MEMORANDUM

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RE: **ME 507 Sumo Robot Final Report**

Contents

Introduction

This report summarizes the work from our Summer 2022 ME 507 sumo robot project. The goal for this class was to design, fabricate, and develop code to autonomously control a sumo robot which can compete against other autonomous robots. We designed a functional sumo robot equipped with multiple sensors to compete against other robots autonomously; a custom PCB was also designed specifically to collect data from these sensors and provide power to four brushed DC motors. While there are a variety of aspects to this project that we would love to improve, we were ultimately able to produce an autonomous sumo robot that stayed within the arena and searched for other bots to push out.

Bill of Materials

Reference Appendix A for our detailed Bill of Materials for our mechanical design and electronics external from the custom PCB. Reference Appendix B for our detailed Bill of Materials for the custom PCB.

Mechanical and Electrical System Description

The custom mechanical components of our robot are made from 3D printed PLA, waterjet aluminum, and various electronic components. M3 machine screws connect the structural components of our robot, and M2 machine screws fasten our electronic hardware to the frame. A plethora of M2 and M3 thermoplastic heat-set inserts are used to create durable metal threads within the PLA components of the robot. Figure 1 displays our complete sumo robot while connected to an ST Link for deploying new code to our robot in the lab.

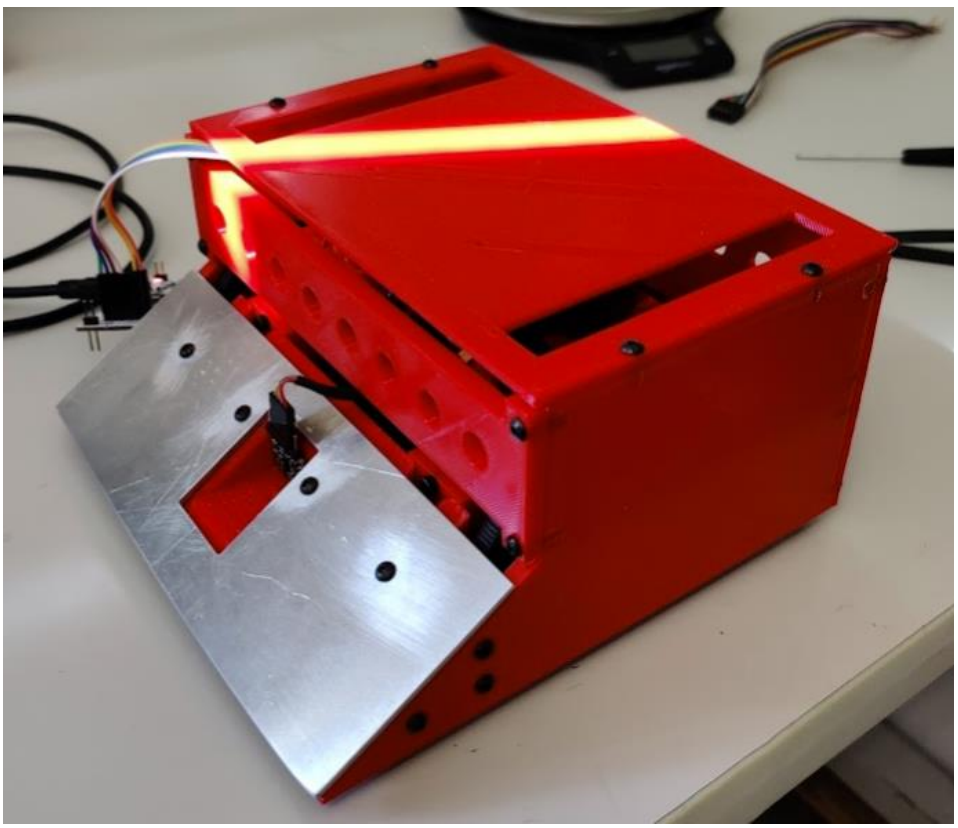


Figure 1: Complete Sumo Robot.

In the center of the robot frame (mounted to aluminum baseplate) is an IMU for measuring the orientation of the robot within the sumo ring. Originally, we wanted to use just a magnetometer to measure the orientation of the robot, but the four brushed DC motors caused too much distortion of the magnetic field surrounding the magnetometer to produce useful readings.

A time-of-flight (TOF) sensor is mounted on the front of the robot for detecting other robots within the sumo ring and is visible in Figure 1 (above). While our enemy detection and tracking worked, adding two TOF sensors could improve the tracking functionality, at the risk of increased difficulties using I2C for data communication, as various groups struggled with this communication type.

