Request For Proposal

MIE444 Project

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1.0 Project Requirements

The goal of this project is to design a robotic system that autonomously localizes itself in a known maze layout, navigates the maze regardless of starting position or orientation, and carries out a specific set of tasks whilst avoiding collisions and obstacles. The maze is walled and has a randomized checkered pattern on the floor. Within the maze, the robot will be tasked with locating and picking up a small load (i.e., a wooden block) in a loading zone (LZ) and delivering it to a desired drop zone (DZ or Point B). It is required to perform these tasks within five minutes.

The requirements and limitations for the design include:

- Budget must not exceed $300 CAD (before taxes).
- 3D-printed parts must be incorporated.
- It must fit within a 12”x12”x12” volume and not exceed a weight of 5 lbs.
- Pre-made rover kits/components must not be used.
- The pick-up mechanism must not use adhesives/velcro attachments.
- It must be powered using a battery pack (i.e., no external power supplies).
- Touch sensors must not be used for detection of obstacles/walls.
- A method to visualize localization during navigation must be prepared.
- It must have a method of updating observers on its status (i.e., arriving to the loading zone).
- The code must have a variable/prompt asking for points A (start location) and B (delivery location).
- The team is required to use its own localization technique to locate point B.

2.0 Detailed Rover Design

Figure 1: Render of the proposed design

The rover design is based on a holonomic drive, which is provided by three motors and three Omni wheels spaced 120º around the robot. The mechanism to pick up the load is a 3-bar linkage that simultaneously moves two gripper arms inwards and upwards using a servo motor. The overall structure of the robot is a layered set of laser-cut sheets that carry different components, with the heavier parts located on the lower layers and electronics located on the top layer. The electronics are centered around an Arduino Mega, which uses ultrasonic sensors as the primary tool for localization.

The structure of the robot assembled from the base up as a set of three laser-cut layers that create a bottom level, middle level, and top level. The motors and the ultrasonic sensors have 3D printed mounting brackets to help simplify construction and ensure they are aligned properly on the levels. The bottom and middle plates are separated by the motor mounting brackets (“sandwiched” between the plates), which also act as mounting points for both layers as the base layer is screwed onto the bottom of the brackets and the middle layer is screwed onto the top. The top and middle plates are spaced by the block pick-up mechanism and the servo motor. The top plate is primarily held by standoffs attached to the top and middle plates; however, the top plate is also supported by the servo mount and the bracket of the block mechanism.

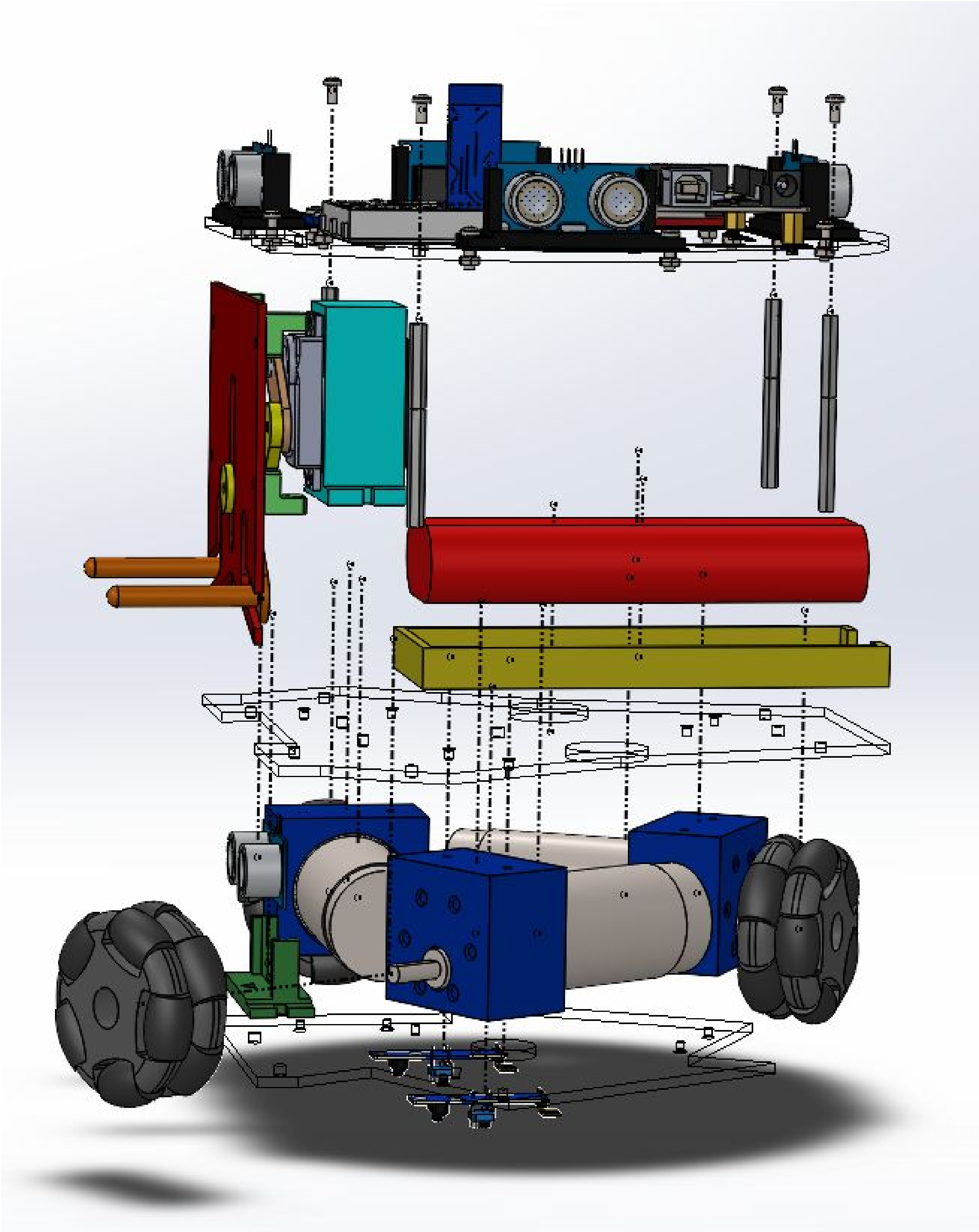


Figure 2: Exploded view of the rover demonstrating the layers. Most fasteners removed for clarity

At the base of the structure sits the drive system, which is composed of three motors and three Omni wheels. The Omni wheels have rollers on them that allow them to “slip” perpendicularly to their direction of rotation. This behavior allows the robot to traverse holonomically (independently in all degrees of freedom) by controlling the speeds of each individual motor such that the overall velocity of the wheels is in the desired direction of motion. This will enable the robot to move with greater agility through the maze because it will not have to reorient itself to change direction.

