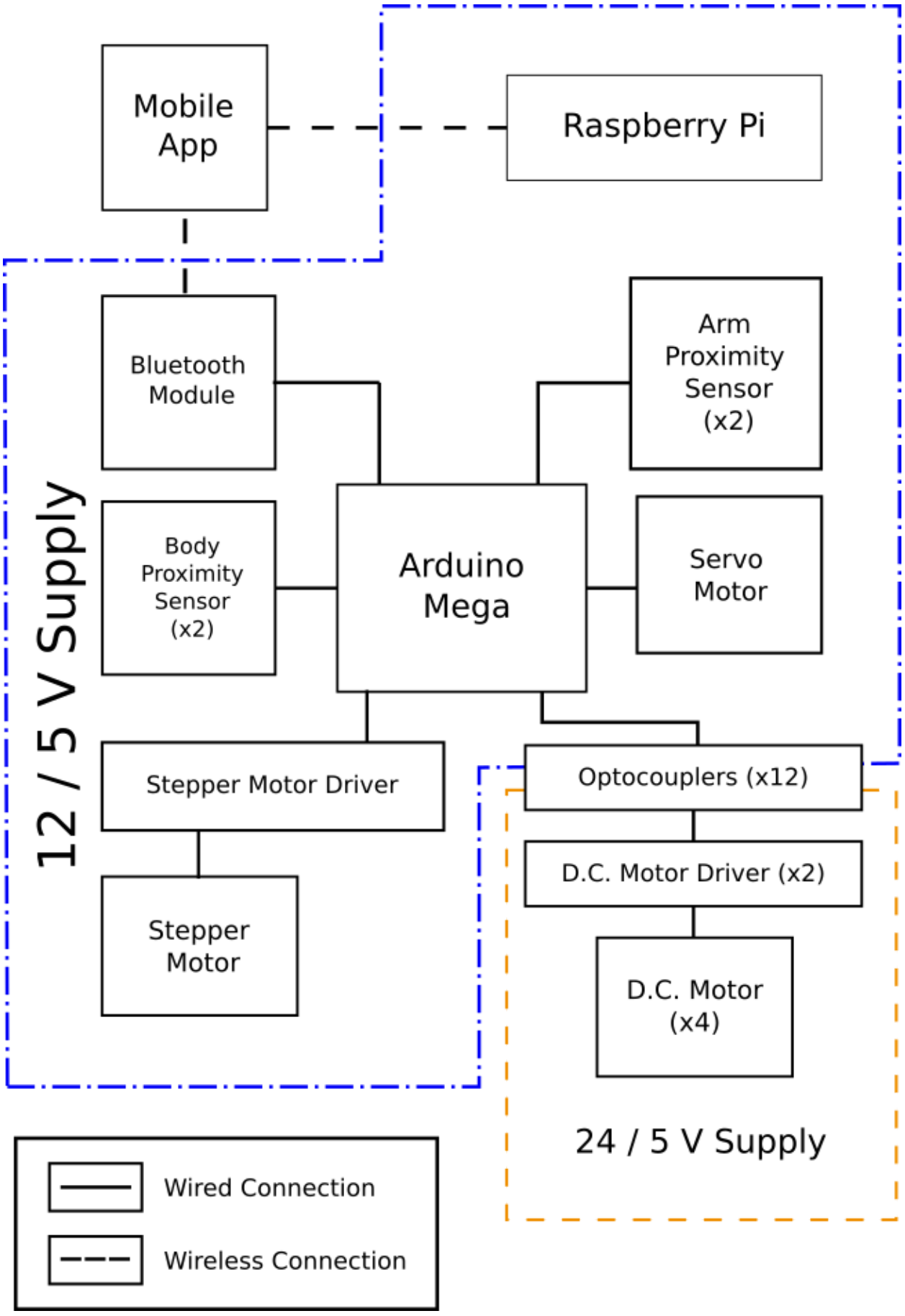
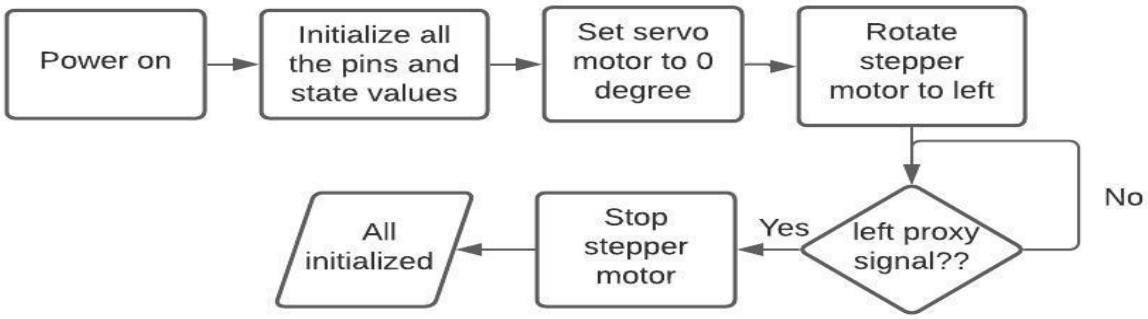
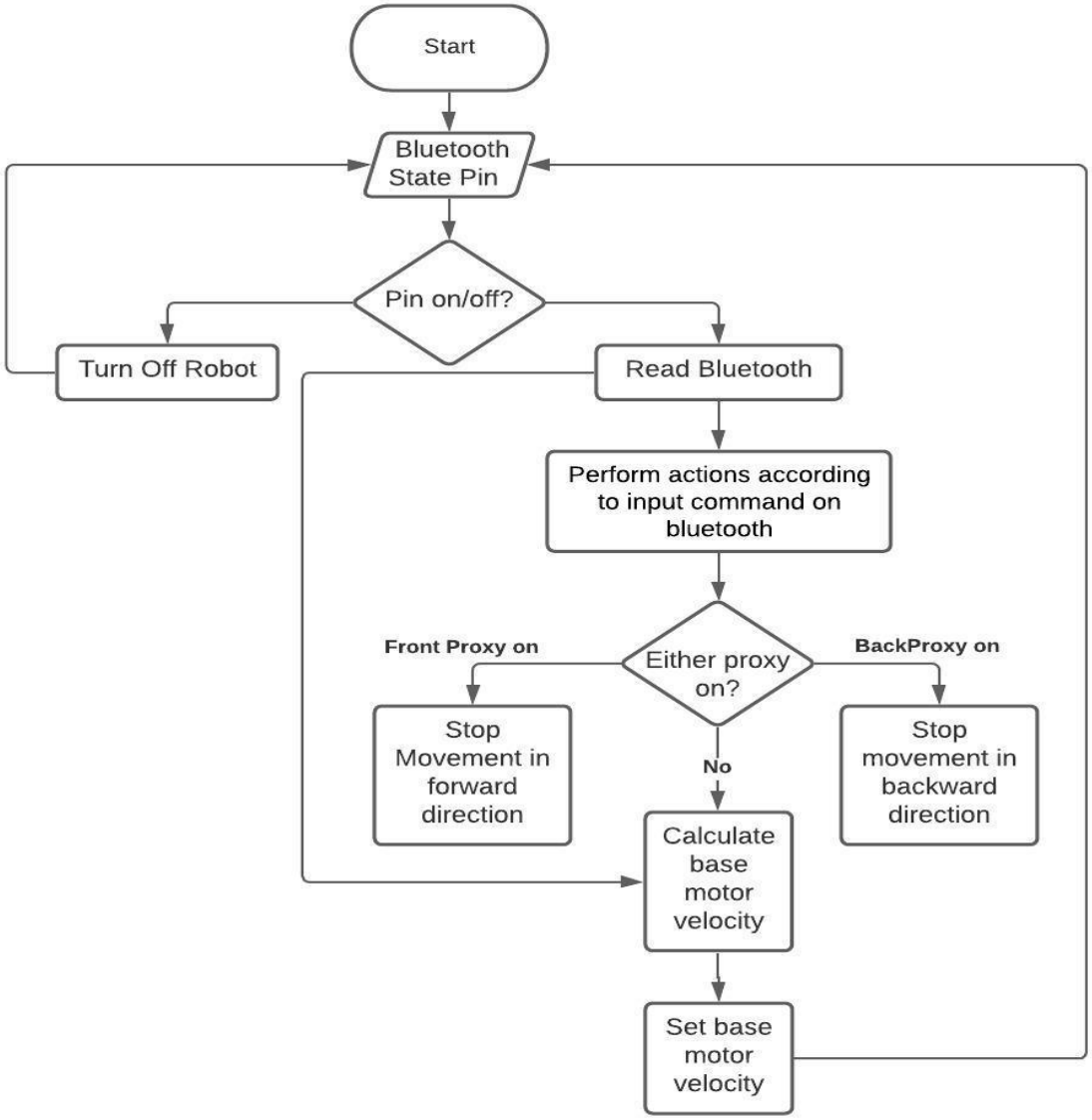

Mobile App
Raspberry Pi
Bluetooth Module
Arm Proximity Sensor (x2)
Body Proximity Sensor (x2)
Arduino Mega
Servo Motor
12 / 5 V Supply
Stepper Motor Driver
Optocouplers (x12)
D.C. Motor Driver (x2)
Stepper Motor
D.C. Motor (x4)
24 / 5 V Supply
Wired Connection
Wireless Connection

Coding


Power on
Initialize all the pins and state values
Set servo motor to 0 degree
Rotate stepper motor to left
left proxy signal??
No
Yes
Stop stepper motor
All initialized


Start
Bluetooth State Pin
Pin on/off?
Turn Off Robot
Read Bluetooth
Perform actions according to input command on bluetooth
Either proxy on?
Front Proxy on
BackProxy on
Stop Movement in forward direction
Stop movement in backward direction
No
Calculate base motor velocity
Set base motor velocity