Two reflectance sensors are mounted at the front of the robot, one in each corner; a future revision of this project would include two more reflectance sensors at the back of the robot to ensure that it does not drive out of the ring in reverse. A 12V 850mAh Tattu battery powers our robot and sits on top of the chassis (Figure 2).

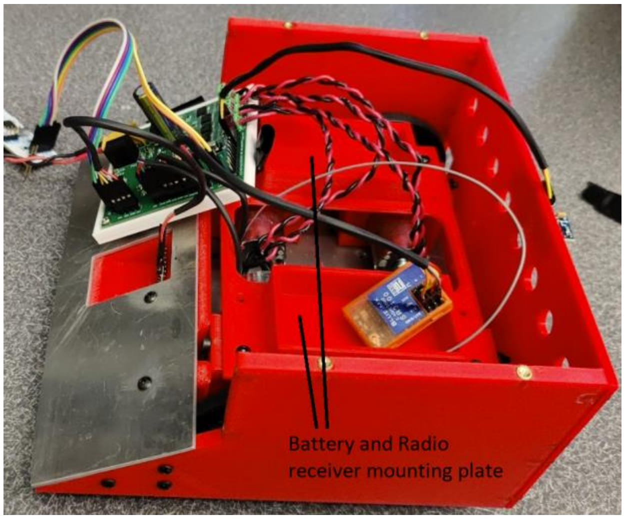


Figure 2: Internal electronics mounting plate.

The chassis of our robot is a waterjet panel of 6061 aluminum (made from leftover stock). Figure 3 displays the motors and wheels connected to the chassis; Mounting hubs couple our motor's torque output to the wheels via a flimsy setscrew. To improve our robot, we suggest using Loctite to permanently fasten the mounting hub to the motor output.

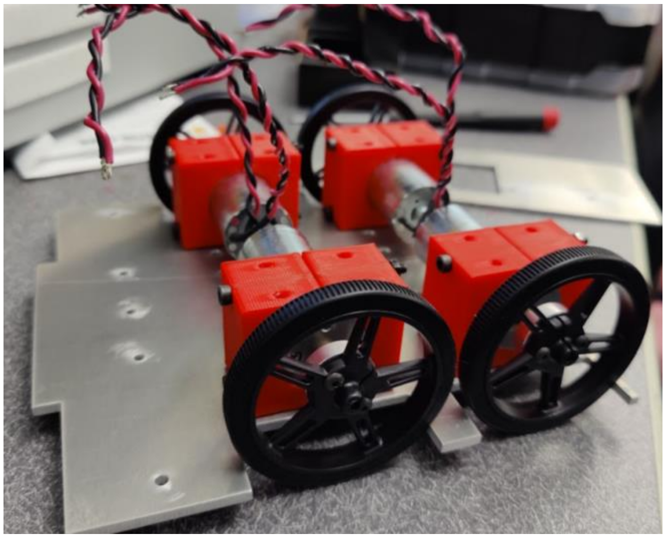


Figure 3: Robot chassis.

Figure 4 displays our custom PCB that controls the various electronics in our system and communicates with our radio remote. The PCB is mounted to the roof of the robot, so that shorter wires connect to the vertical square pins on the PCB. A revised version of this board would use a JST connector variant for the motor power output because the screw terminals were very inconvenient for testing the robot. Reference Appendix D for our electronic circuit schematic.