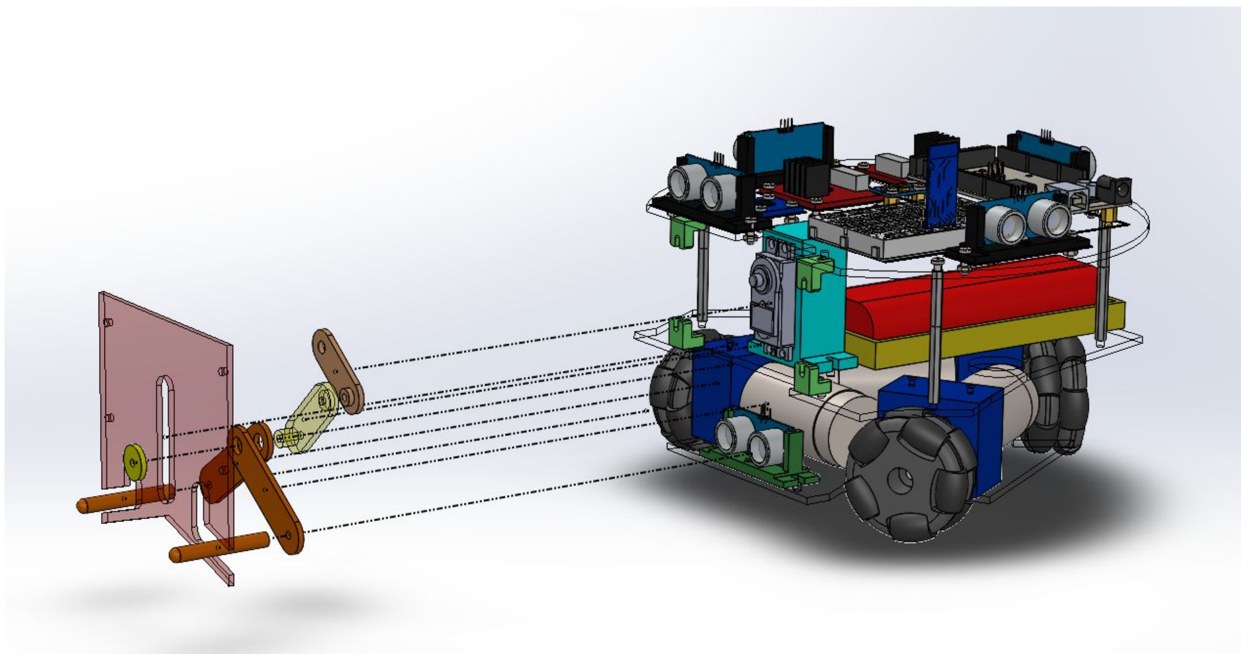


Figure 3: Exploded view of grabber mechanism

The block handling mechanism is located near the base of the robot on the “front” face. It is mounted on top of the middle layer along with the servo motor that drives it. The design is a 3-bar linkage that, when actuated, moves the gripper arms simultaneously inward and upward (the motion is guided by the bracket of the mechanism). Once the robot is in range to pick up the block, the inward motion of the gripper arms will grab the block while the upward motion lifts the block above the ground. When the block needs to be released, the servo will actuate in the opposite direction, which lowers the block onto the ground and opens the gripper arms. As an improvement, the gripper arms should have rubber inserts on inside to achieve better grip on the block. This 3-bar linkage was selected due to its compactness, as it does not require the robot to extend out of its footprint to grab the block and it utilizes a small footprint on the robot itself, allowing more space for other components. Another reason was its simplicity, as it only requires one servo motor to actuate. Other designs proved to be difficult to implement as they required significant space on the robot or significantly added to the robot's footprint, which would cause issues when transporting the block.

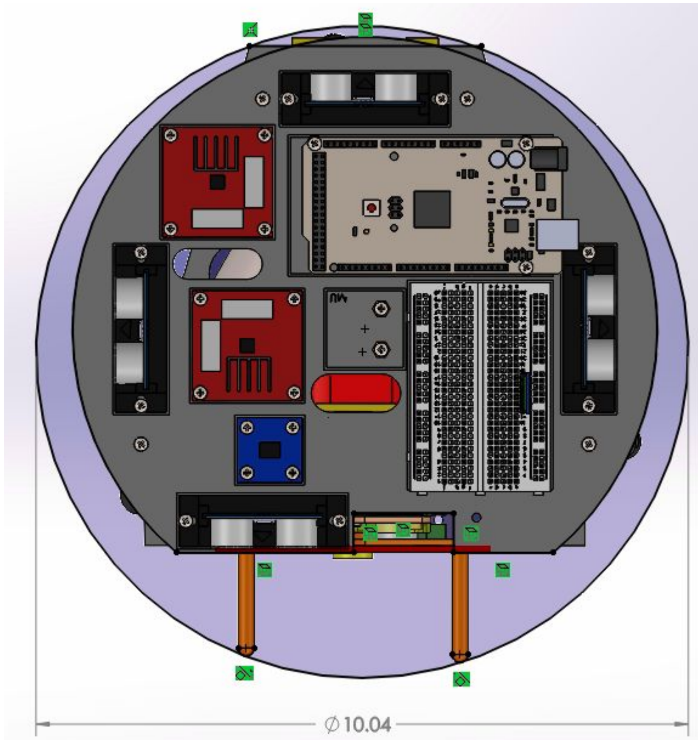


Figure 4: With the gripper fully opened the footprint of the robot is 10" in diameter

There are three sensors mounted on the base. A single, forward-facing ultrasonic sensor is used to detect the presence of a block in front of the rover and the distance needed to reach it. There are also two downward-facing infrared (IR) line following sensors, screwed to the bottom of the baseplate, used to pick up the tiled pattern on the ground to help with localization in the maze. These IR sensors are spaced 3" apart parallel to the front of the rover so they can identify two tiles at once when the robot moves forwards or backwards. It is noted that only one sensor will pick up a new tile as the rover moves sides, as the other will be on the tile previously scanned by the first sensor.

