



SOFTWARE BLOCK DIAGRAM

COMPARISON AND SELECTION OF HARDWARE

- MCU
- Solar Panels
- Voltage Regulation
- 3Charge Controller
- Reflectors
- Motors
- Motor Controllers
- Sensor
- Batteries
- Antenna

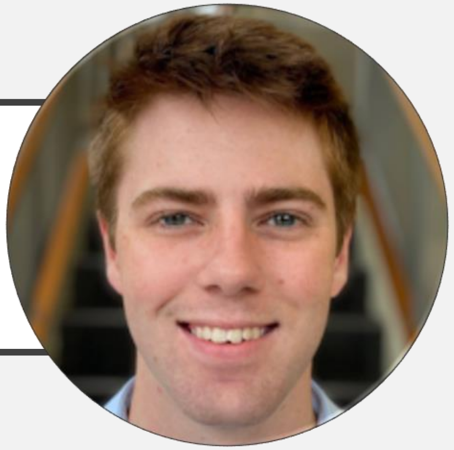
MCU

	ESP32	MSP430	Raspberry Pi 0	Arduino MKR1310	Arduino MK1010
Cost - Processor & DevKit (USD)	9.18	20	15	46	38.6
Wi-Fi	Yes	No	Yes	No	Yes
Bluetooth	Yes	No	Yes	No	Yes
Zigbee	Yes	No	Yes	No	No
Z-Wave	No	No	Yes	No	No
LoRaWAN	No	No	Yes	Yes	No
6LoWPAN	No	No	Yes	No	No
UART	Yes	Yes	Yes	Yes	Yes
I2C	Yes	Yes	Yes	Yes	Yes
SPI	Yes	Yes	Yes	Yes	Yes
PWM	Yes	Yes	Yes	Yes	Yes
ADC	Yes	Yes	Yes	Yes	Yes
DAC	Yes	Yes	No	Yes	Yes
Flash Memory	4 MB	128 KB	None	256 KB	256 KB
RAM	520 KB	2 KB	512 MB	32 KB	32 KB
Operating Voltage (V)	3.6	5	5	3.3	3.3
Current Draw (A)	0.379	0.2	2.5	0.154	0.154
Power Consumption (W)	1.3644	1	12.5	0.5082	0.5082

- Microcontroller was chosen over FPGA, presenting characteristics that were better fits for the project such as low power consumption, cost and high amounts of documentation.
- ESP32 had the best combination of low cost, low power and networking capabilities and all connections required.

Criteria	Microcontroller	FPGA
Environmental robustness	✓	
Low power consumption	✓	
Parallel processing		✓
Ease of use	✓	
Processing power		✓
Cost	✓	
Scalability		✓
Integration/Peripherals	✓	
Documentation	✓	

SOLAR PANELS

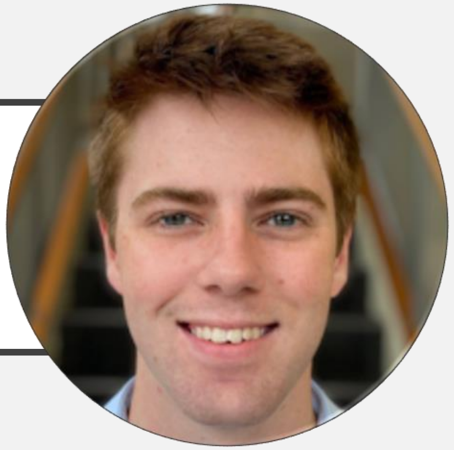


Solar Panel Technology	Efficiency	Low-Light Perf.	Temp. Tolerance	Radiation Resistance	Degradation	Weight & Size
Monocrystalline	High	Excellent	Good	Good	Low	Relatively heavier
Polycrystalline	Moderate	Good	Good	Good	Low to Moderate	Moderate
Thin-Film	Low	Varies	Good	Varies	Moderate to High	Lightweight & Flexible

SOLAR PANELS

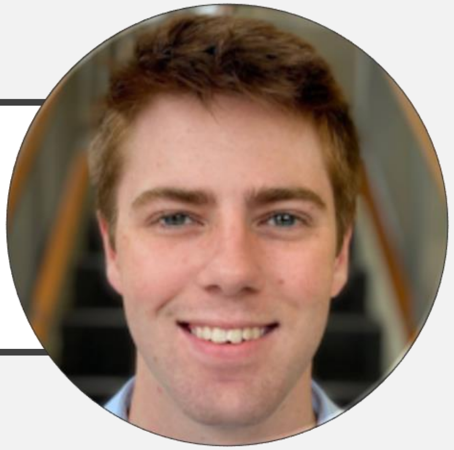
Model	RNG-50D-SS	HQST-50P-US	SP-52-L
Brand	Renogy	HQST	Solbian
Technology	Monocrystalline	Polycrystalline	Monocrystalline
Price	$ 59.99	$ 65.99	$ 499.00
Pmax at STC	50 W	50 W	52 W
Voc	22.3V	23.3V	10.9V
Vmp	18.6V	19.8V	9.1V
Imp	2.69A	2.53A	5.7A
Isc	2.94A	2.63A	6A
Weight	7.7 lbs	8.4lbs	1.8lbs
Dimensions (inches)	22.9 x 20 x 1.2	25.9 x 18.6 x 1.2	43.7 x 11.49 x 0.1
Temp Coefficient of Pmax (%/degC)	-0.37	-0.37	-0.38

VOLTAGE REGULATION



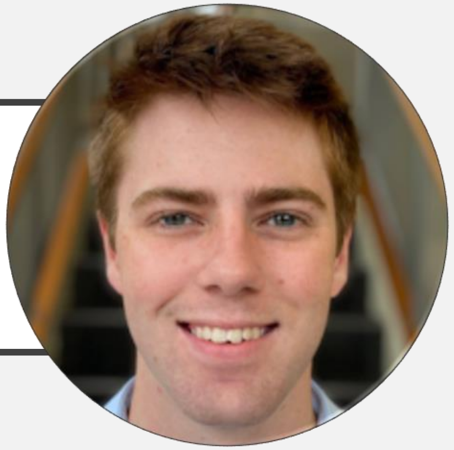
Specifications	Linear Regulators	Switching Regulators		
		Buck	Boost	Buck-Boost
Efficiency	Moderate	High		
Heat	Moderate	Low		
Voltage Output	Step-Down	Step-Down	Step-Up	Up or Down
Output Ripple	Low	Low	High	Low
Complexity	Low	Moderate	Moderate	High
Cost	Low	Moderate	Moderate	High

VOLTAGE REGULATION



Model	LM1085IT-5.0/NOPB	DROK MiniBuck Converter	LM2596	TPS54JA20 ✓
Brand	Texas Instruments	DROK	Texas Instruments	Texas Instruments
Input Voltage	2.6-26V	2.5-24V	3-40V	2.7–16V
Output Voltage	3.3 or 5	3.3 or 5	1.5 to 35	0.5 to 5.5V
Output Current	3A	3A	3A	12A
Price	2.19	1.97	1.495	0.65
Type	LDO Buck	Buck	Buck	Buck

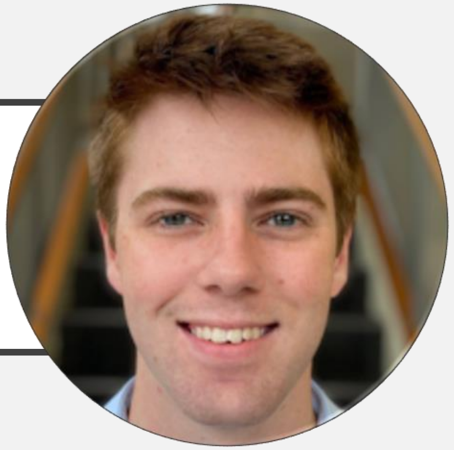
CHARGE CONTROLLER



- Two broad categories of Solar Charge Controllers:

1. PWM
   - Basic pulse width modulation
   - Lower efficiency
   - Cheaper
2. MPPT
   - Tracks highest power producing operating point
   - Higher efficiency
   - Typically, more expensive

CHARGE CONTROLLER



Model	BQ25798RQMR	SR11004	Adventurer
Brand	Texas Instruments	SMARAAD	Renogy
Input Voltage	24V max	26V max	50V max
Output Voltage	18.8V max, Programmable	12/24V	12/24V
Output Current	5A	10A	30A
Price	6.25	39.99	59.99
Power	Not Specified	260W	1500W
Type	MPPT	MPPT	PWM
Programming MPPT	I2C	Not Specified	NA
MPPT Type	Sets Voltage to % of Voc	Not Specified	NA
Charge controls	Programmable	Battery Chemistry presets	Preprogrammed depending on chemistry

REFLECTORS

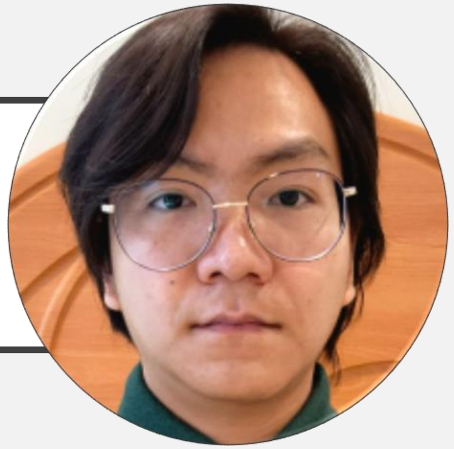
- Material Chosen to fabricate:
- Aluminum has high heat resistance, durable, and high reflectivity in the moon environment.
- Mylar increase reflectivity instead of glass which has higher heat change resistance and won’t crack, which reduces quality of refection
- Proof of concept: plywood as cheaper alternative and easier to fabricate.

MOTORS

- Stepper motor: Nema 34 robustness and strong torque to control the rotation of the whole tower. Can be used on DC system
- Incorporated gearbox to increase movement range and control for stepper motor.
- Servo Motors: a cheaper alternative for smaller part movements.

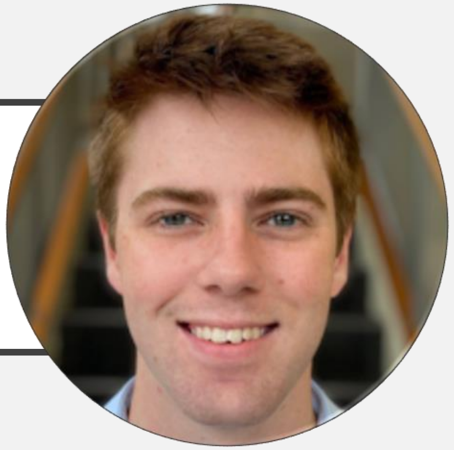
Types of Motors	DC Brush	DC Brushless	AC	Stepper	Servo
Financial Cost	Small: $5-$50 Medium: $20-$100	Small: $10-$100 Medium: $100-$500	Small: $50- $200 Medium: $200-$2,000	Small: $10-$50 Medium: $50-$200	Small: $50-$200 Medium: $200-$1000
Size	~8mm-35mm	~13mm-35cm	~10cm-30cm	~0.4cm-20cm	~0.4cm-10cm
Torque	0.36-160 nNm	4-400 nNm	203000Ncm-610000Ncm	10-10000Ncm	10-1000Ncm
Speed	5,000 to 14,000 rpm	100,000 rpm	1800-3600 rmp	Low	High
Voltages requirement	4.5V/4.5V/7.0V	4-24V	115V/208V/230V	3V-100V	3V-100V
Durability	High	High	High	High	Low
Weight	0.5-160g	10-1000g	750g	150-5000g	

MOTOR CONTROLLERS



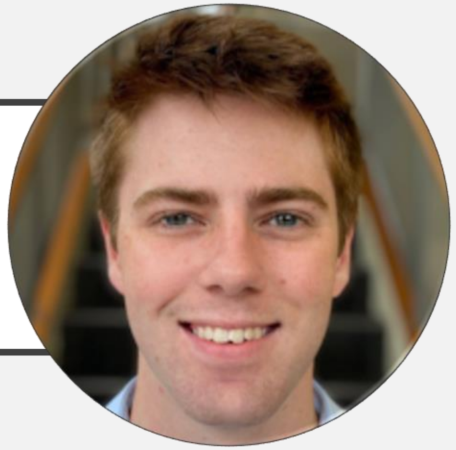
- Stepper Controller DRV8834, cheap and can handle the amperage provided by the system.
- PCA9685 PWM: Design specific for servo and can control all three servos planned in the system, compatible with ESP32 C6 and run on I2C protocol.