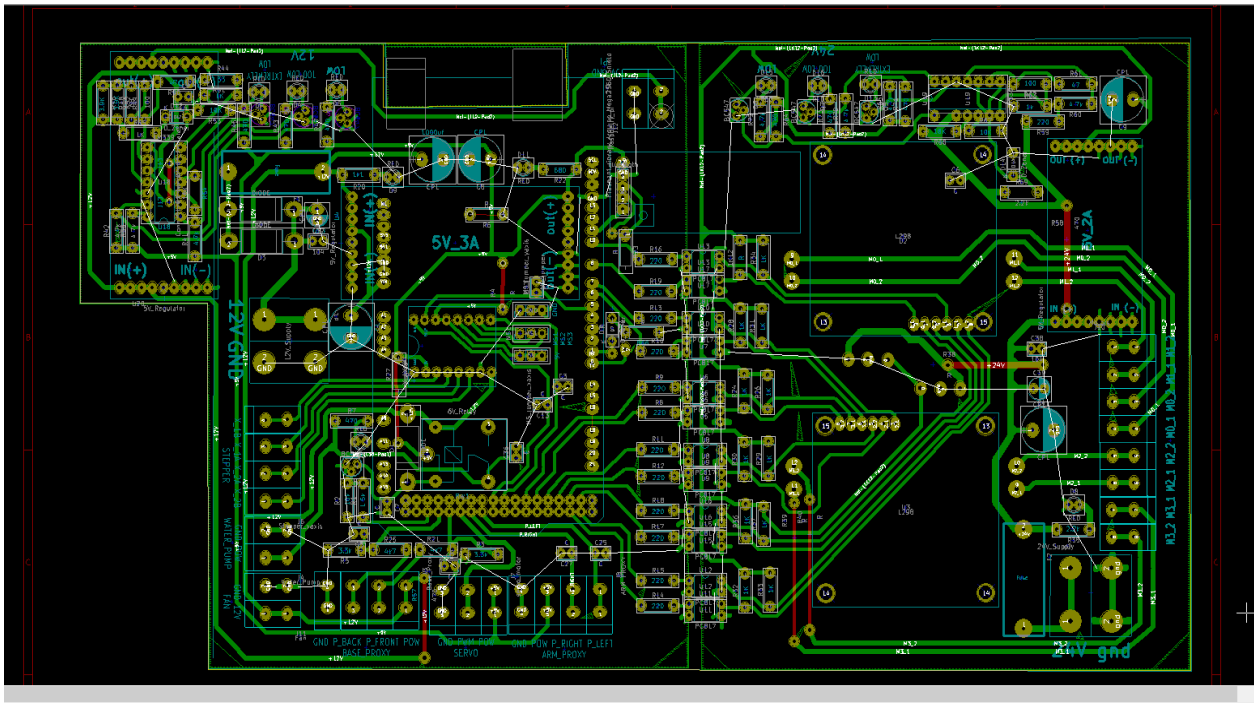
Manufacturing of the circuit board

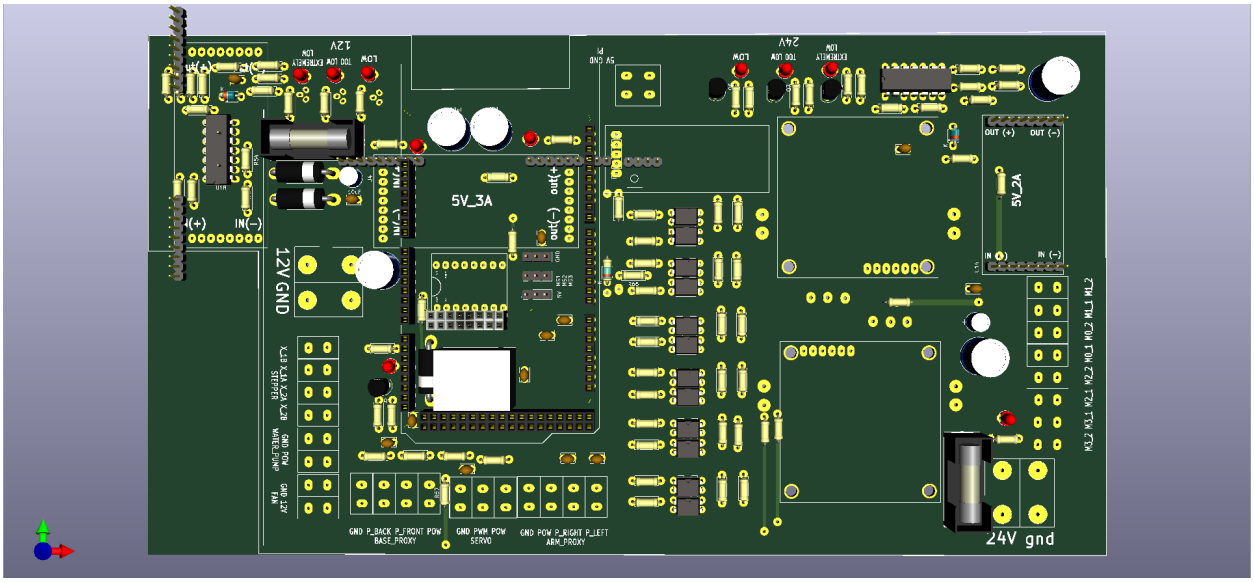
After testing the workings of all the components in the breadboard using loose connections a secure connection was needed for well organized and structured components connections. Thus a circuit board was developed where all the necessary components were soldered in a single board with required power supply and pinouts with copper tracks as a secured connections.

PCB designing

Before placing the components on the copper board a formatted and sorted layout of connection was required which was obtained using a software called KiCAD. KiCAD is a free software suite for electronic design automation and facilitates the design of schematics for electronic circuits and their conversion to PCB designs. KiCad uses an integrated environment for all of the stages of the design process: Schematic capture, PCB layout, Gerber file generation/visualization, and library editing.

In schematic design the necessary components along with their respective connections were made. In this step all the components got annotated and the connection between them was secured. The schematic generated a netlist of all the components with their labels and connections paths. The generated netlist was loaded into the pcbnew where the actual routing between the components are done.Internally pcbnew supports up to 32 copper layers and 32 technical layers. This part also allows the 3D views of the PCB and its components.





Design Printing

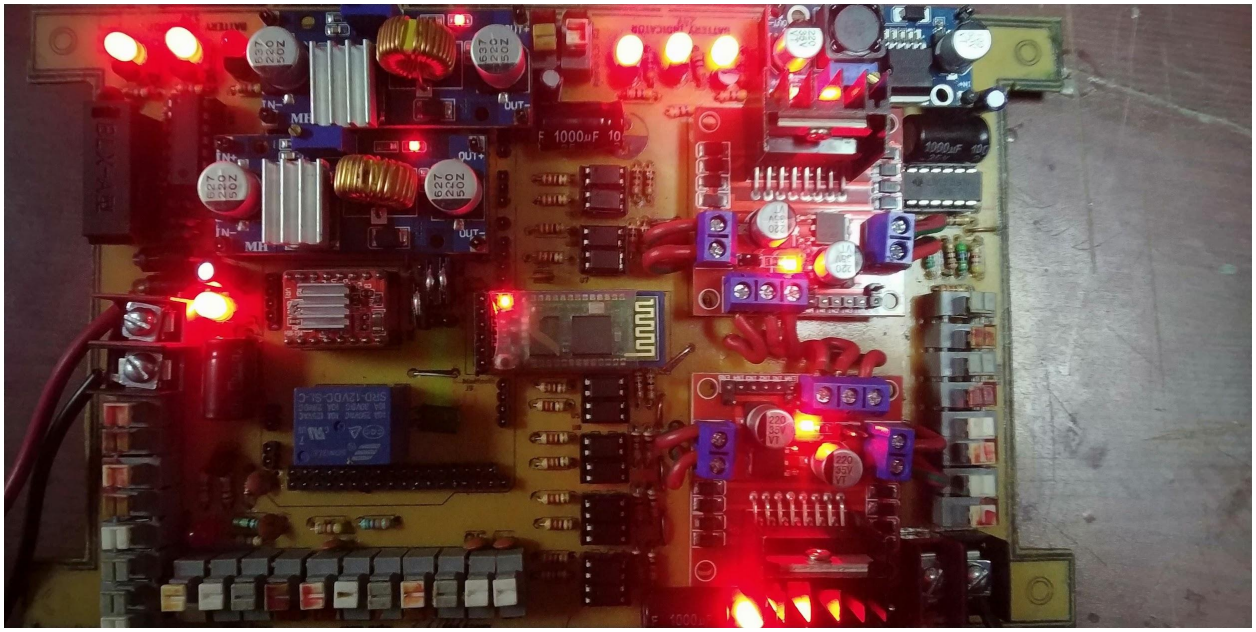
The copper board with a side having the copper layer was used which was cleaned using a stanwood paper. The copper board was also cut into the size of the designed circuit layout. After that the designed layout of the circuit board was printed out in a glossy paper which, using heat, was transferred to a copper board. The places necessary with tracks, routes and components placement were layered with the toner from the printed layout on the glossy paper on the side with the copper layer and the other side was covered with the footprints of components which was printed in mirror image form.

Etching of copper board

This is an important step where the places with tracks and route are safely preserved under the toner and the rest of the copper surface is etched with the help of a mixture of acid H_2SO_4 and catalyst H_2O_2 solution. This step needs to be done very carefully since the places where the toner hasn't been placed properly during the printing process can be etched and the routes can have poor connections.