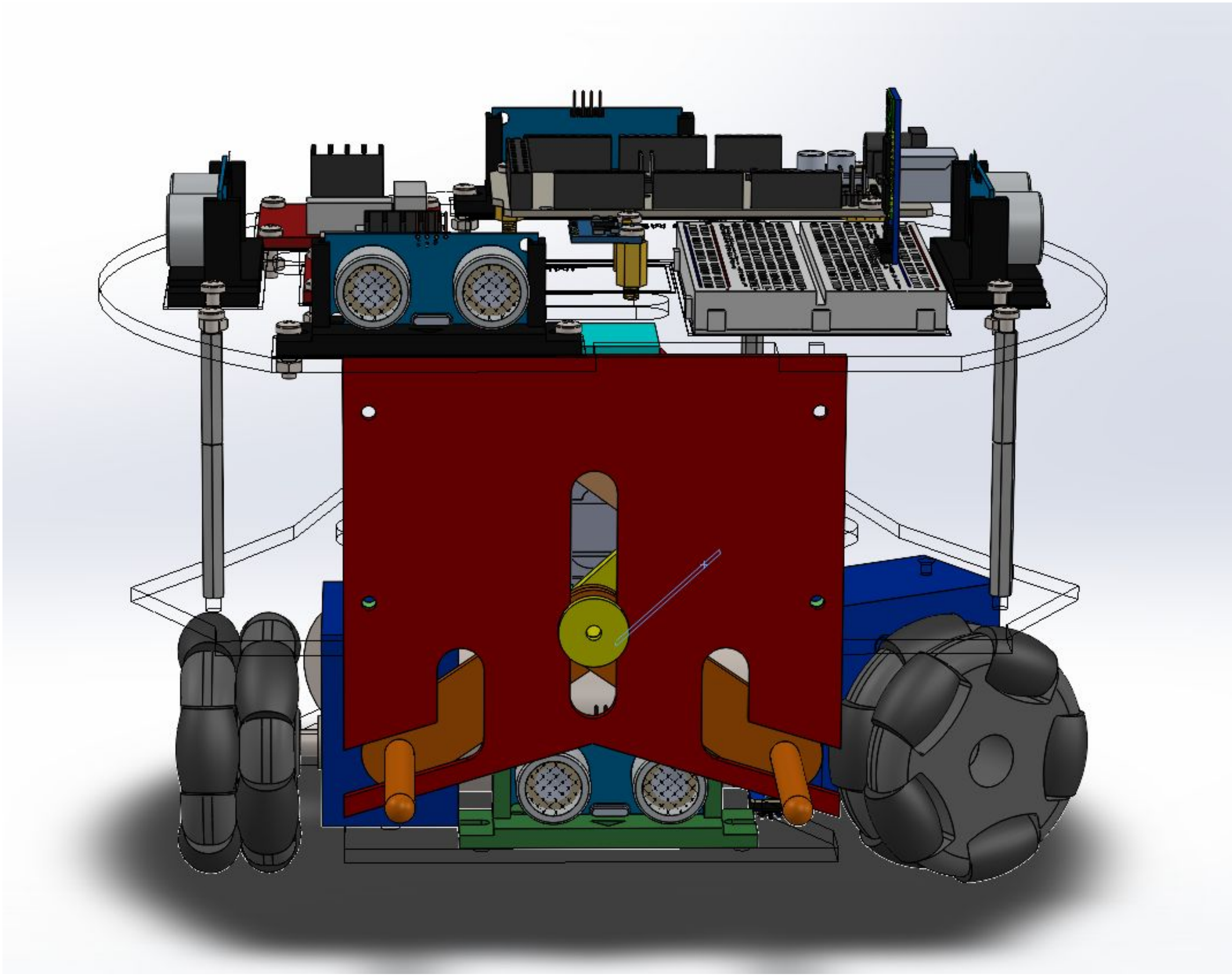


Figure 5: Front face of the robot.

Above the base is the second layer (middle plate), which seats the battery, the battery mounting bracket, the servo motor, and the block pick-up mechanism (and its bracket). The battery is stowed within the structure as it does not require any potential adjustments once connected and seated. The battery bracket is mounted to the middle plate using screws and prevents the battery from sliding when in motion; the battery is simply dropped in the bracket to seat and lifted out to remove. Another reason for this placement of the battery is to help maintain a low and central centre of mass to prevent the robot tipping in motion.

The top layer is where a majority of the electronics are mounted. The main component of the electronics system is the Arduino Mega. It was selected over the Uno or Nano variants to provide an ample amount of inputs/outputs to the system, as well as several helpful hardware peripheral features, such as additional UARTs and PWM pins. Alongside the Arduino is the breadboard, which is used for making the connections the electronics system needs and allows for easy revisions to the connections, if needed.

However, this may also lead to connections loosening and disconnecting when the rover is in motion/vibrating. Therefore, the breadboard should be replaced with a soldered protoboard (or even a custom circuit board) for more secure connections once the system has proven functional in preliminary tests and any issues have been addressed and fixed.

Around the perimeter of the top layer, spaced roughly at 90º steps, are the ultrasonic sensors used to detect the distance to the nearest obstacle in each direction. The reason for four sensors is because this is the number of primary travel directions (forward, backward, left, right), thus the rover has constant feedback on its surroundings in each primary direction of travel for safer holonomic motion. If it did not have feedback in a certain direction (e.g., behind itself), the rover would need to align a sensor in that direction (likely by rotating itself) before it could safely travel in that direction, which requires time and could cause collisions due to the rotation.

Other electronics mounted at the top are the two 2-motor drivers, which are used to control the drive motors, and the IMU6050 and NMC5883L, which are both used to help the robot maintain its heading. These are all mounted into the top plate using fasteners (as is the Arduino), due to their bulk (to prevent motion/damage to parts), as well as the IMU6050 and NMC5883L modules needing to be aligned with the robot in a known and constant way. The IMU6050 in particular needs to be located on the central axis of motion for the robot to accurately detect the robot's motions.