BATTERIES



Specifications	Lead Acid	NiCd	NiMH	Li-ion		
				Cobalt	Manganese	Phosphate
Specific Energy	30-50	45-60	60-120	150-250	100-150	90-120
Internal Resistance	Very low	Very low	Low	Moderate	Low	Very low
Cycle Life	200-300	1000	300-500	500-1000	500-1000	1000-2000
Self-Discharge/month at RT	5%	20%	30%	< 8%		
Operating Temperatures	-20 to 50 C	0 to 45 C	0 to 45 C	0 to 45 C		
Maintenance Requirements	3-6 Months topping charge	Full discharge every 90 days		Maintenance free		
Safety Requirements	Thermally stable	Thermal stable, fuse protection		Protection circuit mandatory		
Cost	Low	Moderate		High		

BATTERIES



Model	ML5-12	HW-4F7	PQ12V/6AH
Brand	Mighty Max Battery	Howell Energy	Power Queen
Voltage	12	12	12.8V
Amp Hour	5	7	6
Technology	SLA AGM	LiFePO4	LiFePO4
Price	16.99	32.99	19.59
Temperature Rating	-20 to 50	-20 to 70	Not Specified
Weight	3lbs	1.9lbs	1.8lbs
Dimensions	3.5 x 2.8 x 4.2	5.9 x 2.6 x 3.7	5.9 x 2.6 x 3.7
Charging Requirements	CV	CC 3.5A, CV 14.6V, Built-in BMS	Not Specified, Built in BMS

SENSOR

Sensor Final 4 Options:

- VL6180X and SI1145 include IR which is not needed
- MAX44009 only has breakout board; does not work for PCB

- VEML7700 best choice for price/ability

	VL6180X	MAX44009	SI1145	VEML7700
Cost (USD)	$14.49	$5.96	$9.95	$4.95
Measuring Principle	TOF/IR Laser Photodiode	Photodiode	IR-LED Photodiode	Photodiode
Max Lux	100000	188000	128000	120000
Ambient Light Sensing	Yes	Yes	Yes	Yes
IR Sensing	No	No	Yes	No
UV Sensing	No	No	Yes (extrapolated)	No
Operating Voltage (V)	3	3.6	3.6	3.6
Operating Current (mA)	0.3	0.0003	7	0.0045
I2C	Yes	Yes	Yes	Yes
SMBus	No	Yes	No	No
ADC	Yes	Yes	Yes	Yes
Size (mm^2)	234	4	360	15.98
Operating Temperature (C)	[-20 - 70]	[-40 - 85]	[-40 - 85]	[-25 – 85]
C/C++ Libraries	Yes	Yes	Yes	Yes

COMPARISON AND SELECTION OF SOFTWARE

- Vectoring and Positioning / Solar Tracking Algorithm
- Communication technologies
- Development Environment: Languages and Repositories

DEVELOPMENT ENVIRONMENT: LANGUAGES AND REPOSITORIES

Programming Languages

- C: best choice for MCU programming, low-level
- Java: best for object-oriented programming, low-level
- Python: best for existing libraries, high-level

Choice: C ✓

Repositories

- GitHub: most popular repo, widely used among many software devs
- Bitbucket: Git based repo, includes task scheduling and team goal software

Choice: GitHub ✓

VECTORING AND POSITIONING / SOLAR TRACKING ALGORITHM

Algorithms	Heliostat	Kalman Filtering	Skyview Factor	Ray Tracing	Two-axis Solar Tracking System	Sun tracking Photodiode
Financial Cost	Open Source	Ambiguous	Open Source	Not available	Open Source	No available
Sensor	Ambient Light	Ambient Light	Ambient Light	Ambient Light	Ambient Light	Photodiode
Algorithm code library	Available on GitHub	Available in python	Available on GitHub	Available in Research paper	Available in GitHub	Not available
Efficiency	High	Low	Medium	Medium	High	High
MCU compatibility	Good (C Language)	Fair (Python)	Bad (R Script)	Good (C Language)	Good (C Language)	Bad (No code)
Additional Requirements	Change to an algorithm to change light measuring location	Compass Reading or gyroscopic data				

ANTENNA

- The combination of the certain gain range, circular polarization, high-efficiency and wideband characteristics made patch and helical antenna types the ideal choices.
- The PC140's circular polarization while also being above average in gain and efficiency made it the preferred antenna product.

	Dipole	Patch	Reflector (Parabolic)	Yagi – Uda	Helical Antenna	Aperture (Horn)
Gain (dBi)	1.76-7	0.5 -10	10 - 40	5 – 20	3 – 15	10 – 25
Polarization	Linear	Linear/ Circular	Circular	Linear	Circular	Linear/ Circular
Efficiency	High	High	High	High	High	Very High
Bandwidth	Narrowband	Wideband	Narrowband	Narrowband	Wideband	Narrowband
Directivity	Omni - directional	Omni - directional	Highly Directional	Highly Directional	Directional	Highly Directional

	PC140	WPC.25A	FXP74	PC17	FXP70
Average Gain (dB)	-1.92	-1.14	-2	-3.6	-2
Peak Gain (dBi)	1.67	5.15	4	.9	1.1
Efficiency (%)	64	76.9	50	44	63.7
VSWR	<2	<2	<2	<1.5	<1.5
Polarization	RHCP	Linear	Linear	Linear	Linear
Cost (USD)	$27.26	$9.21	$7.69	$16.60	$27.09

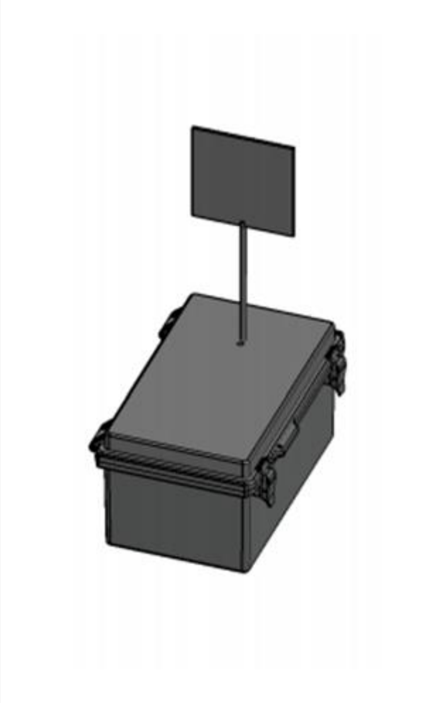
COMMUNICATION TECHNOLOGIES

- The combination of low power consumption, suitable range, options for frequency and high scalability made Zigbee the ideal communication technology to implement.

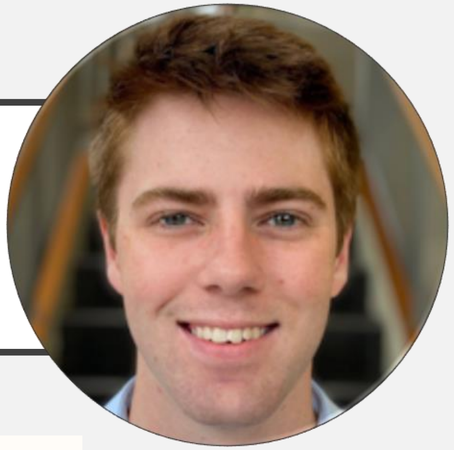
Criteria	Wi-Fi	LoRaWAN	Bluetooth	6LoWPAN	Zigbee	Z-Wave
Range (m)	45	15000	10	100	980	800
Data rate	54 Mbps	50 Kbps	1 Mbps	250 Kbps	250 Kbps	100 Kbps
Power consumption	30 uA-250 mA	1 uA-16 mA	9 uA-39 mA	0.3 uA-35 mA	12 uA- 54 mA	1 uA-23 mA
Max devices	255	120	3-4	100	100	232
Scalability	✓	✓	✕	✓	✓	✓
Frequency	2.4/5/6 GHz	902.3-914.9 MHz	2.4 GHz	2.4 GHz	915 MHz/2.4 GHz	908-916 MHz