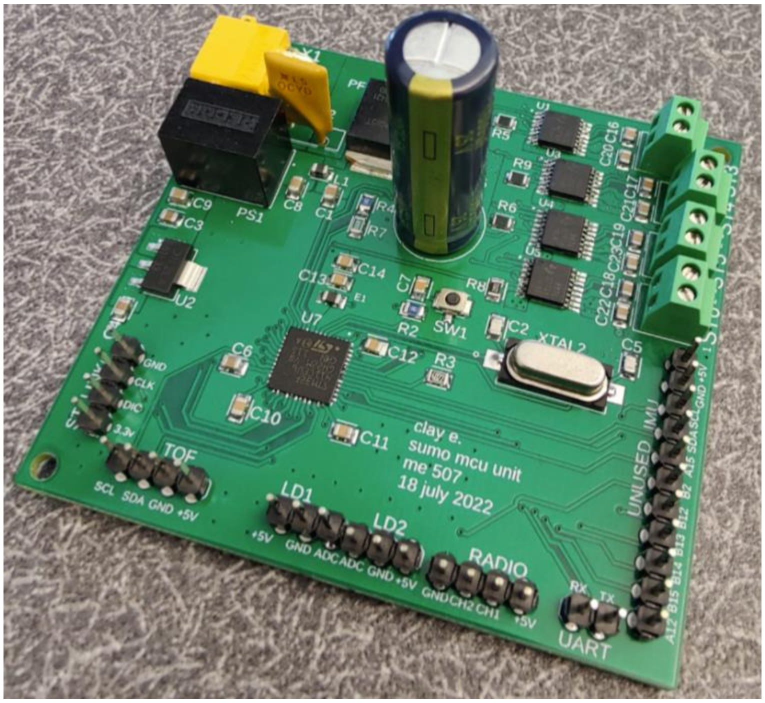


Figure 4: Sumo Robot PCB.

We were lucky when fabricating our sumo bot PCB; after the initial reflow attempt to assemble the SMD components there was non-negligible amount of rework to do. The motor drivers had a total of four shorts, and the MCU had a plethora of shorts. Fortunately, these were all easy to fix and while the soldering on the MCU was not perfect it worked consistently.

Some interesting features of our sumo MCU circuit include reverse polarity protection in the form of a P-Channel MOSFET and a 10 kOhm resistor, to protect our circuitry from the battery.

We added two step-down voltage regulators, one to take the 12 V input voltage from the battery to 5 V – we used this for a variety of sensors and our radio receiver – in addition to a second regulator which takes the 5 V rail and steps it down to 3.3 V for the MCU V_{DD}, and to power the ST Link that we used to upload new firmware to our STM32 MCU chip. Reference Appendix D for our voltage regulator temperature rise calculations. We added a variety of capacitors, resistors, and inductors in accordance with the corresponding component datasheets to protect our regulators, MCU, and motor drivers. We also added a large 1500 μF bulk capacitor for our motor drivers.

We added a voltage divider to our circuit for ADC battery voltage measurements – we used this ADC reading to automatically turn off our sumo robot when the V_{BAT} ADC reading was below a threshold that corresponded to ~10 V.

We chose a 25 MHz crystal oscillator for our circuit, which has 8 pF capacitors in parallel to form the “Pierce Oscillator” circuit. Reference Appendix D for our crystal oscillator calculations

We used vertical pin headers for this circuit; while they worked well, it might have been more convenient to use a proper connector like a JST variant connector.

Control System Description

The bot is controlled using 4 motors each controlled by a dual h-bridge motor driver. The motor drivers were in PH/EN mode where only one PWM signal is needed to control the effort value and a GPIO output is used to control the direction of the motor. This allowed for easier orientation control as 2 motors on one side could spin opposite of the others.

The overall software for the robot used cooperative multitasking to control the robot. The program ran through two main tasks, the data task, and the autonomous task. The data task, made up of a C struct, ensured data was collected continuously and processed to be readily available for the autonomous task to reference. The autonomous task, also a C struct controlled the behavior of the robot using a finite state machine. To begin the robot made an initial evasive maneuver to avoid a direct strike. The robot then switched into its recurring states where the bot moved across the arena and periodically spun searching for its opponent. If an opponent was spotted it would switch directly to its charge state. A link to a video of this can be found in the attachments list. Once the robot reaches the edge of the arena it promptly stops and turns. To create precise turns an IMU capable of using absolute orientation was used along with a proportional controller to ensure each turn is correct.

For each sensor used, except the reflectance sensors which just required an ADC reading, a driver compromised of a C struct was used to initialize, control, and collect data. For the time-of-flight sensor (TOF) the ST API was used along with some modification to easily use the module. The dead man switch was created using a radio receiver and when the remote is idle for more than 50 seconds manual controls are enabled. This logic is contained within the main.c module and tracked with the auto_mode variable, with its initial value being true.

Areas for Improvement

The sumo bot performs well on its own and had no real issues falling off the arena on its own or finding stationary targets. The one real lack from the bot was its speed and power. 34:1 motors were used to provide adequate speed and torque to the bot; however, in practice the bot was unable to out-speed and thus outmaneuver its opponents and when faced with a head on challenge was unable to overpower its opponent. This was the biggest downfall of the robot. In future iterations a motor with a lower gear ratio would be beneficial to increase speed and maneuverability. A motor with more torque is also an option however speed would lend itself better to the sumo bot’s current strategy. Lowering the panels of the sumo bot would also improve the design so that other robots cannot get under our frame and reduce our traction.