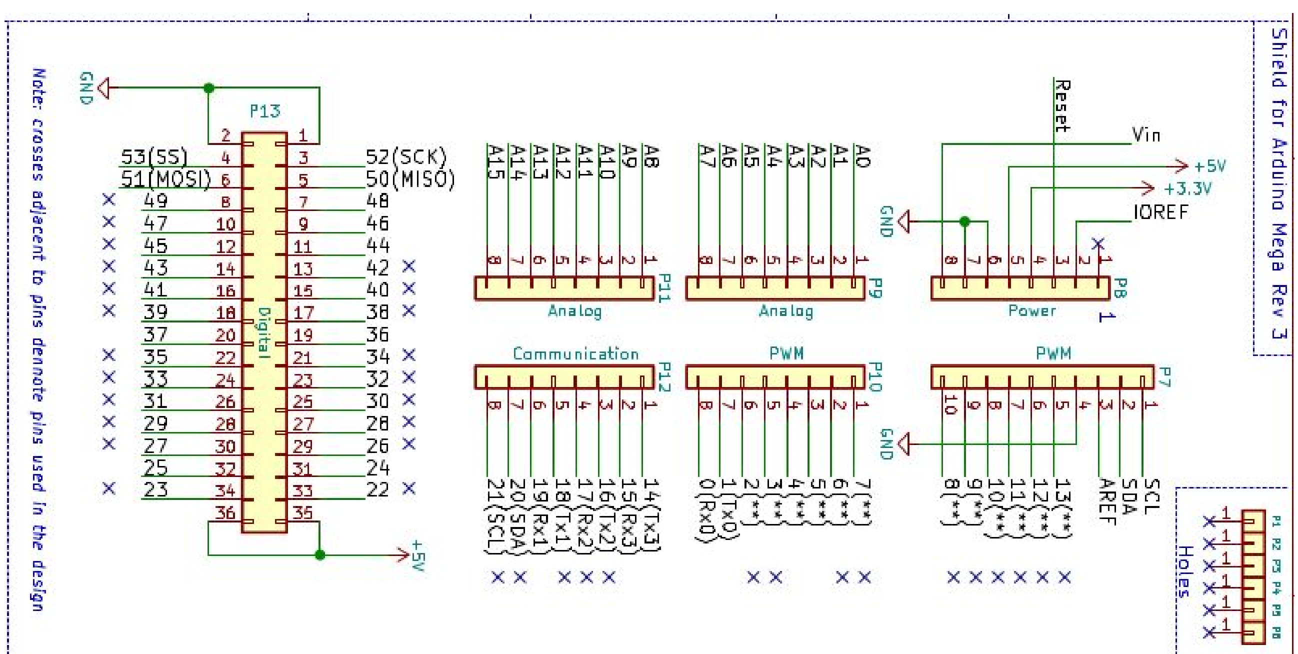


Figure 6: Schematic connections for the Arduino Mega

See Appendix A for the complete design of the electrical system. The electrical design of the rover centres around an Arduino Mega because it met all of the team's requirements on a single board, simplifying the programming and testing of the rover. The specific features that were sought after were its large input/output count (more pins are being used than are available on a single Uno or Nano board), as well as the following hardware that is unique to it:

- 7 PWM Outputs (Uno and Nano are limited to 6 or only 4 if Servo library is used).
    - 3 for motor speed control.
    - 4 for status LEDs.
- 3 hardware interrupt pins for encoders (Only 2 are available on Uno/Nano).
- Additional UARTs, so the Bluetooth module does not have to be disabled when programming.
- Larger program storage space.

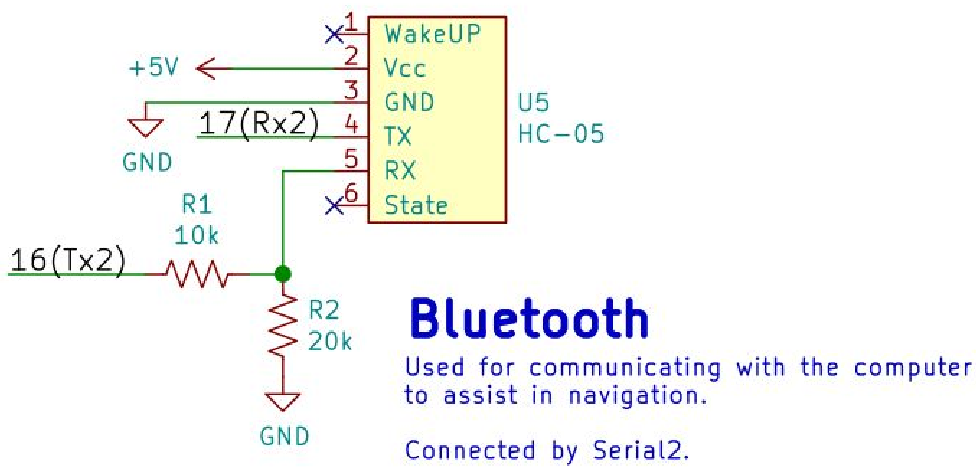


Figure 7: Bluetooth module in schematic

To achieve wireless communication with the off-board computer, so the rover may offload guidance computation, Bluetooth communication is used and achieved through the use of a HC-05 Bluetooth module. This is connected to the Mega using UART2/Serial2 so the Mega can be interacted with by USB and Bluetooth simultaneously to accelerate prototyping and testing. A resistor voltage divider is used to step down the 5V output of the Mega to a 3.3V level tolerable by the module on its RX pin.

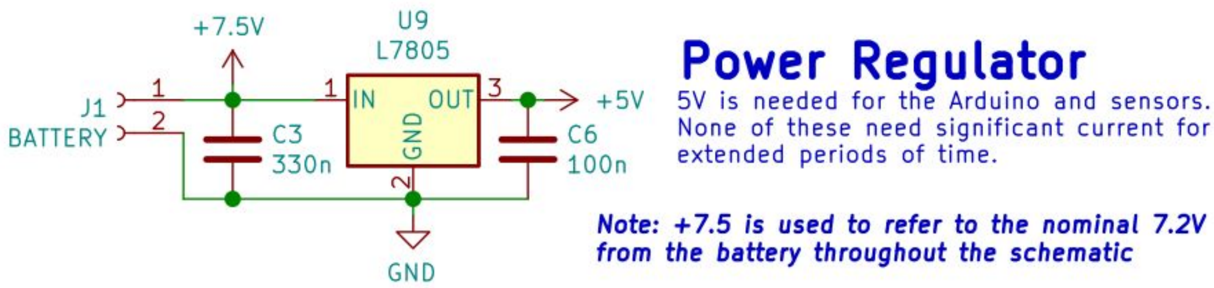


Figure 8: Power supply related components from the schematic

The power source for the rover is a 7.2V NiMh battery, selected for the high current it can supply (10C at 3000 mAh, 30A continuous) so the voltage to the system should not dip due to high current draws, nor should the battery sustain damage from the sustained currents of the rover. The rover's control systems (everything except the motors) receives a regulated 5V supplied by the L7805, which can supply up to 1.5A continuously and thus is sufficient for these less power demanding components. Separating the motors from the rest of the system will have the added benefit of reducing any transient power fluctuations from the motors.