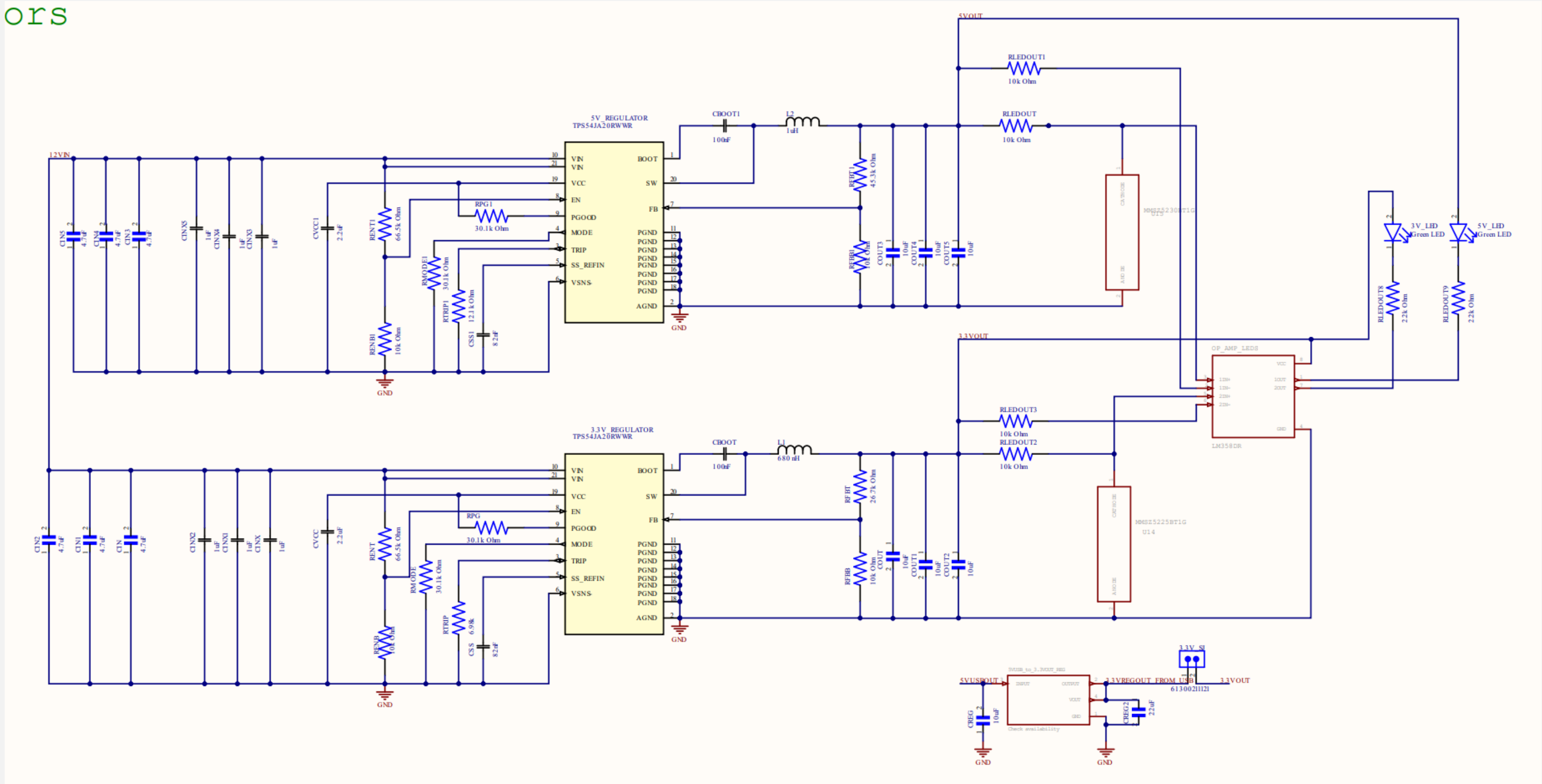
HARDWARE DESIGN

- Design two separate towers, each with their own design constraints
- Majority of focus is on heliostat tower, as it is more complex
- Schematics and PCB designs
- Heliostat structure
  - Tripod on a "Lazy Susan"
- Communication Beacon
  - Antenna on an enclosure