Drilling and soldering

This is the last step of designing and printing of the circuit board. After the etching process the toner over the tracks are removed with the help of acetone (thinner). Then the footprints of components were drilled according to the required size as per the components. Then the components were placed on the front side of the board and soldered to the copper layer. After the drilling and soldering process continuity test and power test were performed.



Working of the main circuit board

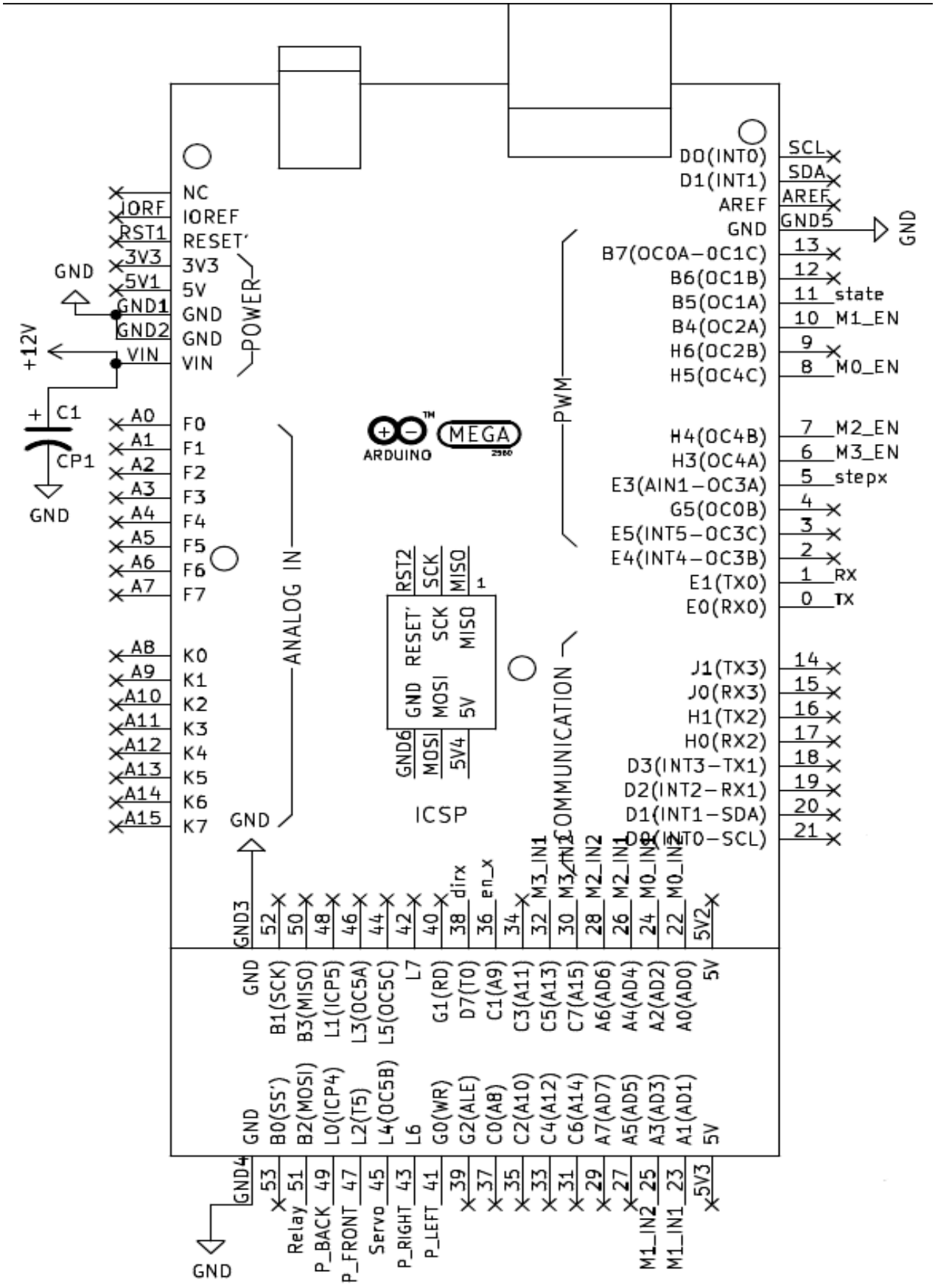
The working of the main circuit board can be divided into two blocks. One for all the components operating with 12V power supply and the other one with 24V operating power. Though all the components of the system are controlled by a single microcontroller, signals from the microcontrollers with 12V side of the board are conveyed to the other 24V side of the board through an optocoupler.

Microcontroller: Arduino mega 2650

All the functions of the robot are controlled using a single controller. Signal pins to/from all the components in the robot are connected to the microcontroller gpio and pwm pins.

Pin number	Components	Working
Vin and Gnd	Battery	Power pin to controller
1 (TX0)	Bluetooth (RX)	Send signal from controller
0 (RX0)	Bluetooth (TX)	Receive signal from bluetooth
11	Bluetooth (State)	State signal to controller
10 M1_EN 8 M0_EN 7 M2_EN 6 M3_EN	L298N, Motor drivers	Pwm signals to motor drivers for speed control of respective 4 motors

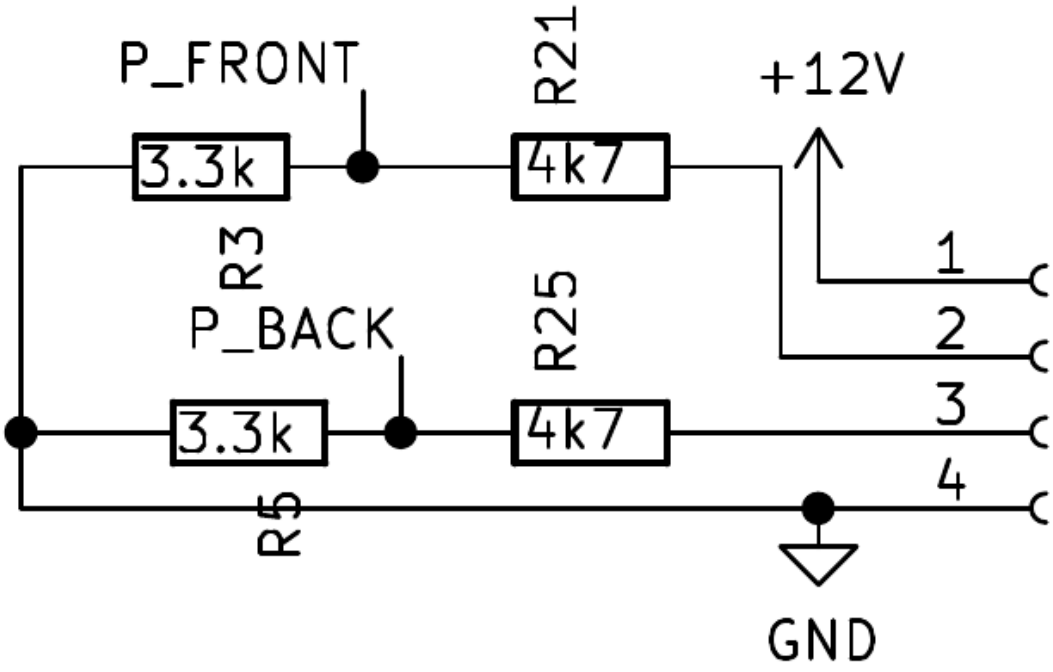
22 M0_IN2 24 M0_IN1 23 M1_IN1 25 M1_IN2 26 M2_IN1 28 M2_IN2 32 M3_IN1 30 M3_IN2	L298N	Alternating signal pins for controlling direction of motors, 2 pins per motor
5 step_x	A4988, stepper driver	Pwm signal for driver for controlling the speed of stepper motor
38 dir_x	A4988	Direction signal to stepper motor
36 en_x	A4988	Signal for enabling stepper motor
45 Servo	Servo motor	Signal for controlling servo motor, direction and speed (steps)
51 Relay	Water pump	Signal for switching water pump, ON/OFF
49 P_BACK 47 P_FRONT	Base Proxy	Signal from base proxy (front or back) when obstacle is detected within the configured range
41 P_LEFT 43 P_RIGHT	Arm Proxy	Signal from arm proxy (right or left) when arm reaches to extreme left or extreme right


POWER
ANALOG IN
PWM
COMMUNICATION
ICSP
ARDUINO
MEGA
NC
IOREF
RESET'
3V3
5V
GND
GND
VIN
F0
F1
F2
F3
F4
F5
F6
F7
K0
K1
K2
K3
K4
K5
K6
K7
D0(INT0)
D1(INT1)
AREF
GND
B7(OC0A-OC1C)
B6(OC1B)
B5(OC1A)
B4(OC2A)
H6(OC2B)
H5(OC4C)
H4(OC4B)
H3(OC4A)
E3(AIN1-OC3A)
G5(OC0B)
E5(INT5-OC3C)
E4(INT4-OC3B)
E1(TX0)
E0(RX0)
J1(TX3)
J0(RX3)
H1(TX2)
H0(RX2)
D3(INT3-TX1)
D2(INT2-RX1)
D1(INT1-SDA)
D0(INT0-SCL)
SCL
SDA
AREF
GND5
13
12
11 state
10 M1_EN
9
8 M0_EN
7 M2_EN
6 M3_EN
5 stepx
4
3
2
1 RX
0 TX
14
15
16
17
18
19
20
21
RST2
SCK
MISO
GND
RESET'
SCK
MISO
MOSI
5V
GND6
MOSI
5V4
GND3
52
50
48
46
44
42
40
38 dirx
36 en_x
34
32 M3_IN1
30 M3_IN2
28 M2_IN2
26 M2_IN1
24 M0_IN1
22 M0_IN2
5V2
GND
B1(SCK)
B3(MISO)
L1(ICP5)
L3(OC5A)
L5(OC5C)
L7
G1(RD)
D7(T0)
C1(A9)
C3(A11)
C5(A13)
C7(A15)
A6(AD6)
A4(AD4)
A2(AD2)
A0(AD0)
5V
GND
B0(SS')
B2(MOSI)
L0(ICP4)
L2(T5)
L4(OC5B)
L6
G0(WR)
G2(ALE)
C0(A8)
C2(A10)
C4(A12)
C6(A14)
A7(AD7)
A5(AD5)
A3(AD3)
A1(AD1)
5V
GND4
53
51
49
47
45
43
41
39
37
35
33
31
29
27
25
23
5V3
Relay
P_BACK
P_FRONT
Servo
P_RIGHT
P_LEFT
M1_IN2
M1_IN1
GND
GND
GND
+12V
VIN
C1
CP1
GND
A0
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
IORF
RST1
3V3
5V1
GND1
GND2

Body Proximity Sensor

The robot senses obstacles by employing two proximity sensors which are calibrated to sense obstacles (in a straight line) upto 30 cm. The proximity sensor consists of three wires:

Ground Wire	Signal Ground (0V)
Trigger Wire	12 V if the sensor senses an obstacle, o V otherwise.
Power Wire	Power signal of 12 V.