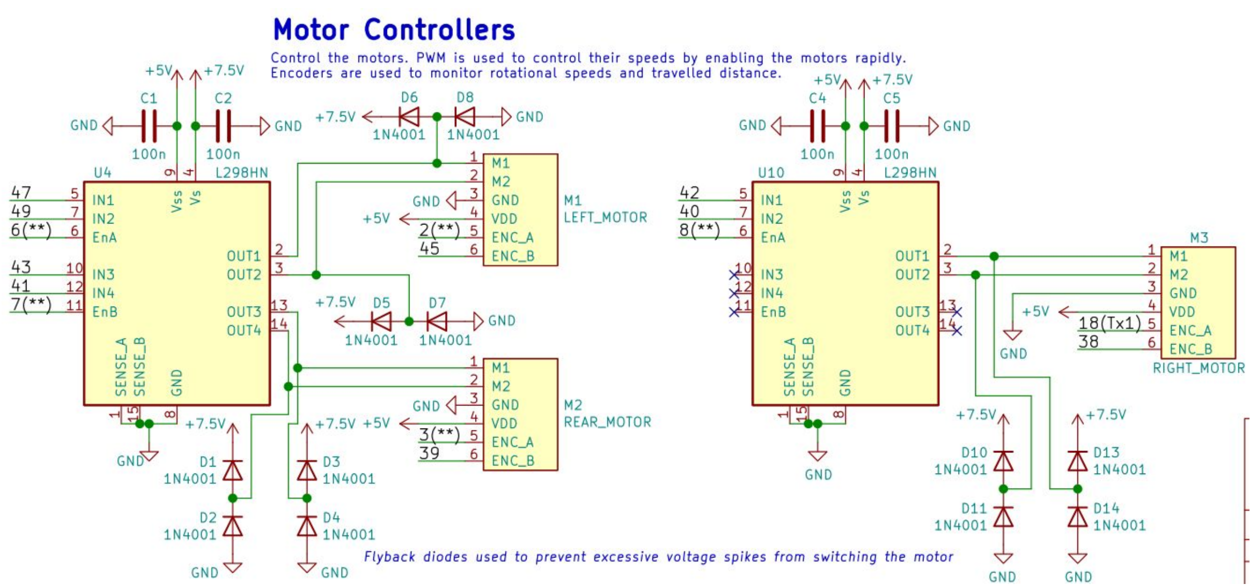


Figure 9: Drive motor system

To control the three motors on the rover, two L298HN-based driver boards are used, which receive power directly from the batteries, as shown in the schematic above. Each motor will be controlled by two [normal] digital pins, to control direction/braking on the IN# pins of the driver, and one PWM pin connected to the corresponding EN# pin for speed from the Mega. Using three pins for each motor allows for complete control of its behavior. The three PWM pins used for the motor are all run from the same hardware clock within the Mega (clock 4) so their PWM waveforms will be aligned and easily configured to be similar (e.g. same frequency).

The motors each have quadrature encoders attached to them, which will allow the rover's motor RPM and approximate travel to be monitored. Ideally, both outputs from each encoder would be connected to hardware interrupt pins on the Mega to ensure not a single tick is missed as the motor rotates and the pins change states, which is possible with the six pins available for this. However, two of these pins are used for I2C communication, therefore only ultimately four interrupts can be utilized, so each encoder in the end only has one output (ENC_A) connected to an interrupt and the other (ENC_B) is a regular digital input to be read when needed.

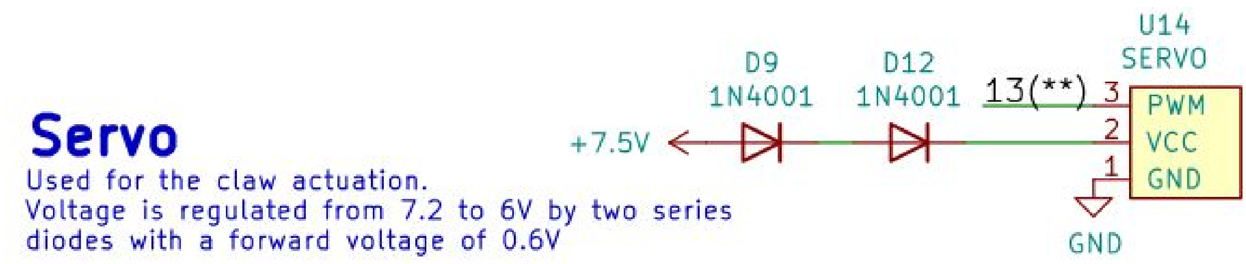


Figure 10: Servo connections

A single MG995 servo is used on the rover to operate the block manipulator mechanism, connected to pin D13 for control. The servo is rated for 6V maximum, so it receives power from the battery through two diodes to drop the voltage from 7.2V to less than 6V. The servo can draw between 170mA and 1.2A (based on loading) when in motion which is mostly covered by the 1N4001 diodes rated 1A continuous current. If the motor is found to regularly draw 1.2A, a second parallel set of diodes should be added to split the load on the diodes to a safe level.