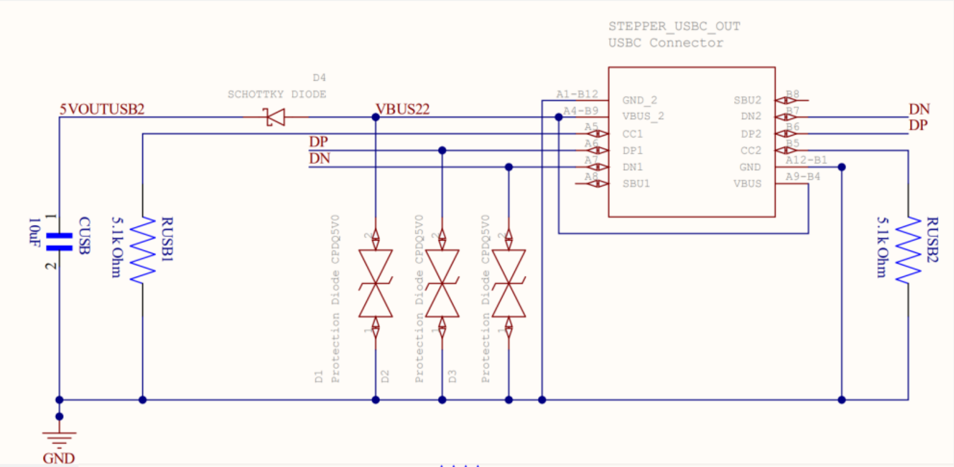


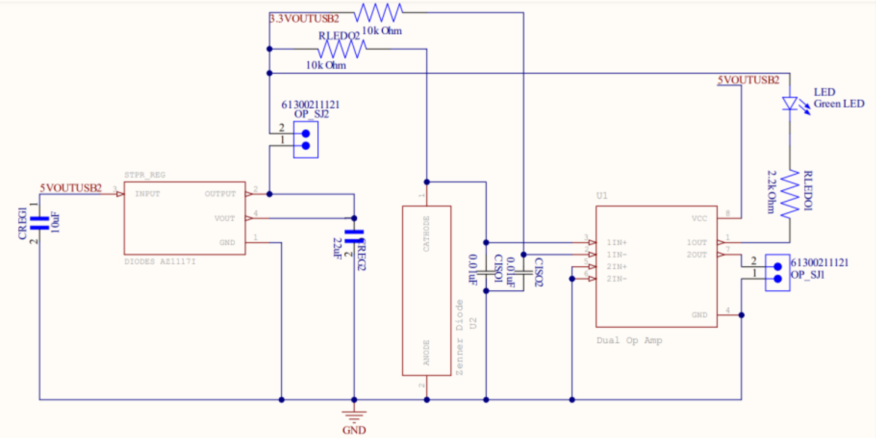
POWER DELIVERY/ ELECTRICAL POWER SYSTEM

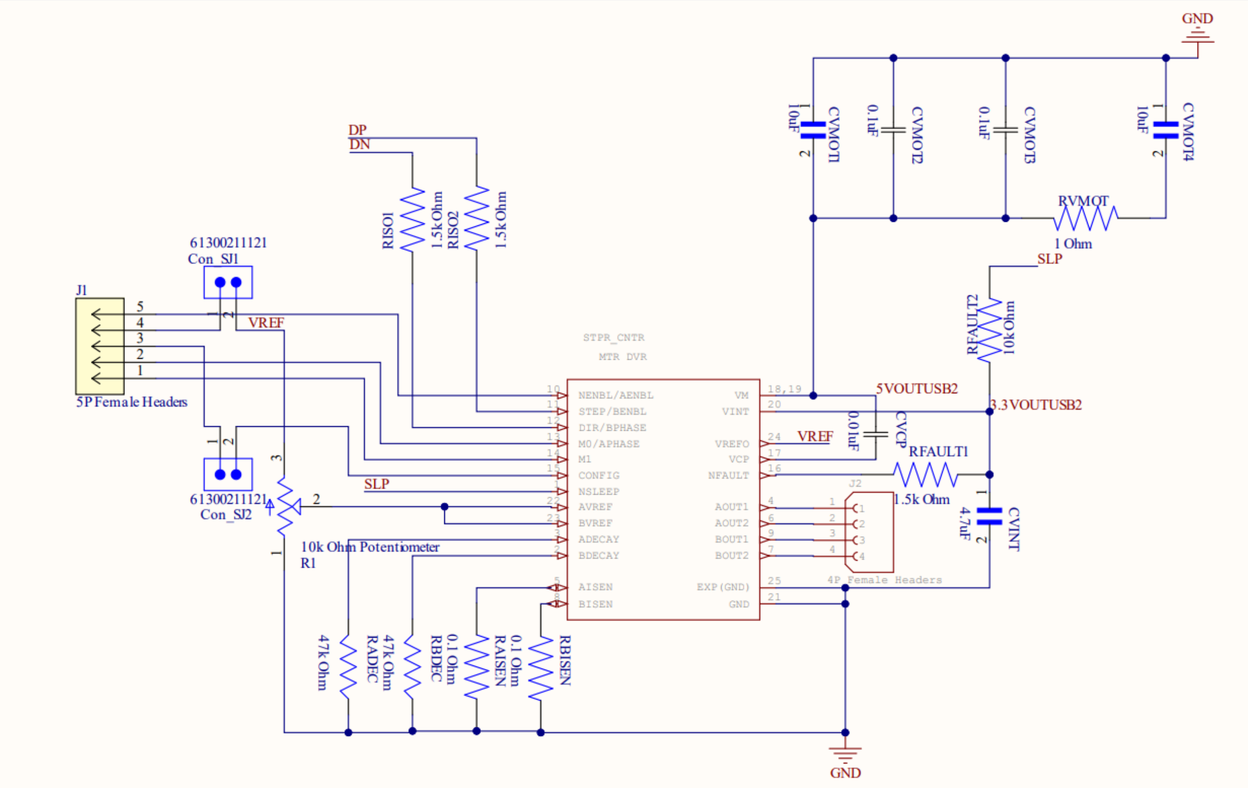




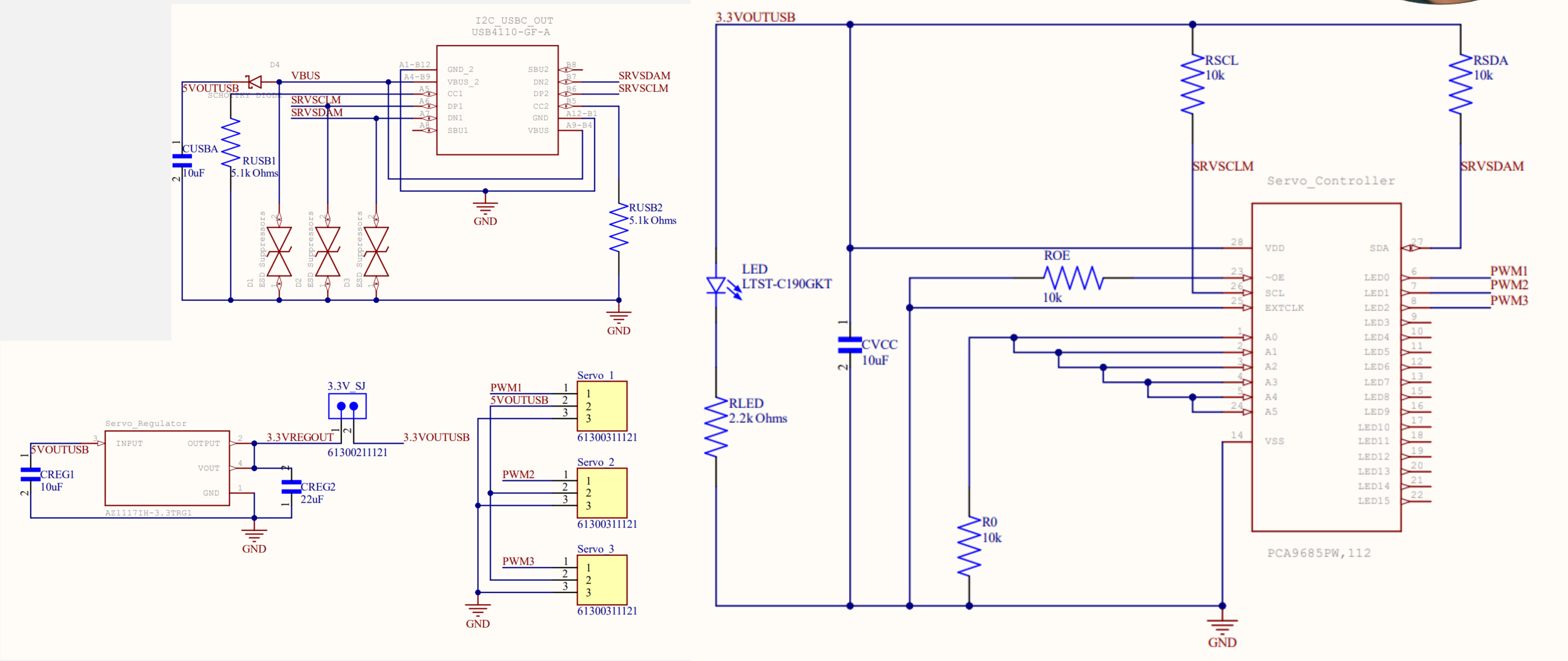
STEPPER MOTOR CONTROLS



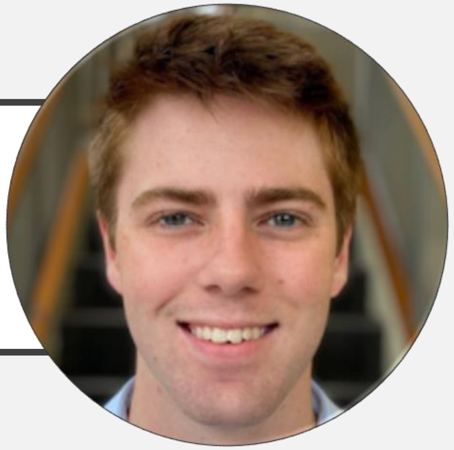


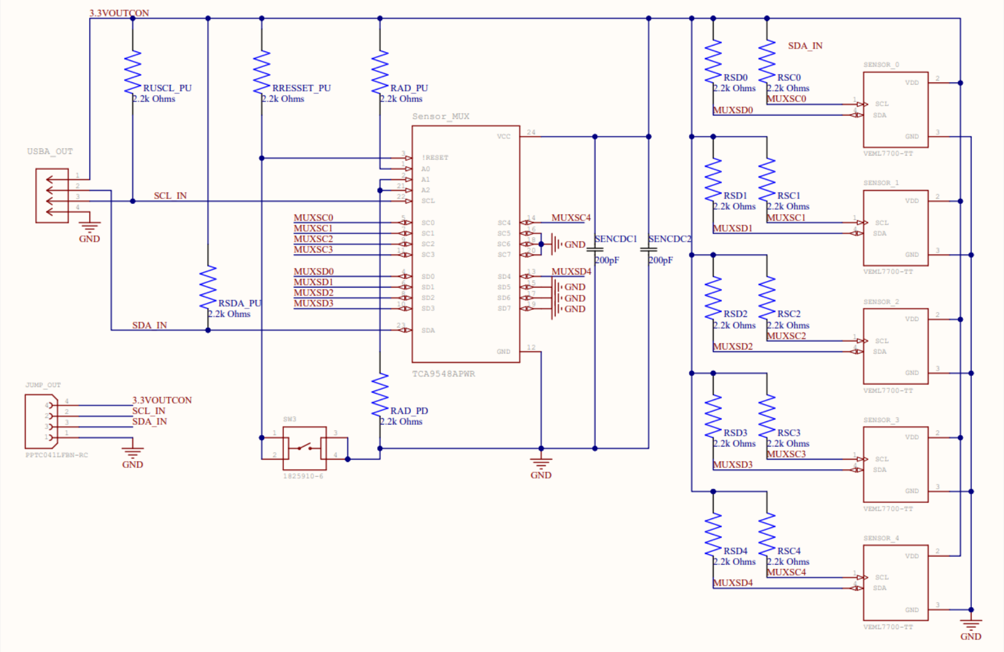


SERVO MOTOR CONTROLS

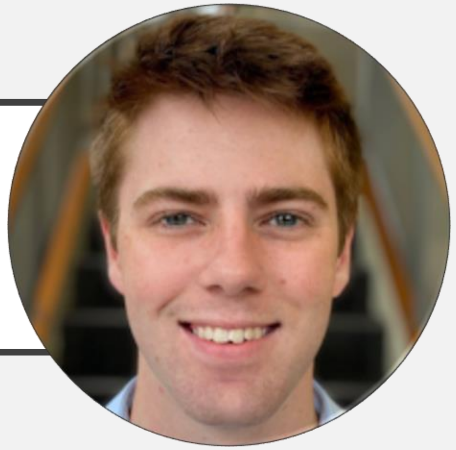


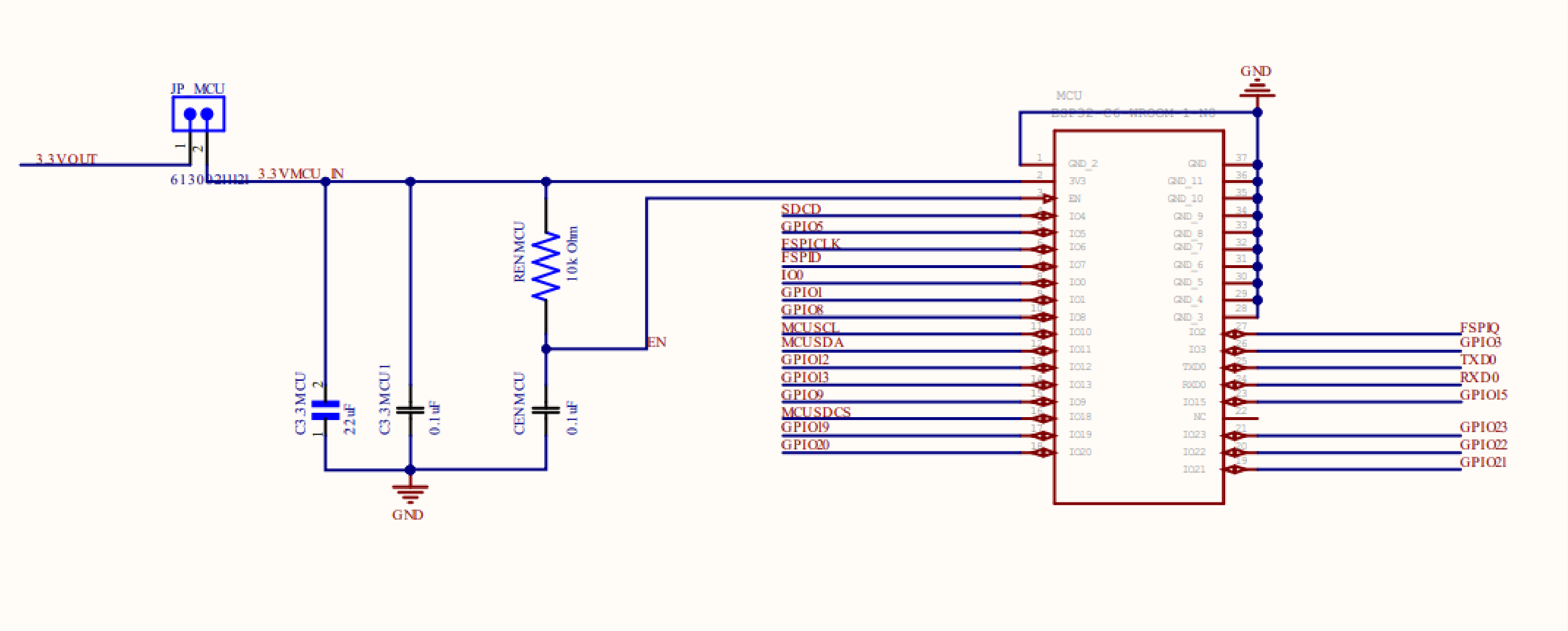
SENSOR CONTROL





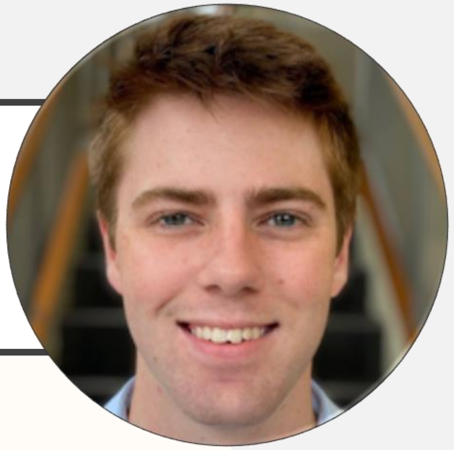
MCU SYSTEM

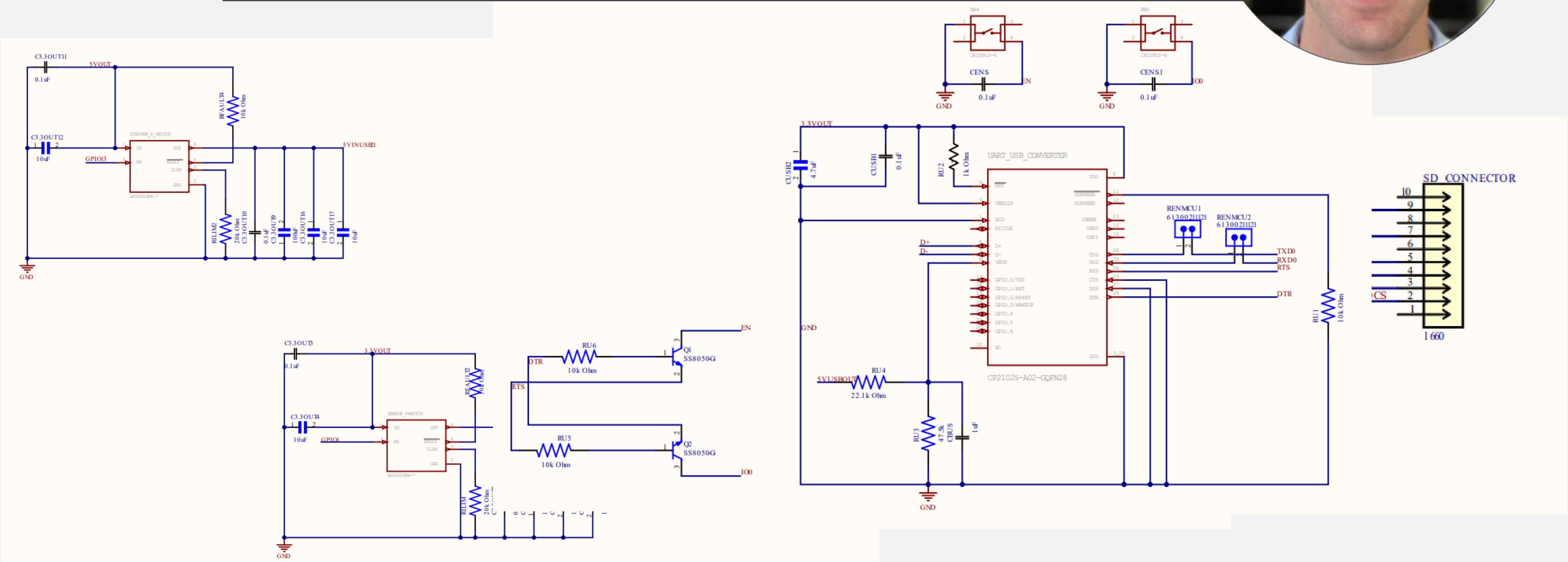




JP_MCU
3.3VOUT
61300211121
3.3VMCU_IN
RENMCU
10k Ohm
EN
C3.3MCU
22uF
C3.3MCU1
0.1uF
CENMCU
0.1uF
GND
MCU
GND
SDCD
GPIO5
FSPICLK
FSPID
IO0
GPIO1
GPIO8
MCUSCL
MCUSDA
GPIO12
GPIO13
GPIO9
MCUSDCS
GPIO19
GPIO20
FSPIQ
GPIO3
TXD0
RXD0
GPIO15
GPIO23
GPIO22
GPIO21