Proxy Front

Proximity Pins	Connected to
Ground (blue)	4
Trigger (Black)	2
Power (Brown)	1

Proxy Back

Proximity Pins	Connected to

Ground (blue)	4
Trigger (Black)	3
Power (Brown)	1

The two resistor divider networks consisting of resistors R3, R21 and R5, R25 are used to step down the proxy trigger voltage of 12V down to 4.95 V (~ 5V approx.).

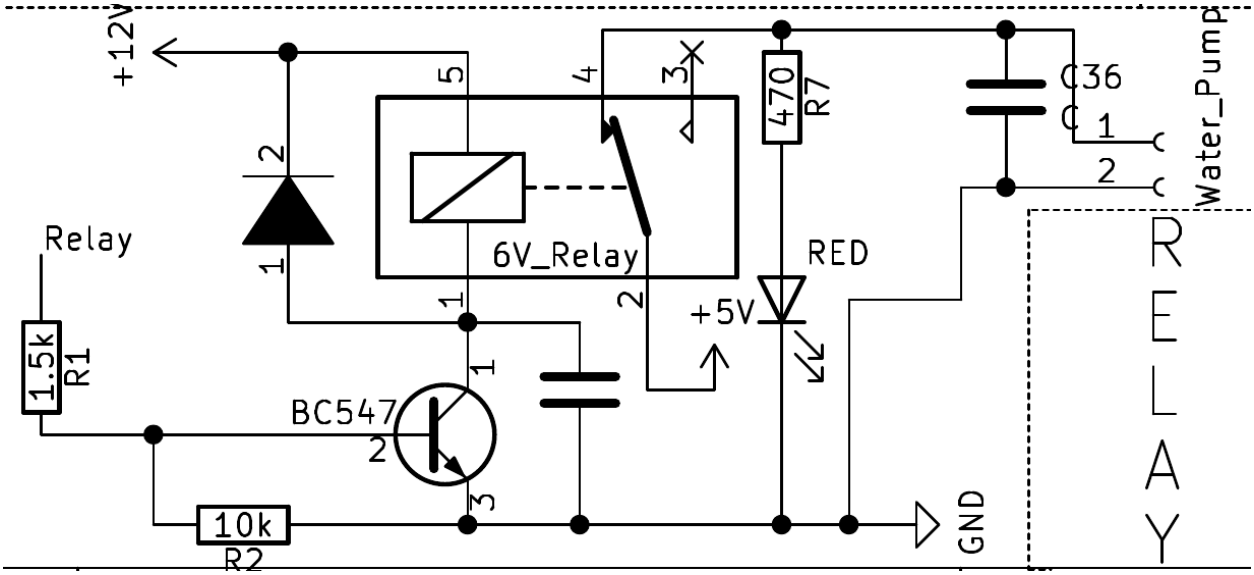
The signals P_BACK and P_FRONT are input to the microcontroller.

Signal Name	Type
P_FRONT	~4.95V if sensor detects obstacle in the front side of the robot, 0V otherwise.
P_BACK	~4.95V if sensor detects obstacle in the back side of the robot, 0V otherwise.

DC Water Pump

The DC water pump is used to spray disinfectant using a nozzle. The DC water pump is made to operate at 5v instead of 12V in order to lower the water pressure on the nozzle and to lower power consumption.

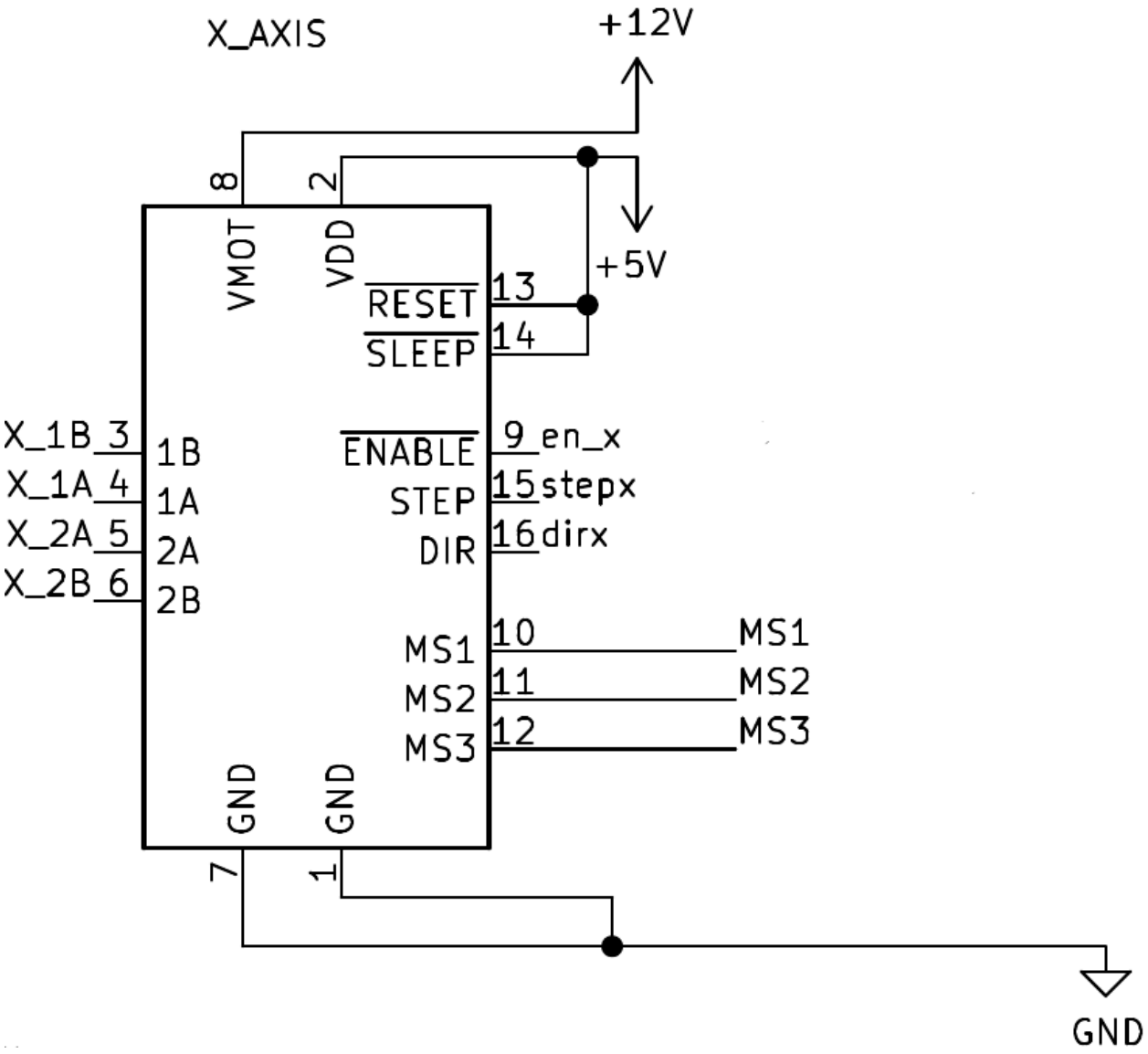
We have used a simple Relay driver circuit to operate the water pump which works on a simple ON/OFF principle.



The Relay signal is an input signal from the Arduino. When the Relay signal is high (5v), the transistor turns on which turns on the relay and which in turn turns on the water pump. The signal lines 1 and 2 (in the above fig) are connected directly to the Vcc and Ground wire of the DC water pump. The capacitor C36 is used as a decoupling capacitor for the water pump. The led RED is used as an indicator for when the water pump is ON or OFF.

Arm Stepper Motor

The X-Y rotation of the arm is controlled by the stepper motor at the base of the arm. The stepper motor used is the NEMA-17. We have used the A4988 stepper driver to operate the stepper.