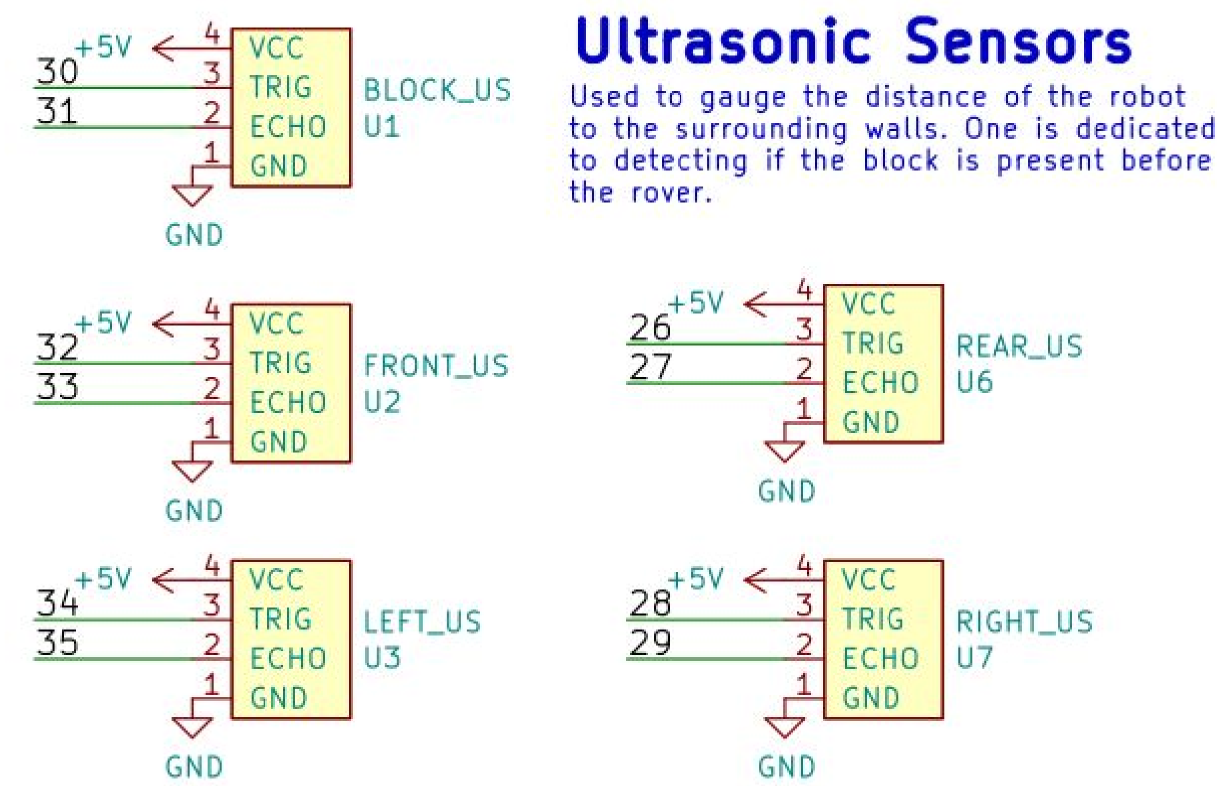


Figure 11: Ultrasonic sensors' connections

All the ultrasonic sensors run off of 5V and are individually connected to two digital pins, one digital output pin on the Mega to trigger a pulse to be sent by the sensor and a digital input to read in the time of flight used to calculate the perceived distance to the obstacle in front of the ultrasonic.

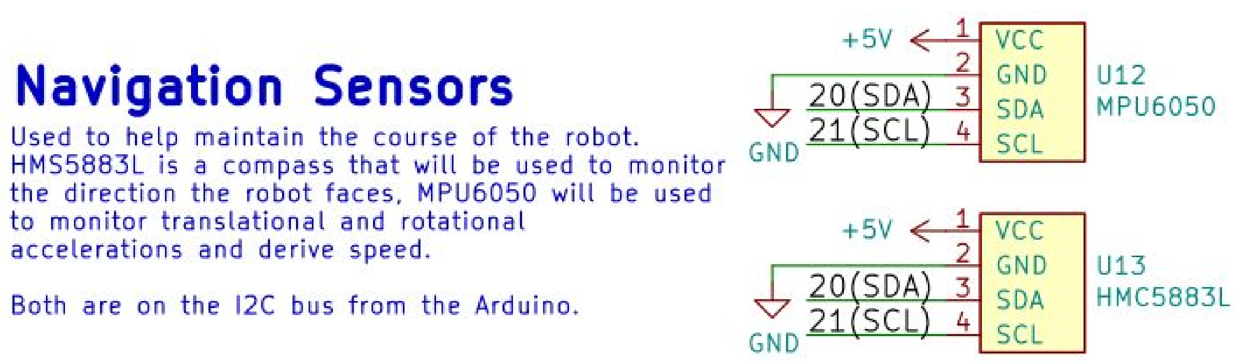


Figure 12: Navigation sensors (IMU6050 and NMC5883L)

To assist in the navigation of the rover, there will be two sensors used to monitor its motions. They are both connected to 5V, and communicate via the I2C bus on the

Mega. The HMC5883L is a three axis compass. It will be used to monitor the rover's absolute orientation to the world to within a degree or two so it can avoid drifting out of alignment with the maze as it travels through it. This is critical for the holonomic drive to function properly. The MPU6050 is a six axis accelerometer/gyroscope combo. It will be used to monitor the robot's translational and rotational accelerations. These are useful to ensure the robot is maneuvering correctly through its motions such as turns or point rotations.

Figure 13: Line following sensor connections

Infrared line following modules are used on the bottom of the rover to scan the ground for the block pattern to assist in localization. They use an onboard potentiometer to set the threshold for what amount of light is a white or black tile and output the result as a digital signal.

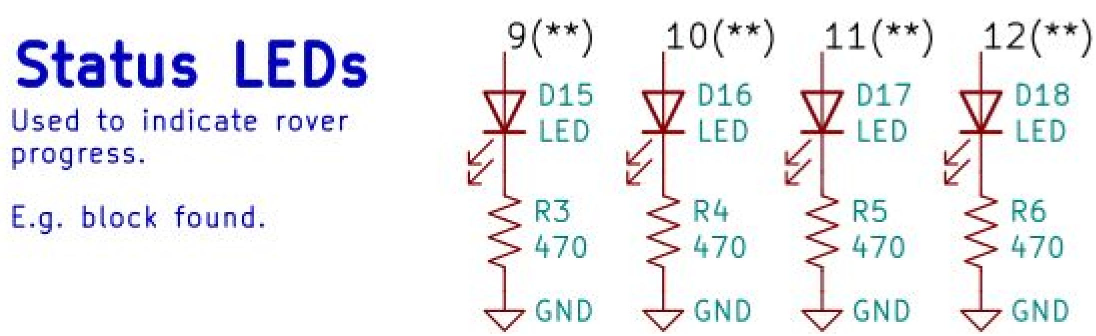


Figure 14: Status LED connections

There are four discrete LEDs available on the rover to visually communicate with observers what the status of the rover is. They are all connected to PWM pins so they may be dimmed for an additional dimension of communication.

3.0 Bill of Materials

Unless otherwise specified, all component prices were cited from the Myhal “MYLFF Material with Costs and Images” document with the exception of the Omni wheels (price cited from Robot shop), the MPU6050 (price cited from Creaton), the HMC5883L (price cited from Creatron), and some standoffs (cited from McMasterCarr).