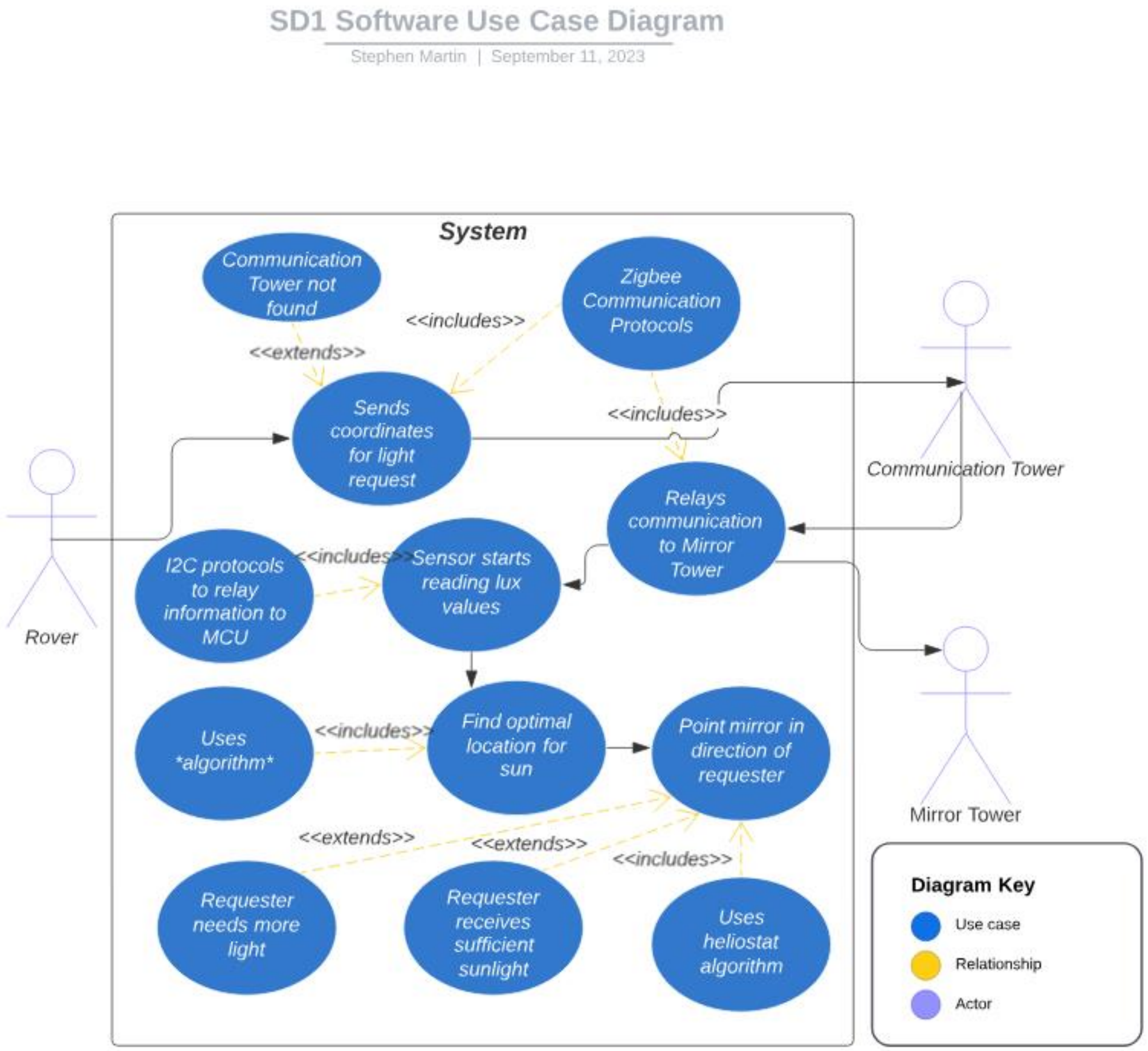
LOWER-LEVEL SUBSYSTEM





SOFTWARE DESIGN

- Details on software design for the overall system which includes:
- Communications through the mesh network
- Collecting sensor information
- Positioning reflector to deliver sunlight to target
- Represented with software diagrams