Another area of improvement would be the increased amount of reflectance sensors. While the robot's strategy was intelligent enough to prevent the bot from running off as it went forward, in some rare occasions the bot would back up or spin off the arena as it was searching or recovering from a hit. This also became an issue when our bot was pushed at an angle as when the bot spun around to move it could fall off the arena.

High-Level Wiring Diagram

Reference Appendix C for our wire harness diagram.

Attachment List

- STMCube Project
  - Auto_Sumo C and Header File
  - Sumo_Data C and Header File
  - Motor_Driverz C and Header File
  - Radio_Receiver C and Header File
  - bno055 C and Header File
  - lidar C and Header File
  - vl53lox API Files
  - main C file
  - Various drivers and C files for unused sensors (MPU6050, GY-271, etc.)
- Videos
  - Arena Bounds Test: https://youtube.com/shorts/sXKXyOqw_T0?feature=share
  - Sumo Battle Video: https://youtu.be/zhU0vuP5z1M

Appendix

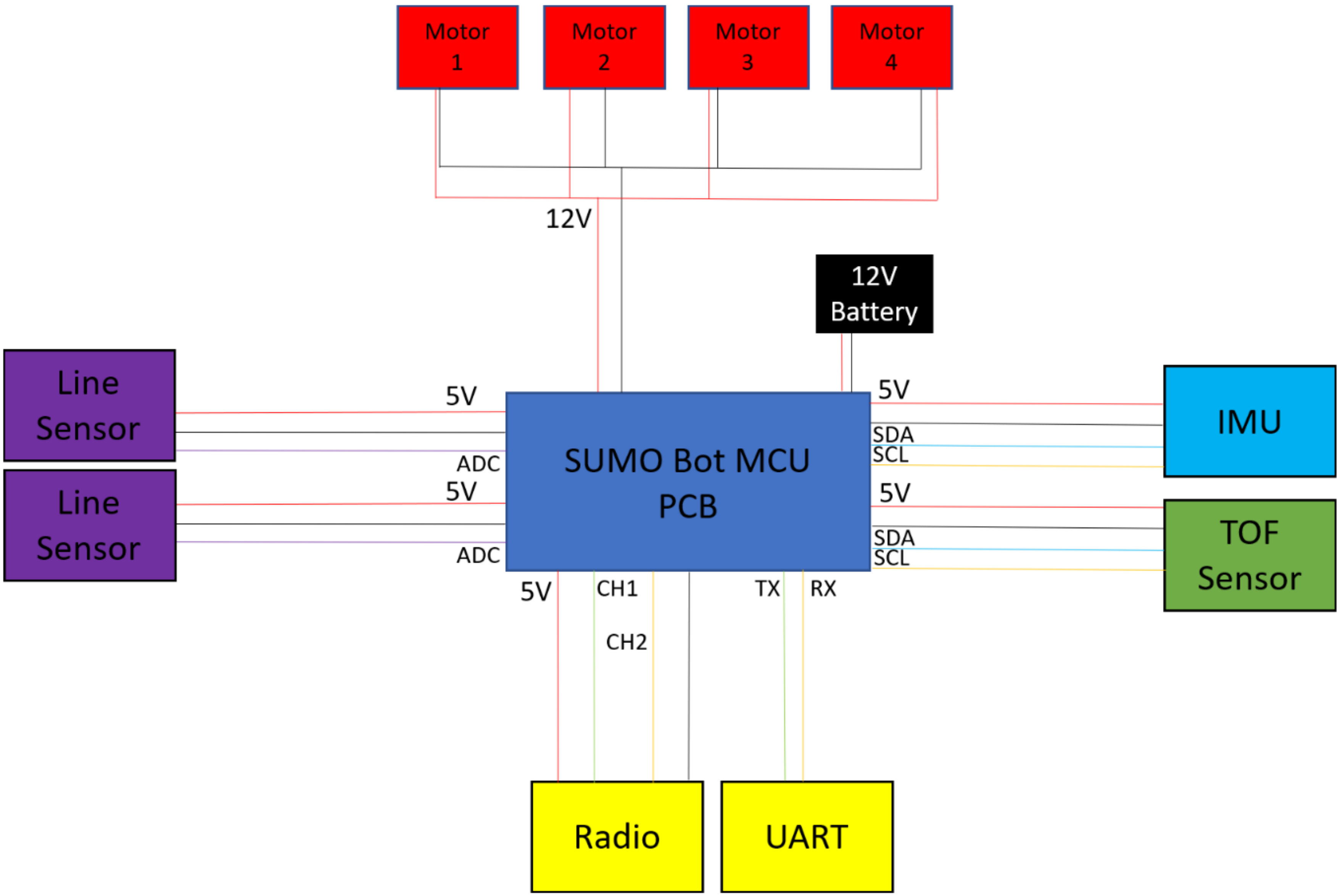
Appendix A – Mechanical and Electronics Bill of Materials