Table 1: Bill of materials

Item #	Description	Purpose	QTY	Price (CAD)	Total Price (CAD)
1	Arduino Mega	Robot control	1	$14.06	$14.06
2	Ultrasonic Sensor	Detection of walls and block	5	$1.13	$5.65
3	IR Linetracking Sensor	Monitoring pattern on the ground	2	$0.78	$1.56
4	Omni Wheel	Enable holonomic motion	3	$9.12	$27.36
5	DC Motor	Drive wheels	3	$12.17	$36.51
6	MPU6050	Used to maintain robot orientation	1	$27.00	$27.00
7	MG995 Servo	Used to actuate block "claw"	1	$4.80	$4.80
8	HC-05 Bluetooth Module	Communication from robot to computer	1	$5.96	$5.96
9	Red LEDs	Indicate robot status	3	$0.01	$0.03
10	Green LEDs	Indicate robot status	3	$0.02	$0.06
11	Resistors	Limit current through LEDs	3	$0.01	$0.03
12	DC motor driver	Drive the motors	2	$2.62	$5.24
13	5V regultor	Supply power to arduino and sensors	1	$0.14	$0.14
14	Jumper wires	Connect systems	40	$0.07	$2.80
15	Diodes	Flyback diodes, voltage regulation	14	$0.01	$0.14
16	Stranded Wire (by	Connections for motors and	3	$0.15	$0.45

	meter)	batteries			
17	7.2V TurnigyNiMh Battery pack	Battery	1	$25.25	$25.25
18	McMaster Carr M3 25mm Male-Female Standoff - 93655A360	Attach top layer to middle layer	4	$4.90	$19.60
19	McMaster Carr M3 35mm Female-Female Standoff - 94868A730	Attach top layer to middle layer	4	$4.37	$17.48
20	M3 Standoffs (10mm)	Prop up electronics on the top layer	4	$0.17	$0.68
21	HMC5883L	Maintain robot orientation	1	$12.85	$12.85
22	Base Plate	Holds motors and IR sensor array - Laser cut from acrylic, .Dfx included	1	--	--
23	Middle Plate	Holds battery and gripper servo - Laser cut from acrylic, .Dfx included	1	--	--
24	Top Plate	Holds Arduino, sensors, and other electronics - Laser cut from acrylic, .Dfx included	1	--	--
25	Gripper Plate	Enables gripper motion path - Laser cut from acrylic, .Dfx included	1	--	--
26	US Sensor Mount	Mounts ultrasonic sensor to plates - 3D printed, .stl included	5	--	--
27	Gripper Plate Bracket	Mounts gripper plate to front of robot - 3D printed, .stl included	4	--	--
28	DC Motor Mount	Mounts motor to base plate - 3D printed, .stl included	3	--	--
29	Battery Mount	Mounts battery to middle plate - 3D printed, .stl included	1	--	--

30	Servo mount	Holds the servo used for the gripper - 3D printed, .stl included	1	--	--
31	Servo link	Provides power to grabber mechanism from servo - 3D printed, .stl included	1	--	--
32	Intermediate link	Turns rotation of servo into reciprocating motion - 3D printed, .stl included	1	--	---
33	Grabber link	Connects to the gripper - 3D printed, .stl included	2	--	--
34	Grabber peg	Grips payload - 3D printed, .stl included	2	--	--
35	Intermediate washer	Used to hold the intermediate link to the front face - 3D printed, .stl included	1	--	--
Total Price					**$207.65**

4.0 Maze Solving Strategy

The rover design will use both ultrasonic and infrared sensors for localization. The accelerometer/gyroscope (IMU or Inertial Measurement Unit) will be used for navigation in order to maintain the robot's orientation to ensure the robot does not drift when traversing the maze. The first step of maze solving will be to make the robot align itself with the grid pattern on the floor of the maze. This will be achieved by rotating the robot slowly on the spot and monitoring the four ultrasonic sensors (located on the top of the robot) to determine at which orientation a local minimum is recorded for all of them, implying that their beams are perpendicular to the walls.

When the robot has oriented itself, it will then use the ultrasonic sensors to determine the distance to the nearest wall in each direction and estimate its location based on this data. If its location cannot be determined, it will move in an open direction and iterate until it has localized. During this movement, the downward facing IR sensors will read the pattern on the ground and use this to attempt to create a second localization. The location estimate of the IR sensors will be combined with the location estimate of the ultrasonic sensors (mentioned previously) to create a final localization estimate.

Once the robot has confidently localized itself, the location of the robot will be displayed on a Matlab plot and a sequence of motions will be communicated to the robot which will guide it to the loading zone (LZ). The Matlab plot will be updated as the robot moves through the maze. Upon entering the LZ, the robot will rotate slowly, scanning the LZ using both front facing ultrasonic sensors (one located on the top layer and the other located on the bottom layer). The lower ultrasonic sensor's reading will be compared to the upper one until a significant difference is detected, indicating that the block is in front of the robot.

The robot will then travel forward until it is within range and pick up the block. Lastly, the robot will realign with the maze and be provided a path to take to the block to the delivery location/zone (DZ).