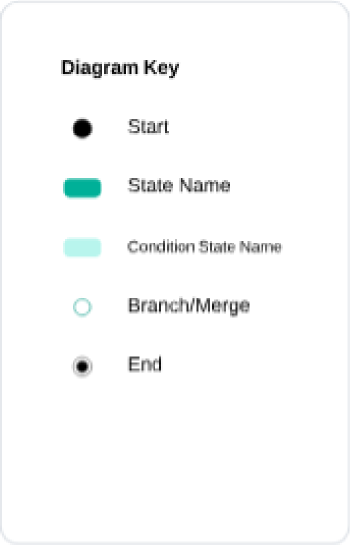


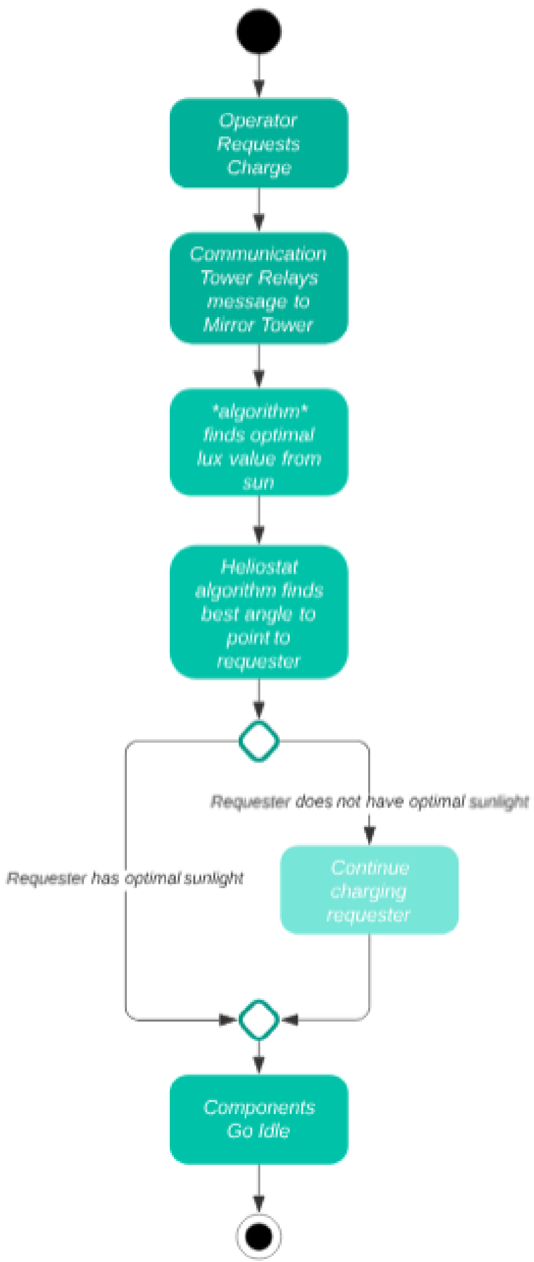
CASE DIAGRAM

ACTIVITY DIAGRAM

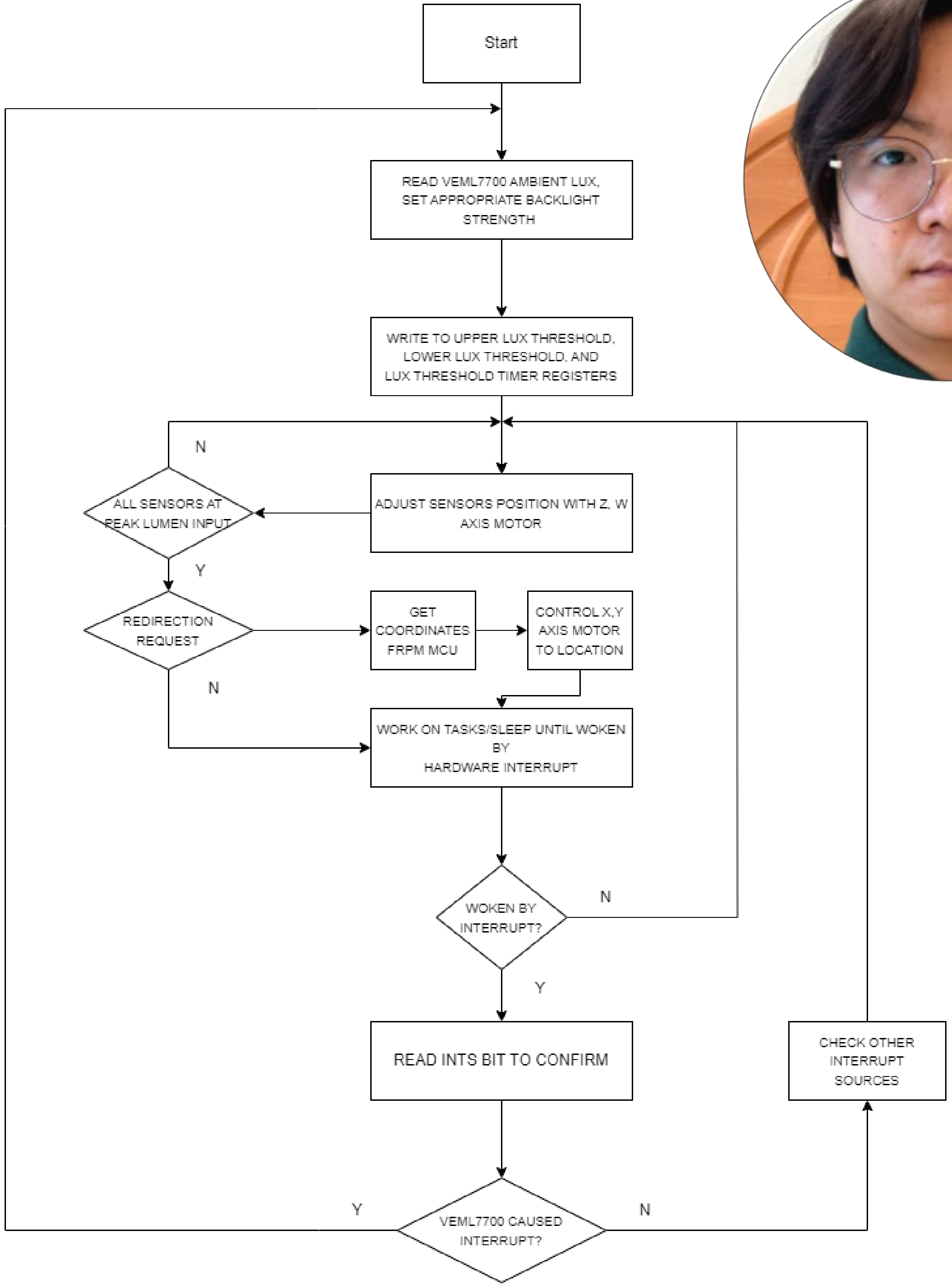
SD1 Activity Diagram

Stephen Martin | September 11, 2023

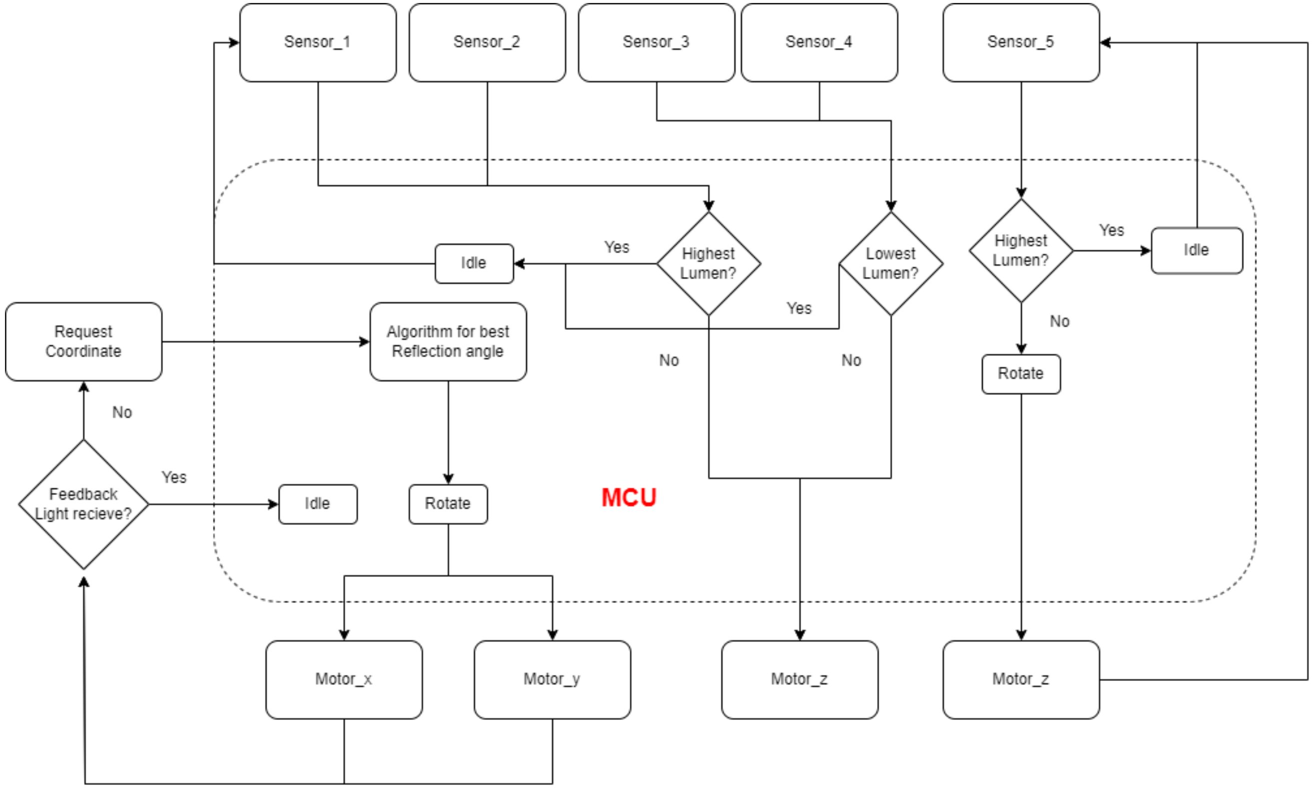




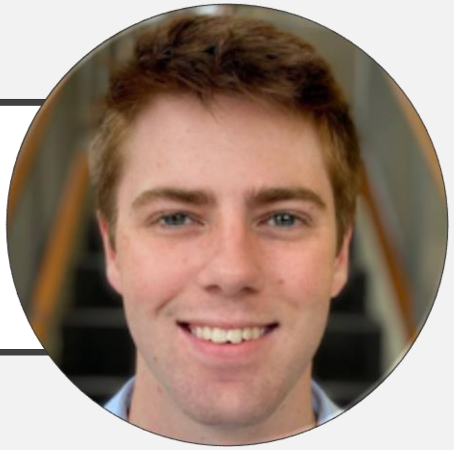
MOTOR POSITIONING OF REFLECTOR BASED ON LIGHT INTENSITY ALGORITHM.



MOTOR POSITIONING OF REFLECTOR BASED ON LIGHT INTENSITY ALGORITHM



POWER CONTROL ALGORITHM

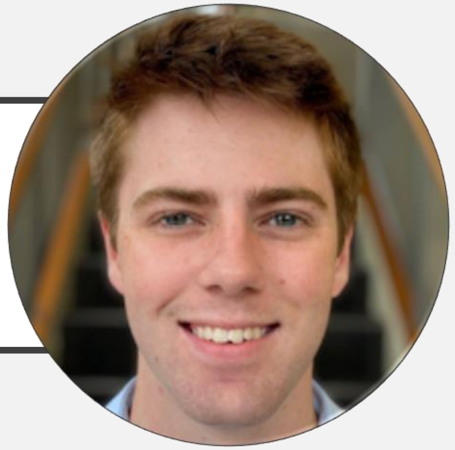


- Goal was to reduce power consumption when the sun would not be visible

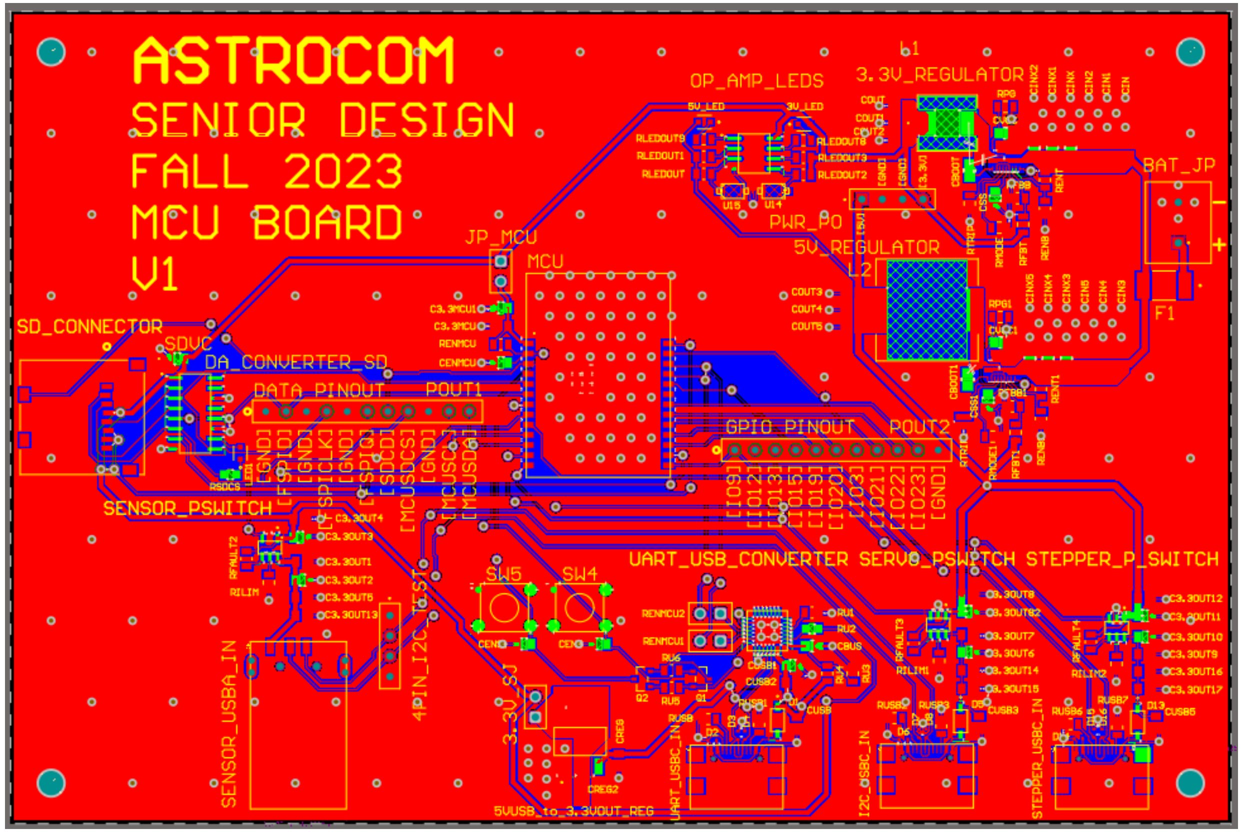
- Reducing usage of non-essential components during these times would preserve battery charge

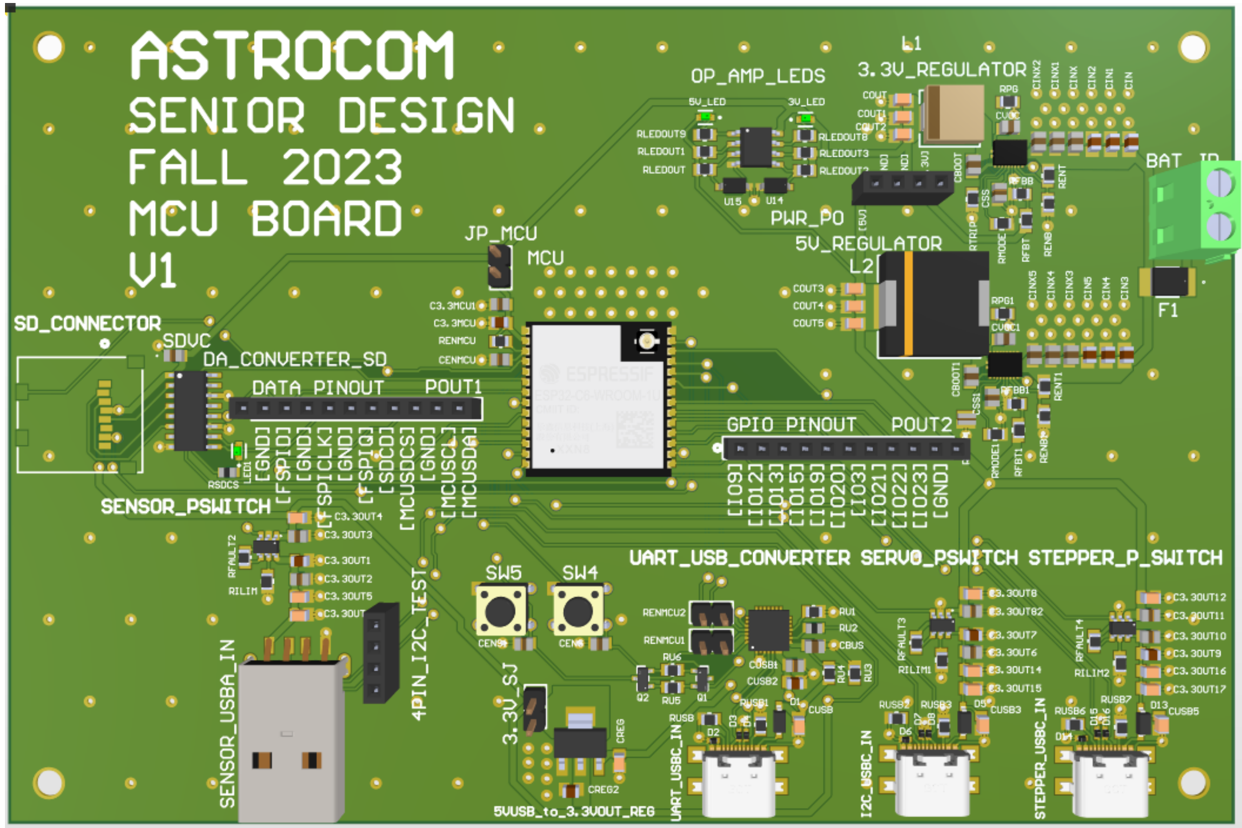
Component	Essential/Non-Essential	Low-Power Considerations
MCU	Essential	Low-Power Mode, only essential functions
Antenna	Essential	Receive only
Sensors	Essential	Sensors will be turned on periodically
Stepper Motor	Non-Essential	
Servo Motors	Non-Essential	