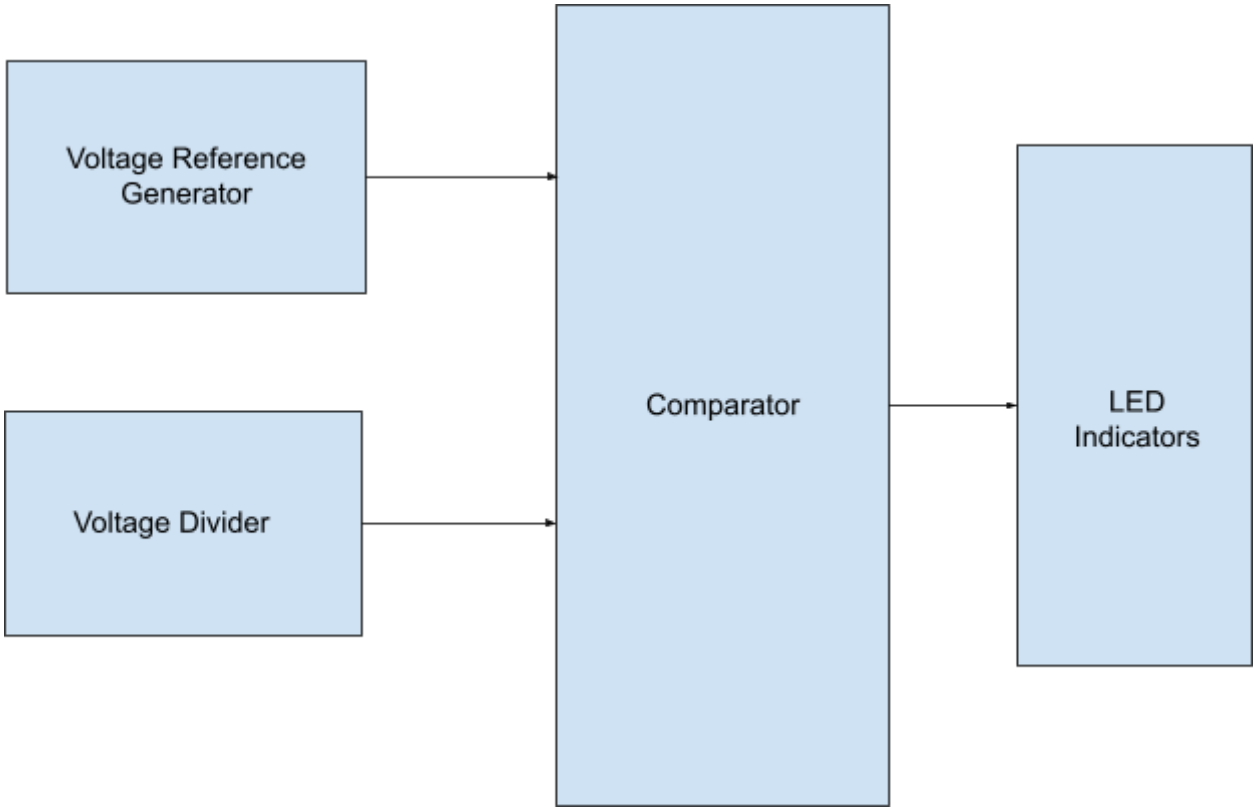
Signal Lines	
en_x	Input from Arduino to Enable the stepper driver. The driver functions only when the Enable is given a LOW signal (0 V). This is

	controlled by the Arduino.
stepx	The signal input to the driver according to which the motor operates. By providing a PWM signal to this pin, we were able to control the rotation speed by varying the PWM frequency.
dirx	Used to control the rotation direction of the motor. A high signal (5v) will produce anti clockwise rotation while a low signal (0V) will produce clockwise rotation.
MS1, MS2, MS3	These are the microstep pins used to control the stepping angle of the stepper motor.
X_1A, X_1B, X_2A, X_2B	These signals are sent to the stepper motor.

Battery Level Indicator

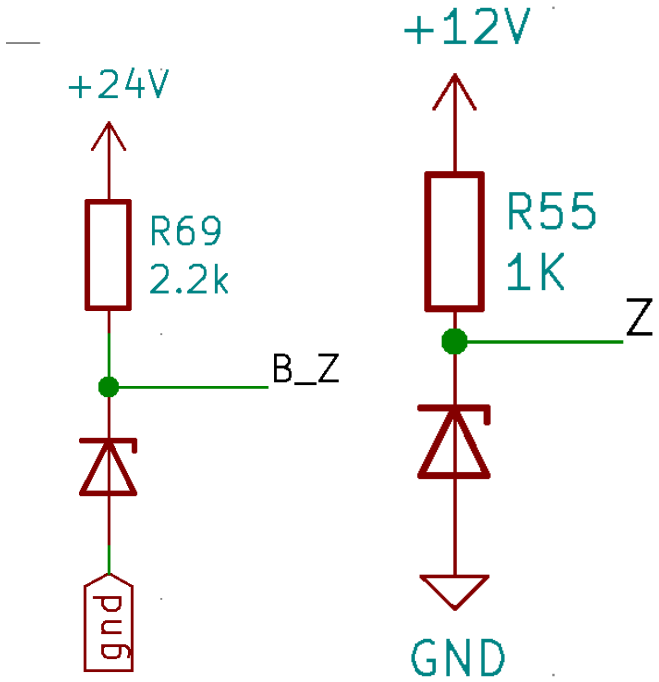
The Battery level Indicator is used to indicate the level of battery. We have used two indicator circuits for the two batteries, ie., one indicator for 12V supply and another indicator for 24V supply.

The battery indicator consists of a reference voltage generator, comparators and a voltage divider.



Voltage Reference Generator

The voltage reference generator consists of a 3.7 V Zener Diode placed in series with a current limiting resistor (1 kOhm for 12 V and 2.2 KOhm for 24V supply).. The B_Z and Z signal is the 3.7 reference voltage used in the voltage comparator for the 24 and 12V supply respectively..



Voltage Divider

The voltage divider is a simple resistor divider, which divides the supply voltage of 12V and 24V into smaller voltages. As the battery voltage drops (due to use), the voltage at the divider will also decrease.

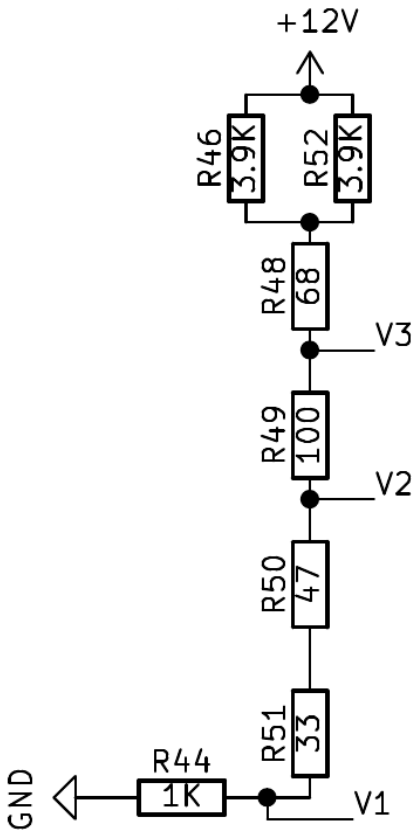
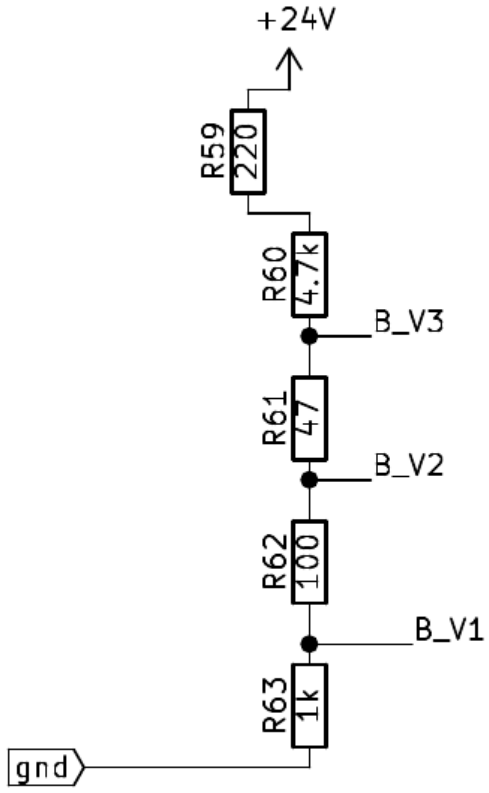


Table for 12V battery

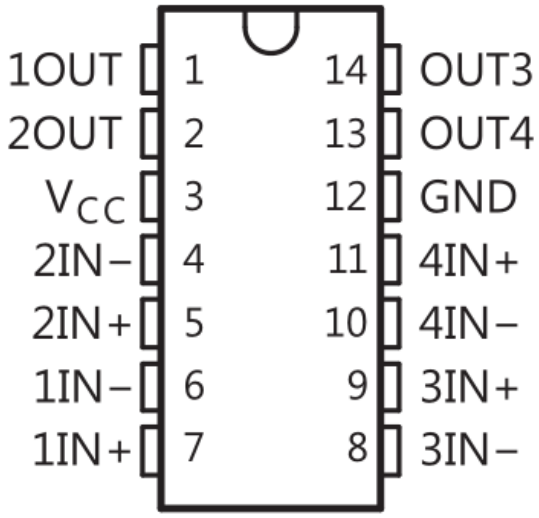
Battery Voltage	V1	V2	V3
10	3.12695	3.377	3.689
11	3.439645	3.7147	4.0579
12	3.75234	4.0524	4.4268



Battery Voltage (Volts)	B_V1	B_V2	B_V3
20	3.296	3.626	3.782
21	3.4608	3.8073	3.9711
22	3.6256	3.9886	4.1602
23	3.7904	4.1699	4.3493

Voltage Comparator

The voltage comparator used is a LM339 quad comparator which contains 4 comparators in a single IC.