Level	0	1	2	3	4	Part Name	Description	Quantity	Unit Pri	Total Pric	Link
0	X					Sumo Bot	Full Assembly Sumo Bot	1		0	Built In-House
1		X				Chassis System		1		$0.00	Built In-House
2			X			Drive System	Wheels	1		$0.00	
3				X		Wheels	Pololu 60 mm diameter silicone wheels	2	$5.75	$11.50	https://www.pololu.com/product/1420
				X		Mounting Hub	Pololu mounting hub that couples the motor output to the wheel	2	$8.49	$16.98	https://www.pololu.com/product/1081
2			X			Chassis/Frame	Order with the JLC Electronics Order	1	TBD	#VALUE!	JLC Electronics or printed from polycarbonate
3				X		Front Panel Mount	Mount for holding angled front panel and side panels in place	1	$0.00	$0.00	3D printed from PLA
3				X		Back Panel Mount	Mount for holding back panel and side panels in place	1	$0.00	$0.00	3D printed from PLA
1		X				Electronic System	PCB, Motors, Sensors, Etc.	1		$0.00	Built In-House
3				X		Radio Comms	Receiver for radio communications with handheld remote	1	$24.29	$24.29	https://www.amazon.com/SING-LTD-Receiver-Ch
3				X		Microcontroller	STM32F411CEU6	1	$0.00	$0.00	Provided by Charlie
2			X			Propulsion System	Motors and Motor Drivers	1		$0.00	
3				X		Motor Driver Chip	Motor driver with built in current sensor - DRV8876	2	TBD	#VALUE!	https://www.digikey.com/en/products/detail/tex
3				X		Motors	Pololu Brushed DC Gearmotor	4	$28.95	$115.80	https://www.pololu.com/product/3204
						Motor Mounts	Mounts to hold motors in place	8	$0.00	$0.00	3D Print from PLA
2			X			Sensor System		1		$0.00	
						IMU	Inertial measurement unit for orientation control			$0.00	https://www.amazon.com/HiLetgo-MPU-6050-Ac
3				X		Enemy Sensors	VL53L0X TOF Distance Sensor Carrier W/ Voltage Regulator	2	$2.33	$4.66	https://www.pololu.com/product/2490
3				X		Line Sensor	Pololu QTR Reflectance Sensor	1	$12.95	$12.95	https://www.pololu.com/product/4201
3				X		Line sensor wires	TBD	4	TBD	#VALUE!	TBD
3				X		Enemy sensor wires	TBD	4	TBD	#VALUE!	TBD
3				X		M3 fasteners	Various lengths	XX	TBD	#VALUE!	Fastenal in SLO
				X		PCB Mount	Thermoplastic mount to hold PCB and RC receiver	1	$0.00	$0.00	3D printed from PLA
2			X			Battery System	We have to turn on the power!	1		$0.00	
3				X		12.6 V LiPo Battery	Tattu 850mAh 11.1V 45C 3S LiPo Battery Pack with XT30	1	$15.71	$15.71	https://www.amazon.com/dp/B074MG6YGS/ref=
3				X		Battery Mount	Mounts to hold battery in place	1	$0.00	$0.00	3D printed with Tyler's printer?
3				X		M3 Fasteners	Various lengths	XX	TBD	#VALUE!	Fastenal in SLO
2		X				Miscellaneous				$0.00	
3			X			M3 heat set inserts	Thermoplastic heat set inserts for M3 fasteners	XX	$0.00	#VALUE!	I already have plenty
3			X							$0.00	