PCB DESIGN

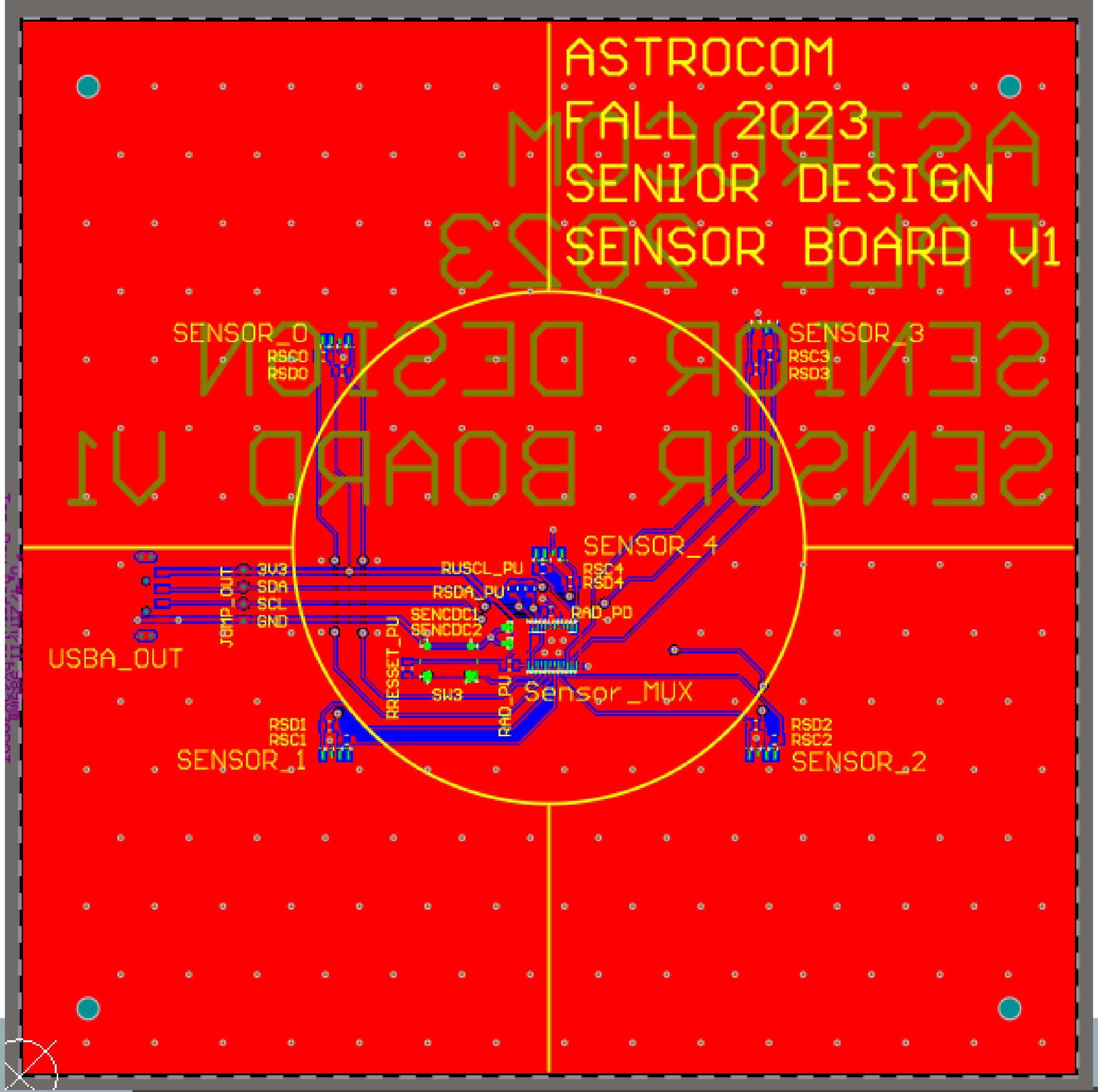


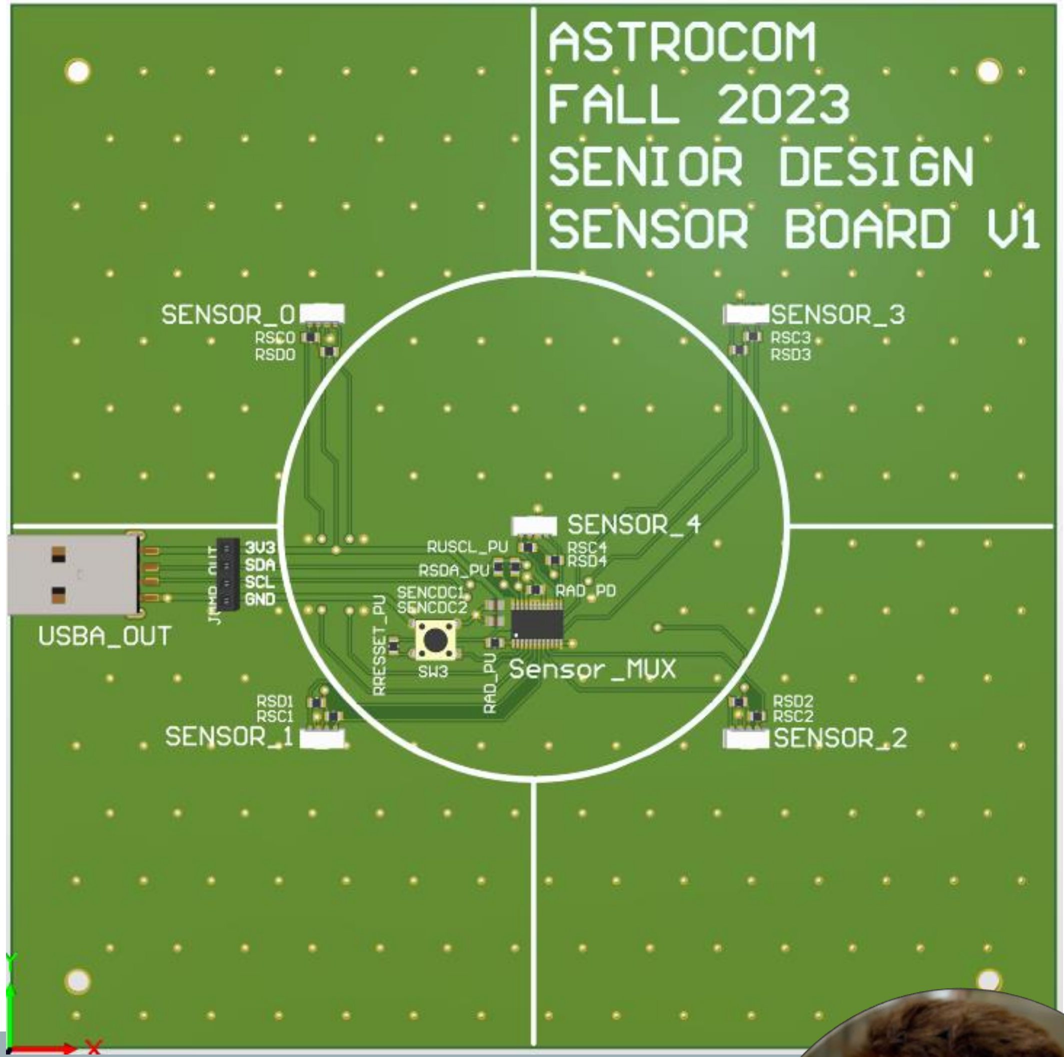
- MCU
- Sensors
- Stepper Motor Controller
- Servo Motor Controller


ASTROCOM
SENIOR DESIGN
FALL 2023
MCU BOARD
V1

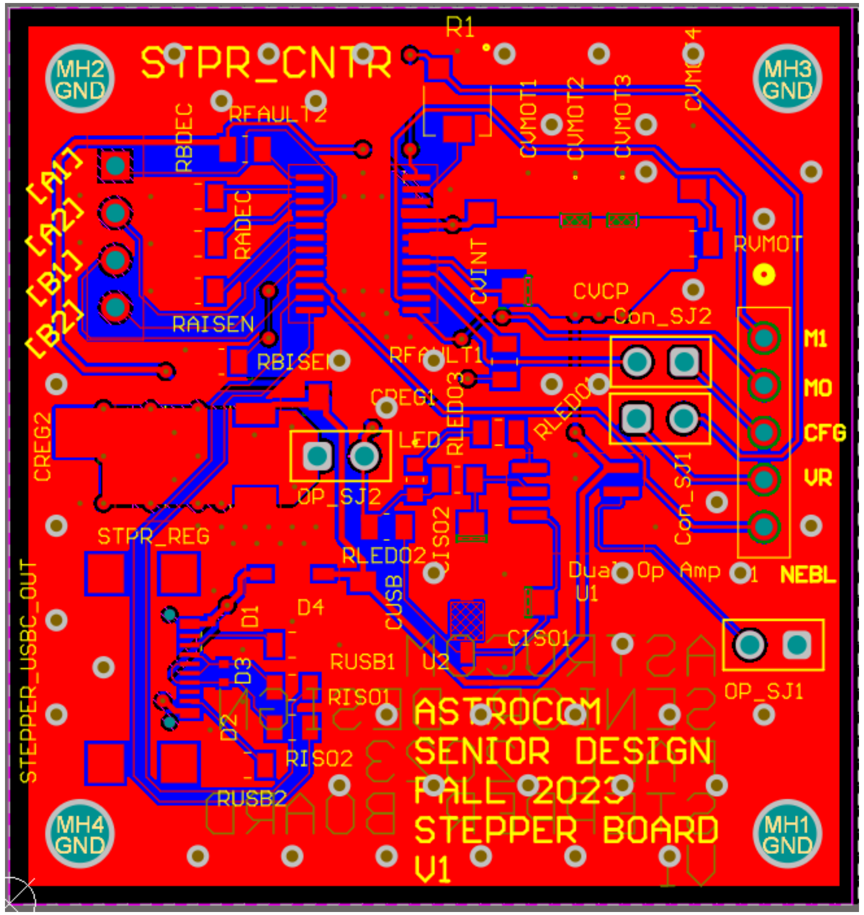

ASTROCOM
SENIOR DESIGN
FALL 2023
MCU BOARD
V1

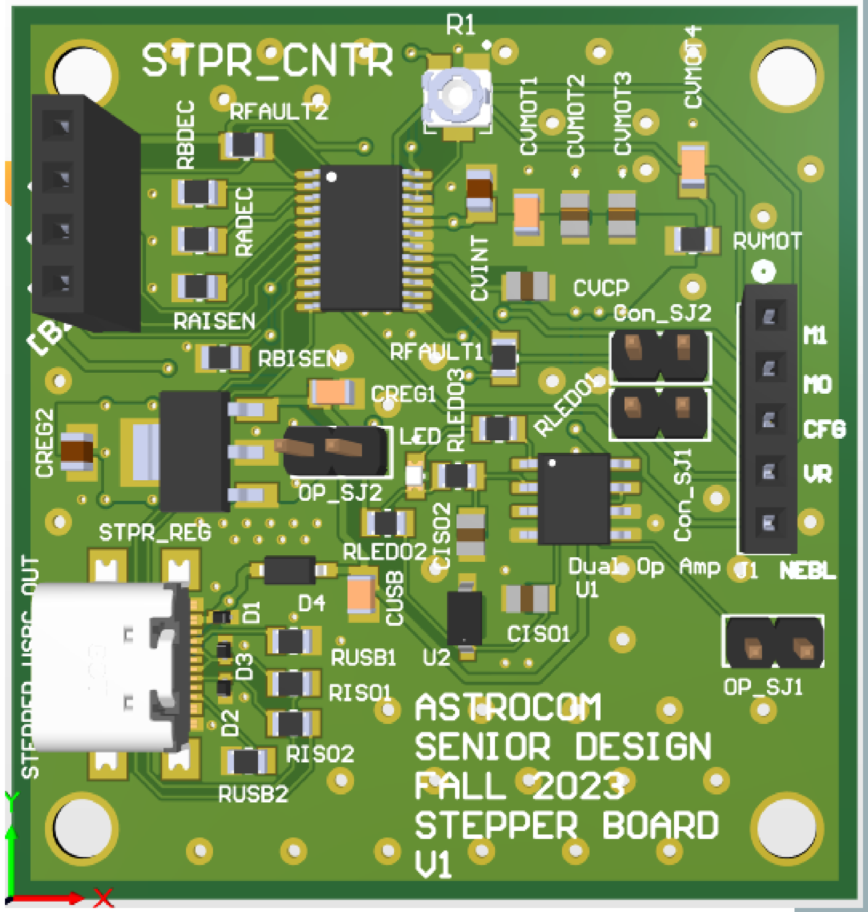
MCU PCB


ASTROCOM
FALL 2023
SENIOR DESIGN
SENSOR BOARD V1
SENSOR_0
RSC0
RSD0
SENSOR_3
RSC3
RSD3
SENSOR_4
RSC4
RSD4
RUSCL_PU
RSDA_PU
3V3
SDA
SCL
GND
JUMP_OUT
USBA_OUT
SENCDC1
SENCDC2
RAD_PD
RRESSET_PU
SW3
RAD_PU
Sensor_MUX
RSD1
RSC1
SENSOR_1
RSD2
RSC2
SENSOR_2