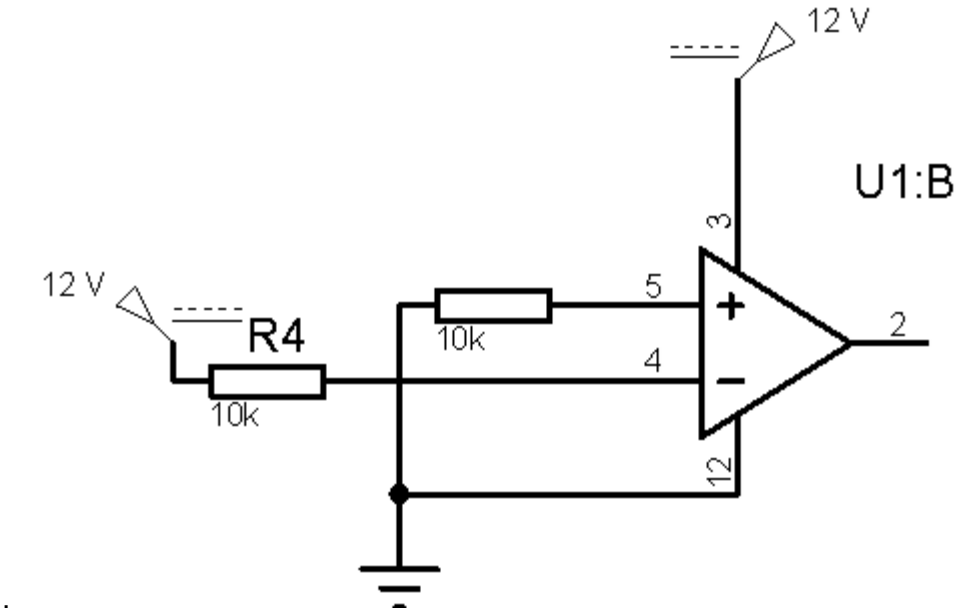


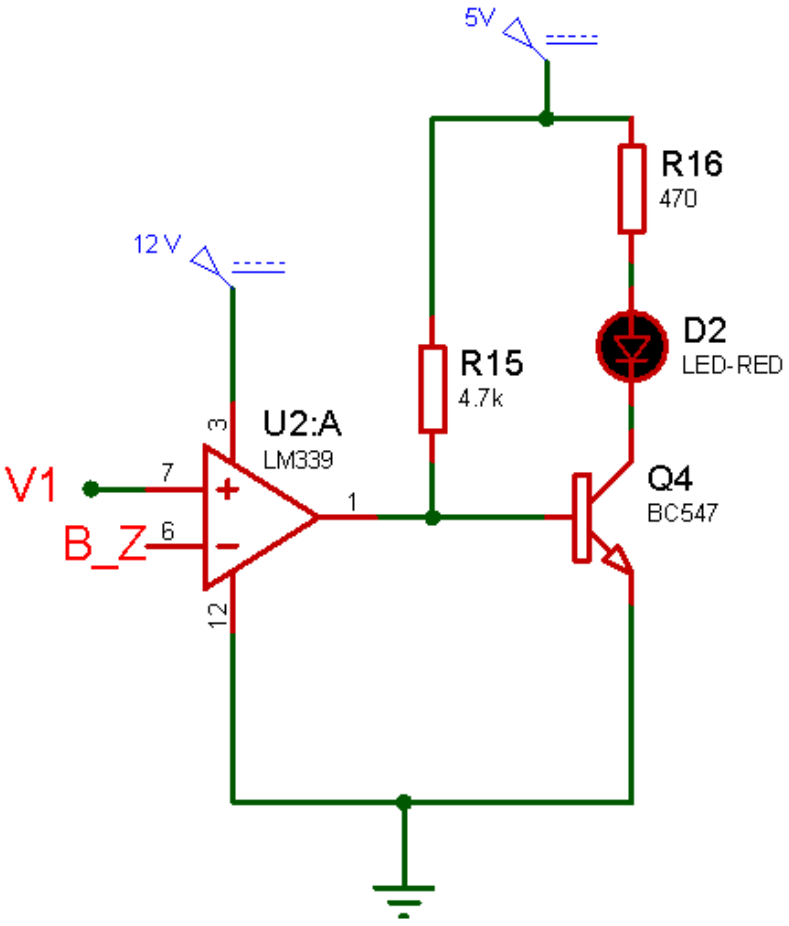
Each comparator of the IC compares the voltages V1,V2,V3 with the reference voltage (Z and B_Z) generated from the zener diode. The output of the LM339 is open ended meaning that the output will be either floating (for V+ > V-) or GND (for V+ < V-). Hence, we have used a transistor output stage in order to drive the LED for the indicator. As an example the complete circuit for comparing the voltage V1 and the signal B_Z is as shown below. Here, the U2:A is one of the comparators of the LM339 whose output is fed to a transistor with a LED connected as shown in the figure. When V+ > V- (i.e, V1 > B_Z), then the output if floating, due to which current flows from the 5V source to the base terminal of the transistor. Due to this, the transistor turns on and the LED lights up.

When V- < V+ (ie., V1 < B_Z), the output of the comparator will be connected to the ground. Due to this the current will flow from the 5V source directly to the ground through the 4.7K resistor. The value of the resistor is chosen such that the current through the comparator will not exceed the maximum allowable current of 4 mA. Here, the current through the op amp will be approximately 5/4700 = 1mA.

The circuits for other voltage signals are similar to this one.

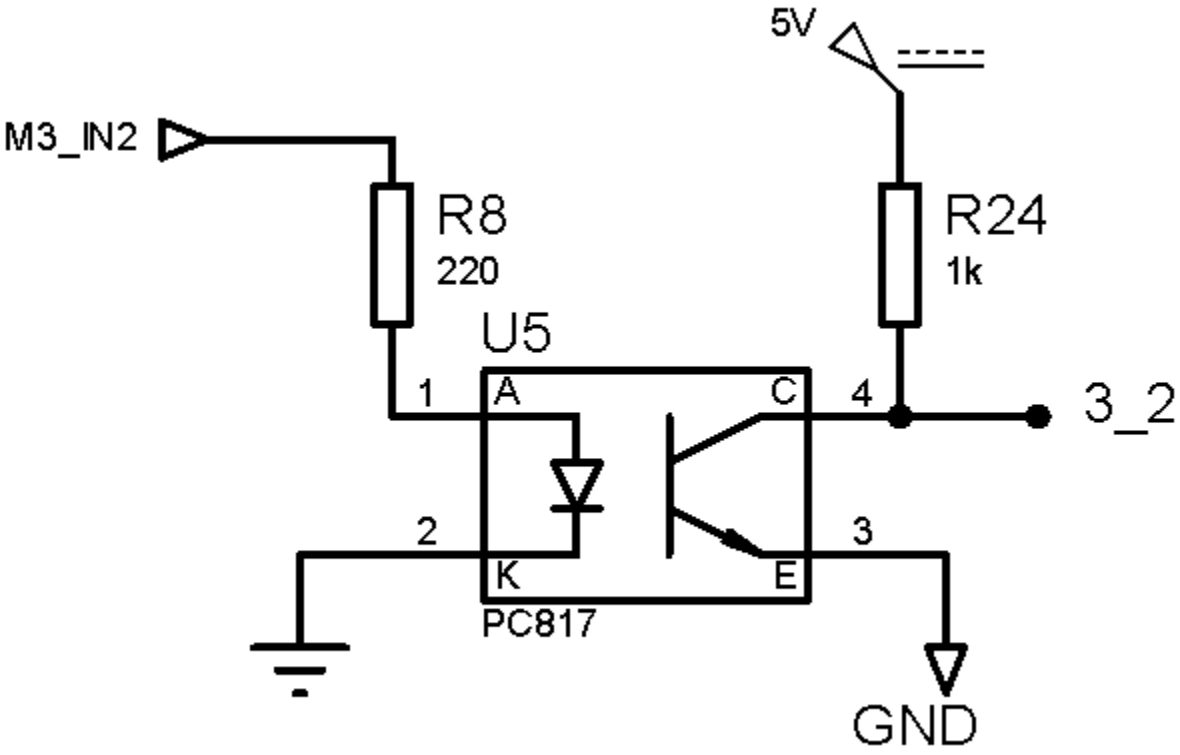
For unused comparators, comparator 2 in both the regulators, we have designed the circuit recommended by the vendor. Here, the output pin of the comparator 2, pin 2 is not connected to anything else.


12 V
U1:B
12 V
R4
10k
10k
5
4
3
2
12


5V
R16
470
12 V
D2
LED-RED
R15
4.7k
U2:A
LM339
V1
B_Z
7
6
3
1
12
Q4
BC547

Optocouplers

We have used optocouplers to electrically isolate the DC motor circuit from the rest of the components. This was necessary as the DC motors used were found to be very noisy which greatly affected the operation of other components in the circuit. We have used a total of 12 optocouplers to isolate all the signals from Arduino to microcontroller. The optocouplers generate an inverted replica of the input signal at the output terminal.



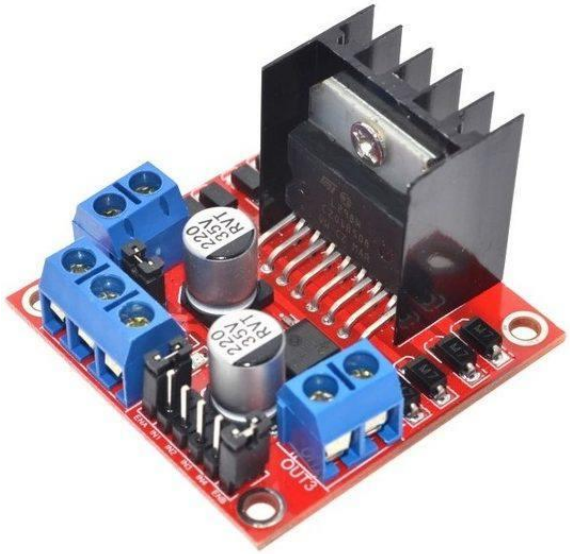
The above shown circuit is for the signal M3_IN2. When the signal M3_IN2 is high, the diode AK is activated due to which the CE terminals start conducting and therefore the output signal 3_2 will be low. Similarly, when the signal M3_IN2 is low, the diode is in OFF state and the CE terminal acts as an open circuit. Therefore, the signal 3_2 will be connected to the 5V supply through the 1K resistor.