5.0 Contribution Table:

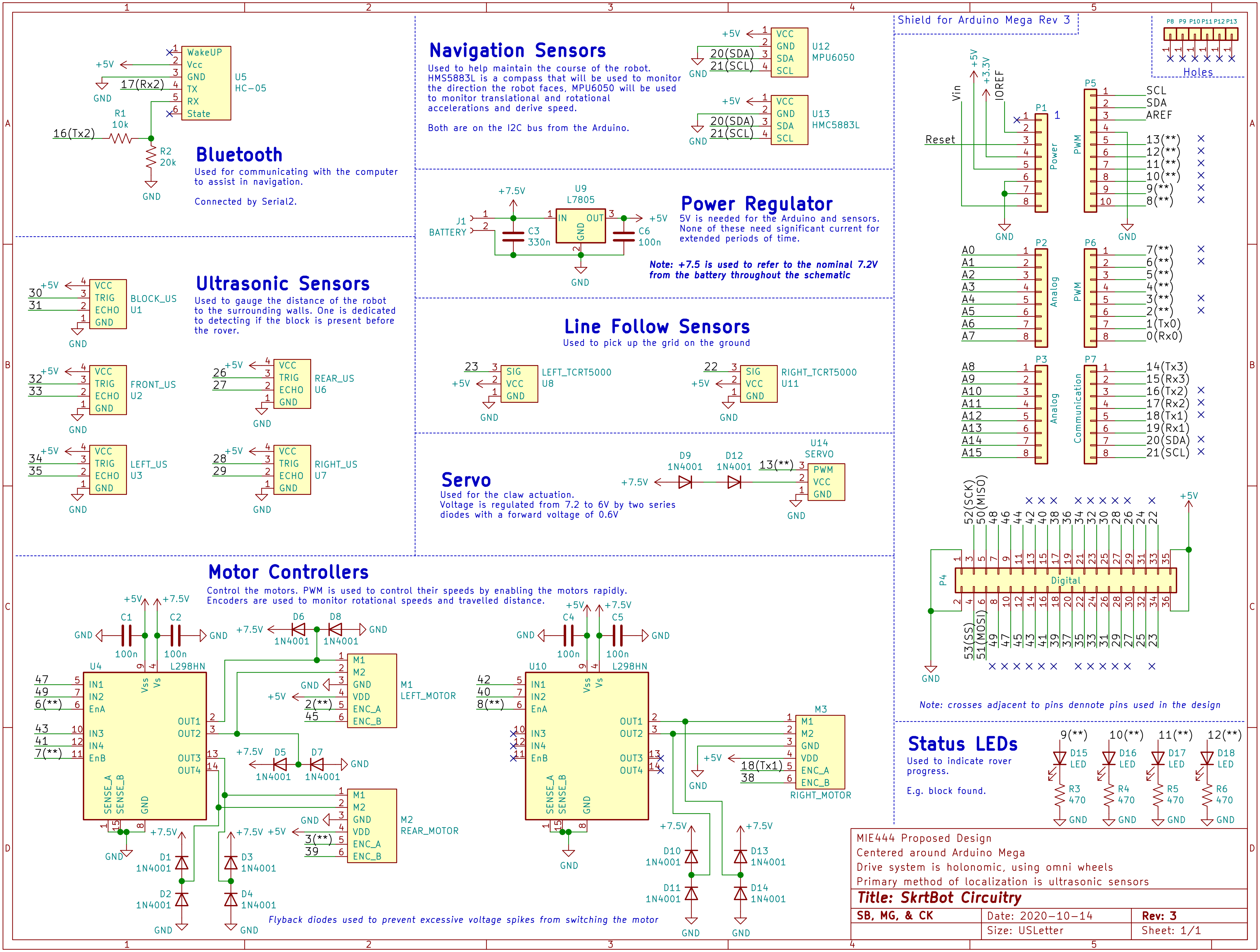
Contributions graded by contribution; 1 - small amount, 3 - majority, blank for none.

Table 2: Contribution

	Catherine	Maximilian	Savo
CAD Model	2	3	1
Schematic			3
Video	3	1	
Project Requirements	2		2
Detailed Design	2	1	2
Bill of Materials	1	1	2
Maze Solving Strategy	2		3

Appendix A: Complete Schematic

See next page. Schematic is also included as a separate PDF file in the submission folder.



Bluetooth
Used for communicating with the computer to assist in navigation.
Connected by Serial2.
U5 HC-05
WakeUP Vcc GND TX RX State
17(Rx2)
16(Tx2)
R1 10k
R2 20k
Navigation Sensors
Used to help maintain the course of the robot. HMS5883L is a compass that will be used to monitor the direction the robot faces. MPU6050 will be used to monitor translational and rotational accelerations and derive speed.
Both are on the I2C bus from the Arduino.
U12 MPU6050
U13 HMC5883L
VCC GND SDA SCL
20(SDA)
21(SCL)
Power Regulator
5V is needed for the Arduino and sensors. None of these need significant current for extended periods of time.
Note: +7.5 is used to refer to the nominal 7.2V from the battery throughout the schematic
U9 L7805
J1 BATTERY
C3 330n
C6 100n
Ultrasonic Sensors
Used to gauge the distance of the robot to the surrounding walls. One is dedicated to detecting if the block is present before the rover.
BLOCK_US U1
FRONT_US U2
LEFT_US U3
REAR_US U6
RIGHT_US U7
VCC TRIG ECHO GND
Line Follow Sensors
Used to pick up the grid on the ground
LEFT_TCRT5000 U8
RIGHT_TCRT5000 U11
SIG VCC GND
Servo
Used for the claw actuation.
Voltage is regulated from 7.2 to 6V by two series diodes with a forward voltage of 0.6V
U14 SERVO
D9 1N4001
D12 1N4001
13(**)
PWM VCC GND
Motor Controllers
Control the motors. PWM is used to control their speeds by enabling the motors rapidly.
Encoders are used to monitor rotational speeds and travelled distance.
U4 L298HN
U10 L298HN
IN1 IN2 EnA IN3 IN4 EnB OUT1 OUT2 OUT3 OUT4 SENSE_A SENSE_B GND Vss Vs
C1 100n
C2 100n
C4 100n
C5 100n
M1 LEFT_MOTOR
M2 REAR_MOTOR
M3 RIGHT_MOTOR
M1 M2 GND VDD ENC_A ENC_B
D1–D8, D10, D11, D13, D14 1N4001
Flyback diodes used to prevent excessive voltage spikes from switching the motor
Shield for Arduino Mega Rev 3
Holes
P1 Power
P2 Analog
P3 Analog
P4 Digital
P5 PWM
P6 PWM
P7 Communication
Vin +5V +3.3V IOREF Reset
SCL SDA AREF
13(**) 12(**) 11(**) 10(**) 9(**) 8(**)
7(**) 6(**) 5(**) 4(**) 3(**) 2(**) 1(Tx0) 0(Rx0)
A0 A1 A2 A3 A4 A5 A6 A7
A8 A9 A10 A11 A12 A13 A14 A15
14(Tx3) 15(Rx3) 16(Tx2) 17(Rx2) 18(Tx1) 19(Rx1) 20(SDA) 21(SCL)
52(SCK) 50(MISO) 53(SS) 51(MOSI)
Note: crosses adjacent to pins dennote pins used in the design
Status LEDs
Used to indicate rover progress.
E.g. block found.
D15 LED
D16 LED
D17 LED
D18 LED
R3 470
R4 470
R5 470
R6 470
MIE444 Proposed Design
Centered around Arduino Mega
Drive system is holonomic, using omni wheels
Primary method of localization is ultrasonic sensors
Title: SkrtBot Circuitry
SB, MG, & CK
Date: 2020-10-14
Rev: 3
Size: USLetter
Sheet: 1/1