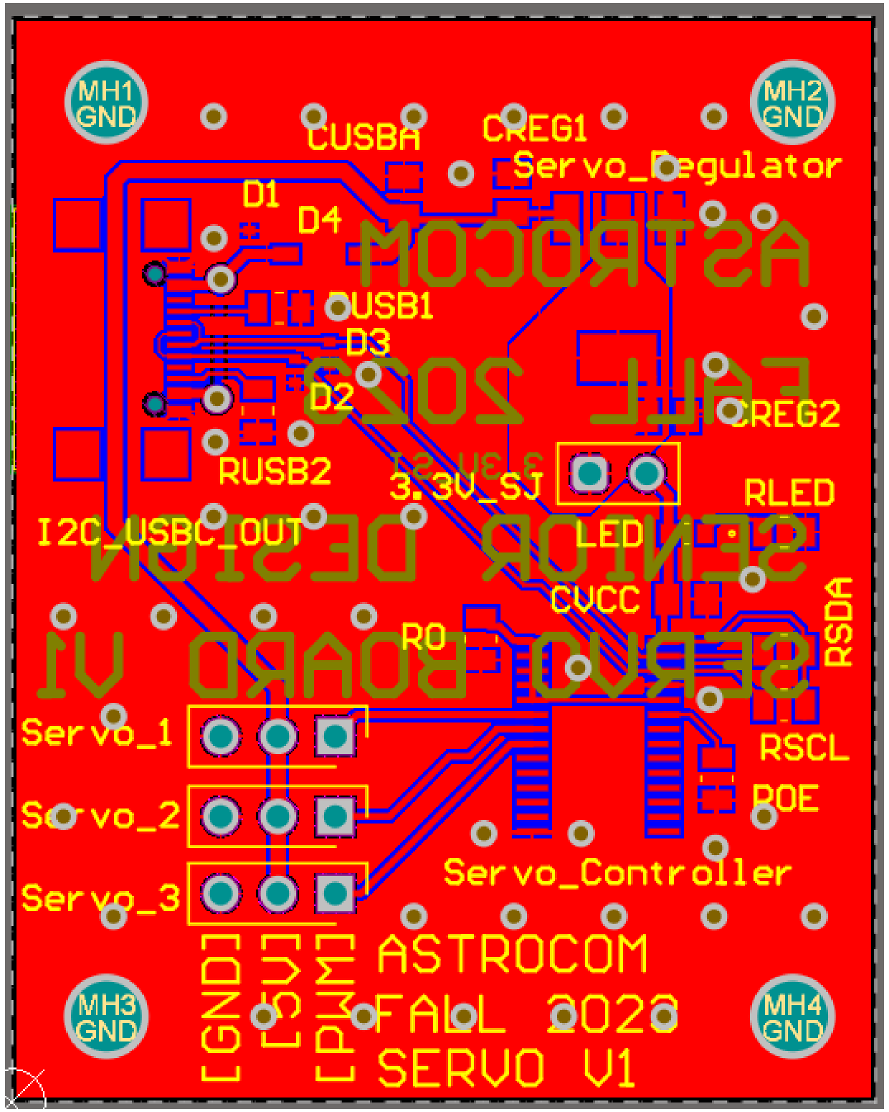

ASTROCOM
FALL 2023
SENIOR DESIGN
SENSOR BOARD V1
SENSOR_0
RSC0
RSD0
SENSOR_3
RSC3
RSD3
SENSOR_4
RSC4
RSD4
RUSCL_PU
RSDA_PU
3V3
SDA
SCL
GND
JUMP_OUT
USBA_OUT
SENCDC1
SENCDC2
RAD_PD
RRESSET_PU
SW3
RAD_PU
Sensor_MUX
RSD1
RSC1
SENSOR_1
RSD2
RSC2
SENSOR_2

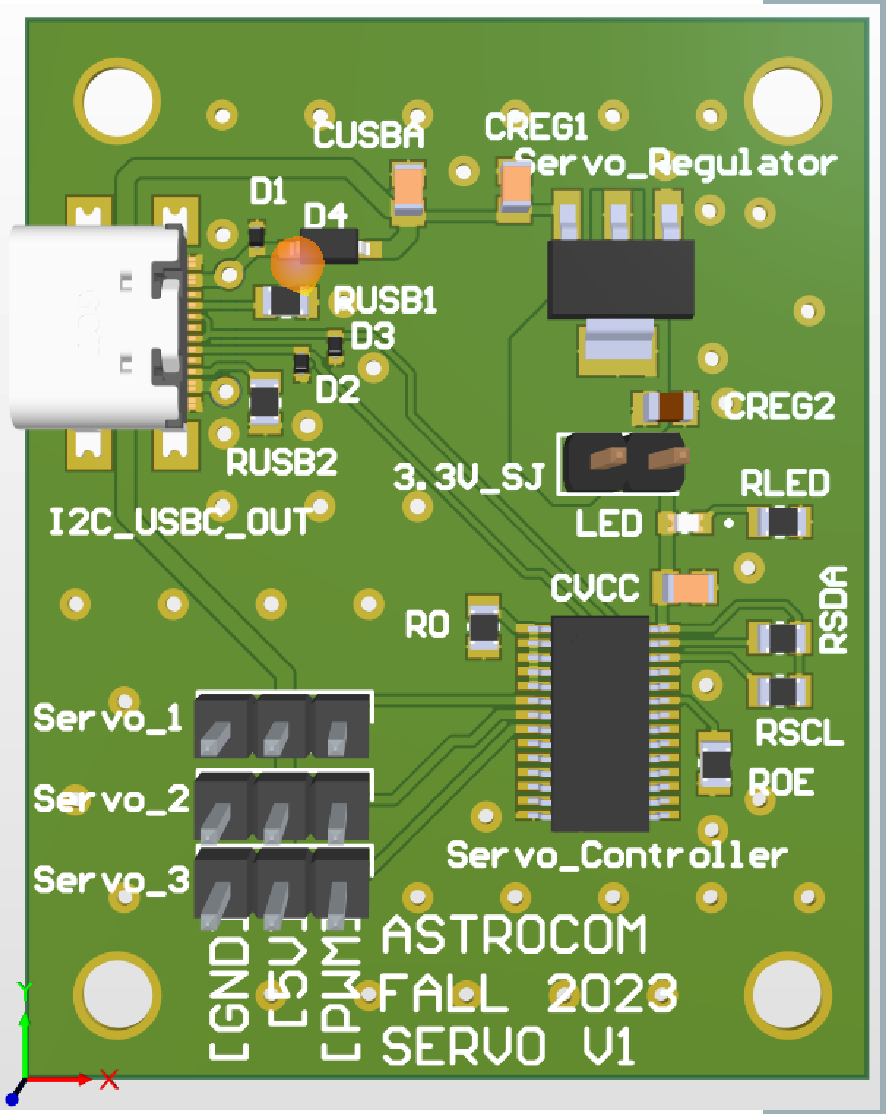
SENSORS PCB





STEPPER MOTOR
CONTROLLER PCB





SERVO MOTOR CONTROLLER PCB

ADMINISTRATIVE CONTENTS

Electrical Engineering	Responsibilities
Alexandre Fiset	PSU Design and Implementation
	PCB Design
	MPPT Tracking Implementation
	Administrative Documentation
Computer Engineering	**Responsibilities**
Binh Pham	Reflector Technology and Design
	Motor and Motor Controls
	Vectoring Technology
	Project Lead
	Positioning and Vectoring Algorithm
Computer Engineering	**Responsibilities**
Pedro Kasprzykowski	MCU Selection and Implementation
	Software Design and Implementation
	Antenna and Communications
	Website Design and Management
Computer Engineering	**Responsibilities**
Stephen Martin	Sensor Selection and Implementation
	MCU Selection and Implementation
	Positioning and Vectoring Algorithm
	Software Design and Implementation

Distribution of work table

MECHANICAL'S BUDGETS

Component	Name	Price/unit	Quantity
Mirror	0.032" x 24" x 24", 3003-H14 Aluminum Sheet	$28.86	1
Mirror Coating	Mylar Sheet	$25.99	1
Frame	ADJ LTS-6 T-Bar Tripod Lightweight Lighting Stand	$54.99	1
Base Panels	Plywood Panels 4ftx8ft	$25.60	2
Communication Tower Box	Junction Box	$26.89	1
Wheel Hub Bearing	Rear Wheel Hub	$44.90	1

ELECTRICAL'S BUDGET

Component	Name	Price	Quantity
Battery	Howell Energy hw-4f7	32.99	1
Motor w	Nema 23	$30.73	1
Motor x-y-z	9.5-11kg*cm Servo Motor	$17.59	3
Charge Controller/BMS	Smaraad SR11004	$39.99	1
Solar Panel	RNG-50D-SS	$49.99	1
Microcontroller	ESP32-C6-DEVKITC-1-N8	$9.00	1
External Antenna	Wlaniot 2.4G	$17.98	2
MicroSD card	5251	$4.50	2
MicroSD card breakout board+	254	$7.50	1

PCB'S BUDGET

Component	Name	Price	Quantity
Microcontroller for PCB	ESP32-C6-WROOM-1U	$3.48	1
Stepper Motor Controller	DRV8833PW	$2.84	1
Servos Motor Controller	PCA9685PW,112	$2.64	1
3.3V Regulator	TPS54JA20	$1.50	1
5V Regulator	TPS54JA20	$1.50	1
USB-A Connector	2057-USB-AP-S-RA-SMT-ND	$0.55	3
Sensor-MUX	TCA9548APWR	$1.78	1
Sensor	VEML7700	$1.88	5
USB-to-UART Bridge Controller	CP2102N-A02-GQFN28	$4.07	1
MicroSD Socket	1660	$1.95	1
Misc.	Resistors, Capacitors, Inductr, Jumpers, Etc.….	~$20.00	