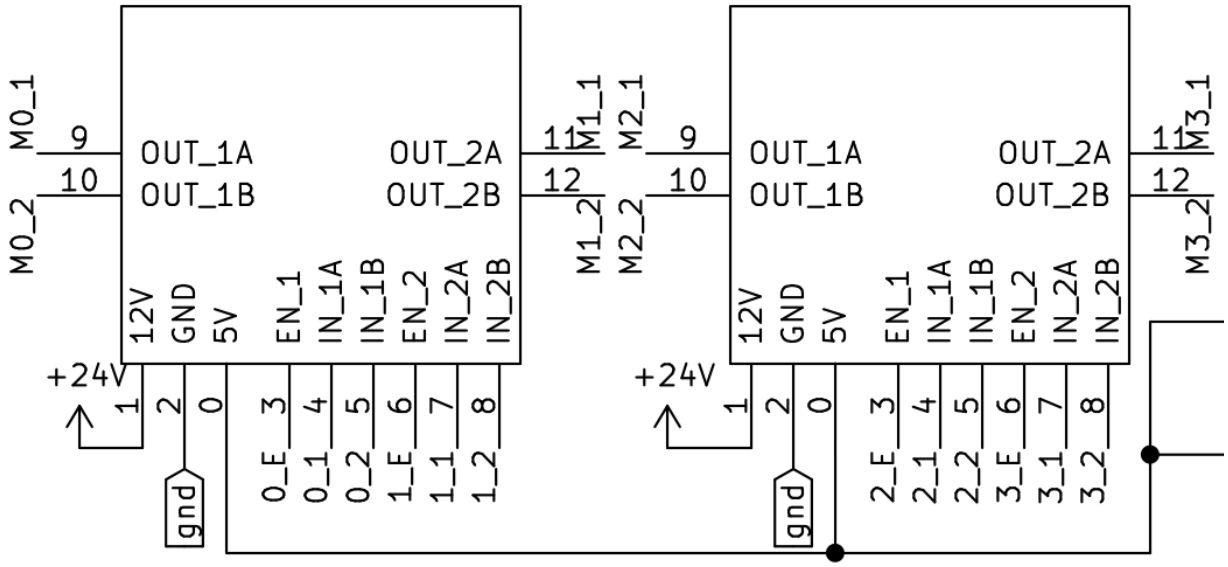
The value of resistor R8 of 220 Ohms was selected to allow the maximum possible current to flow through the optocoupler. Similarly, the value of the resistor R24 was chosen such that only the minimum amount of current will flow through the optocoupler and through the signal line 3_2.

The circuits for other signal lines M3_IN1, M2_IN1 etc. are all similar to the one as shown above.

Motor Driver Circuit

The DC motors are driven using a L298N motor driver module which allows for simple direction and speed control. This module has all the necessary components and circuits already built in for driving motors.

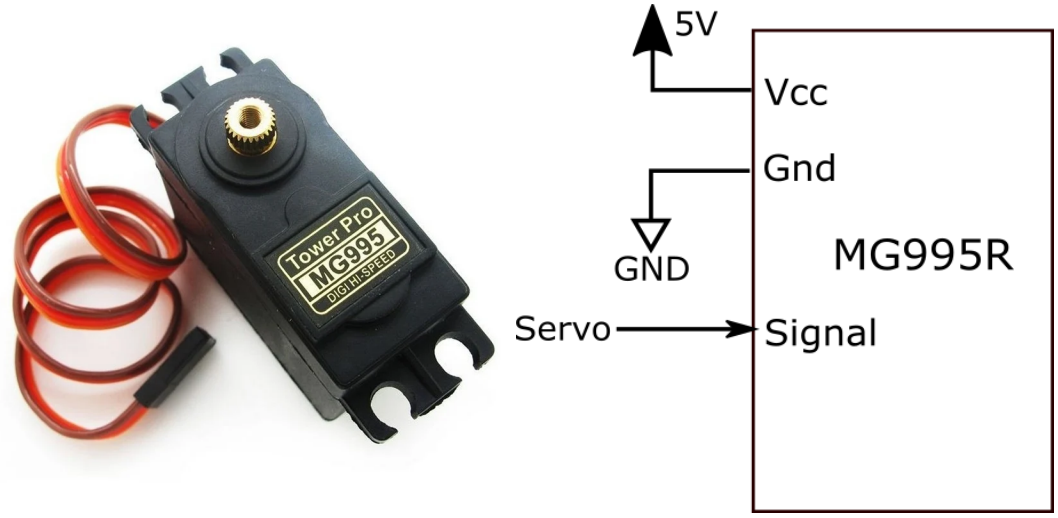




Signal Name	Description
*_E, *_1, *_2	PWM and direction control signals for motors 0,1,2 and 3 as output by the optocouplers.
M0_*, M1_*, M2_*, M3_*	These signal lines are connected to the terminals of motors 0,1,2 and 3 respectively.

Arm Servo Motor

The robotic arm also uses a servo motor for the movement in the vertical direction. The servo motor used is a MG995 servo motor which has a very high torque and can also operate at a smaller voltage of 5 V, which is ideal for our use case since most of our circuit operates at 5V.

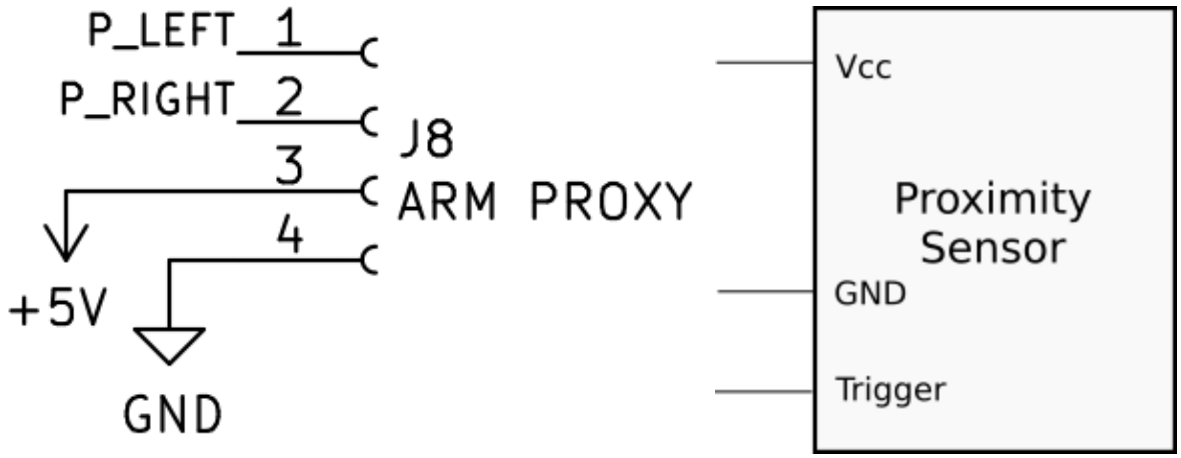


Here, the only signal input to the servo is the Servo signal from the Arduino. The signal is a PWM signal whose duty cycle determines the angle of the servo motor shaft.

Arm Proximity Sensor

The proximity sensors used in the arm are inductive sensors. These are used to limit the rotation of the stepper motor to a fixed angle of about 180 degrees. A metallic strip is attached to the rotating base which the proximity sensor can sense in order to find the maximum range. The proximity sensor has three wires:

Vcc	Used to supply power to the proximity sensor. We used 5v to power this sensor.
Gnd	The ground connection.
Trigger	An output pin whose voltage is low if the sensor detects a metallic obstacle but is high otherwise.

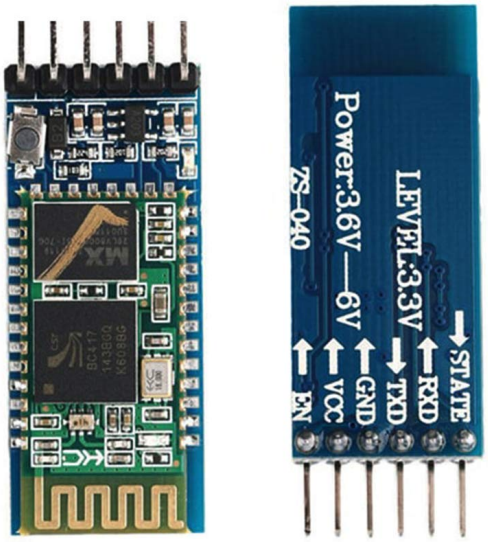


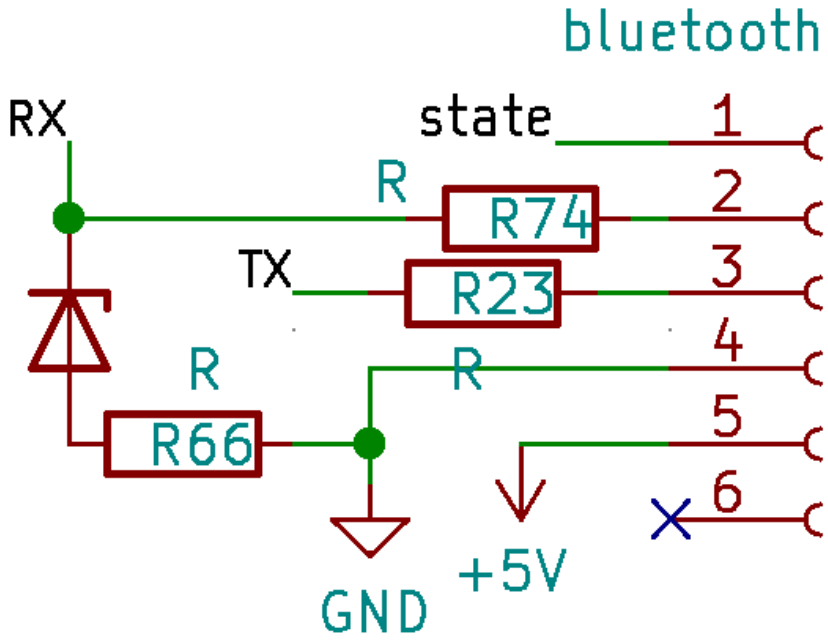
P_LEFT	Trigger output of the left proximity sensor
P_RIGHT	Trigger output of the right proximity sensor
Vcc	Common Vcc input for the two proxies
GND	Common GND for the two proxies.