Appendix B – PCB Bill of Materials

Part Name	Description	Quantity	Total	Unit Price	Total Price	Link	Datasheet
AP7361-33E-13	5V -> 3.3V Step down regulator	1	2	$0.54	$0.54	https://www.digikey.com/en/products/	https://www.
Must be 0805 package	4.7uF, 10V capacitor for 5V-3.3V regulator	2	4	$0.18	$0.36	https://www.digikey.com/en/products/	Datasheet Lin
TI DRV8876	Motor driver with built in current sensor - DRV8876	4	8	$2.36	$9.44	https://www.digikey.com/en/products/	https://www.
EEU-FK1E152L	1500uF / 25V Electrolytic capacitor; for all 4 drivers (if routable)	1	2	$1.75	$1.75	https://www.digikey.com/en/products/	https://www.
885012207013	0.022 uF, small voltage capacitor for CPL CPH on DRV8876	4	8	$0.10	$0.40	https://www.digikey.com/en/products/	https://www.
885012207045	0.1uF, 12-16?V capacitor for VCP and VM	4	8	$0.10	$0.40	https://www.digikey.com/en/products/	https://www.
	1.1 kOHm for ipropi	2	4	$0.26	$0.52	https://www.digikey.com/en/products/detail/vishay-d	
TNPW08053K20BEEA	10 kOhm for vbat	1	2	$0.30	$0.30	https://www.digikey.com/en/products/detail/koa-spe	
RK73G2ATTD1002F	3.2 kohm for vbat	1	2	$0.78	$0.78	https://www.digikey.com/en/products/detail/vishay-d	
CS0805KRX7R8BB104	0.1uF, 25 V capacitor for smoothing 12V Vref	1	2	$0.19	$0.19	https://www.digikey.com/en/products/	https://www.
R-78E5.0-1.0	12V -> 5V Step down regulator	1	2	$3.92	$3.92	https://www.digikey.com/en/products/	https://recom
CL21A106KAYNNNG	10uF, 25V capactor for 12V-5V regulator	3	6	$0.19	$0.57	https://www.digikey.com/en/products/	Datasheet Lin
MLF2012E120JT000	12uH choke inductor for 12V-5V regulator	1	2	$0.23	$0.23	https://www.digikey.com/en/products/	https://produ
ABLS-25.000MHZ-12-B-4-Y-F-T	25MHz crystal	1	2	$0.52	$0.52	https://www.digikey.com/en/products/	
08051A8R0DAT2A	8 pF, 100V capacitor for pierce osciallator; ceramic	2	4	$0.23	$0.46	https://www.digikey.com/en/products/	
ARHL500	Fuse before voltage regulator	1	2	$1.00	$1.00	https://www.digikey.com/en/products/	https://www.
IXTA24P085T	P-Fet for reverse polarity protection	1	2	$3.07	$3.07	https://www.digikey.com/en/products/	https://www.
RK73G2ATTD1002F	10k Ohm resistor in reverse polarity protectoin	1	2	$0.30	$0.30	https://www.digikey.com/en/products/	https://www.
			0		$0.00		
STM32F411CEU6	Microcontroller	1	2	-		Provided by Charlie	
885012207016	0.1 uF, 10V capacitor for V_REF smoothing	5	10	$0.10	$0.50	https://www.digikey.com/en/products/	https://www.
HZ0805D102R-10	Ferrite bead on V_Ref - 1kOhm @ 100MHz	1	2	$0.18	$0.18	https://www.digikey.com/en/products/	
CL21B225KPFNNNE	2.2 uF, 10V Capacitor for V_cap1	1	2	$0.11	$0.11	https://www.digikey.com/en/products/	https://media
885012207016	0.1uF, 10V capacitor for NRST circuit	1	2	$0.10	$0.10	https://www.digikey.com/en/products/	https://www.
B3U-1100P	Reset circuit button, and boot0 button?	1	2	$1.01	$1.01	https://www.digikey.com/en/products/	https://omror
RR1220P-4022-D-M	40.2kOhm resistor for BOOT0 circuit	1	2	$0.16	$0.16	https://www.digikey.com/en/products/	https://www.
RK73G2ATTD1002F	10 kOhm resistor for NRST circuit	1	2	$0.30	$0.30	https://www.digikey.com/en/products/	https://www.
PINHD-1X4/90	4-pin header for blackpill connection						
	Pin header for RC receiver						
	Pin header for IMU						
	Pin header for reflectance sensor 1						
	Pin header for reflectance sensor 2						
	Pin header for TOF sensor						
	Pin header for Motor 1						
	Pin header for Motor 2						
	Pin header for Motor 3						
	Pin header for Motor 4						

Appendix C – Electronics Layout



Appendix D – SUMO Bot MCU PCB Schematic