Bluetooth Module

The module used is a HC-05 bluetooth module which allows the robot to communicate with the phone. The bluetooth module itself communicates with the Arduino through USART. The Tx and Rx pins of the module are connected directly to the Arduino with some additional circuits for protection.

The protection circuit consists of a zener diode in series with a resistor (R66). The output to the Rx pin of Arduino is taken directly from the zener diode which protects the Arduino from overvoltage and voltage spikes at the Rx output pin of the module. Similarly, current limiting resistors are also present at the Tx and Rx pins (R23 and R74) to limit the current in and out of those pins.





Cooling Fan

The cooling fan is a simple DC fan that operates at 12 V. The fan serves to cool the Arduino from heating. It is directly connected to the 12V battery and draws about 600mA of current.

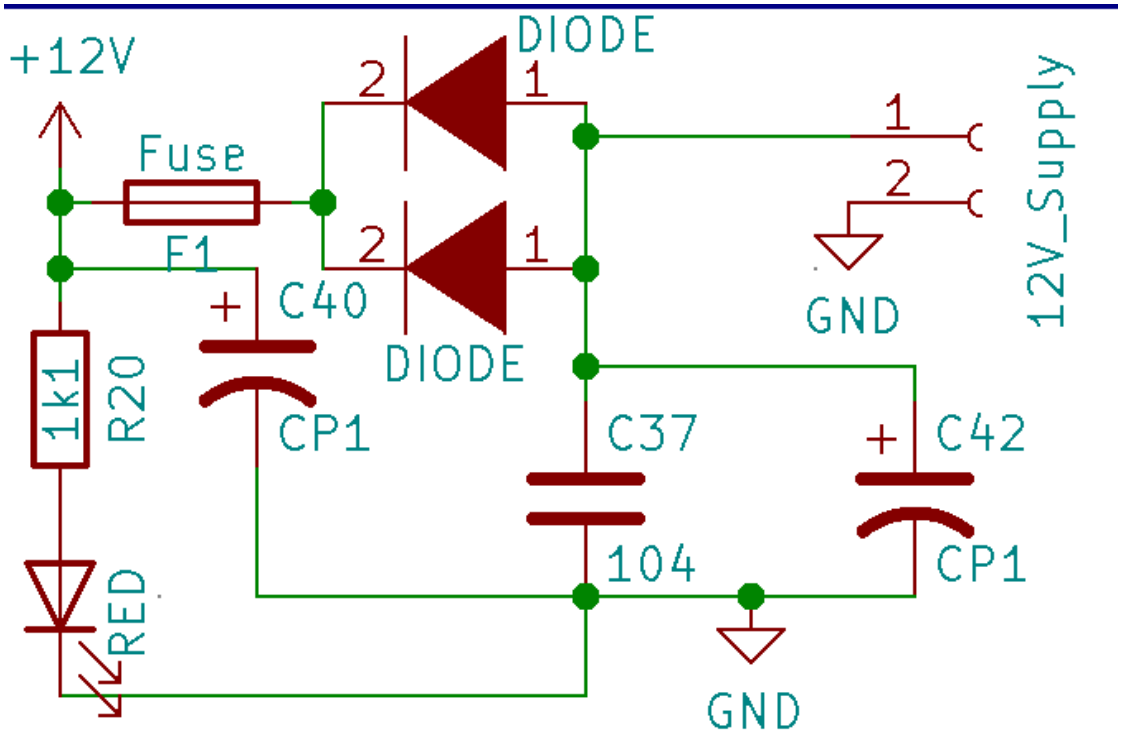
Power Supply

The robot is powered by a 24 V source and a 12 V source. The 24V source is used for the motor driver circuit while the 12 V source is used for the rest of the circuits .The 24 V source is provided by two 12 V LiPo batteries connected in series while the 12 V source is provided by a single 12 V lead acid battery of a much larger capacity. The two sources are electrically isolated from each other and are connected only through optocouplers.

We also use buck converters to step down the 12 and 24 V down to 5v in order to power other components of the circuit.

12 V source

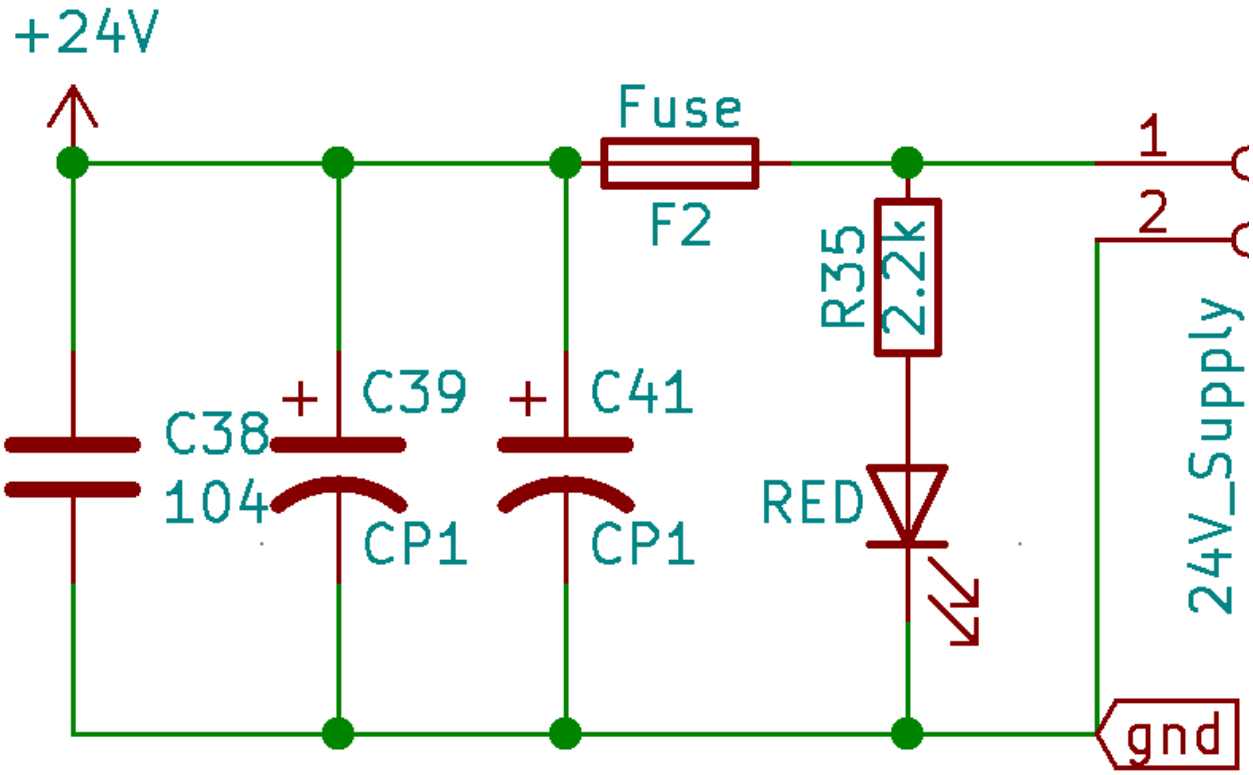
The 12 V coming out of the battery is first passed through some additional circuitry before the 12 V source is generated. The circuitry is as shown below.



The 12V_Supply is directly connected to the positive and negative terminals of the 12 V lead acid battery. The two diodes in parallel prevent any reverse current to flow back to the battery. The parallel configuration of diodes allow much higher current to flow through it.

The fuse limits the total current that can be drawn by the circuit. This is used for over current and short circuit protection.
The LED is used as an indicator whenever the power supply is connected to the battery.
We have also connected multiple capacitors across the positive and negative terminals of the battery and also across 12V. This prevents voltage spikes due to large current draw by circuits.
The 12 V is utilized by the Arduino, Stepper Motor, DC Fan, Body Proximity Sensors, Battery Indicator, and by the Relay driver for the water pump.

24 V Supply



The circuit used for the 24V supply is a simple one which consists of only a fuse protection and some capacitors with an LED indicator. The 24V supply is used by the motor driver L298N, the DC Motors and the battery indicator.

5V Supply

We have used three 5V voltage supplies in our circuit. The 5V is generated by using Buck converters of varying current capacity. One buck is used for the motor driver circuits, second one for powering the Raspberry Pi and the third one is used for powering other components. The buck used for the Raspberry Pi has a max current capacity of 5A while the other bucks have only 2A as the max current capacity.

Buck Component Name in Schematic	Supplies Current To
U4	Stepper Driver (A4988), Servo Motor, Bluetooth Module, Arm Proxy, Battery Indicator, Water Pump.
U20	Raspberry Pi
U14	DC Motor Driver (L298N), 24 V battery indicator.