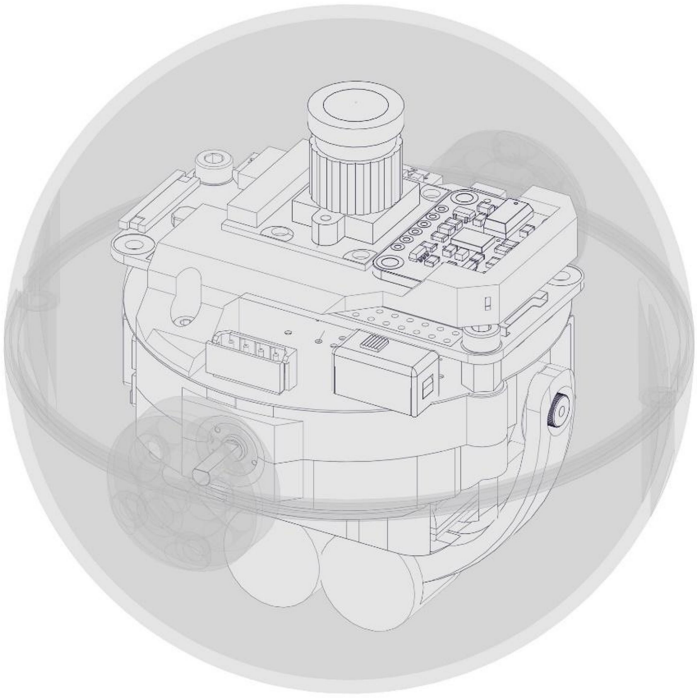
Spherical Robot



Small Spherical Robot Documentation 2022

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Co-Principal Investigator: Dr. Abhishek Gupta.

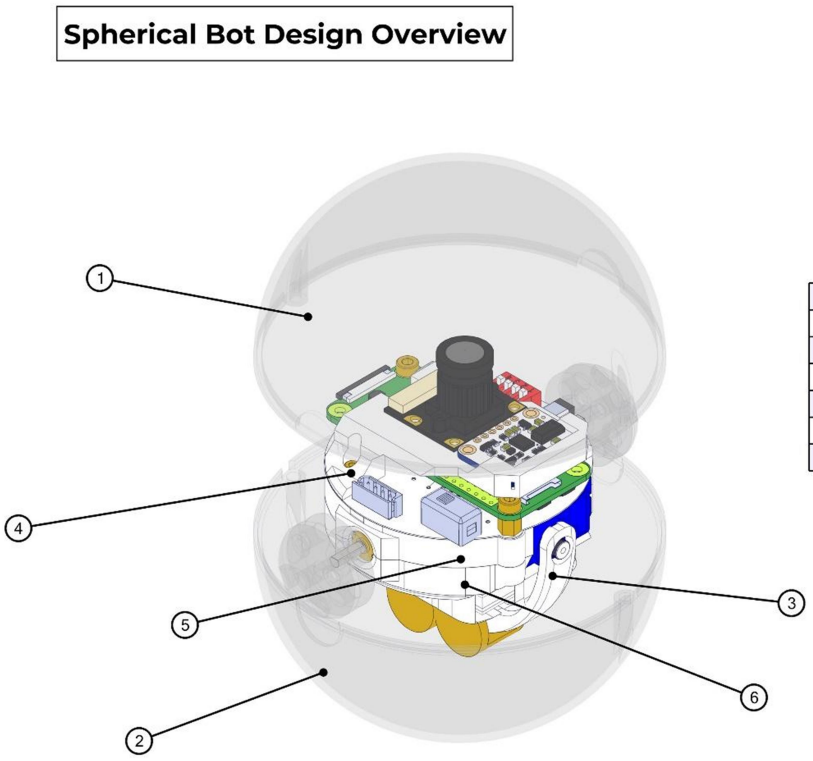
Contents

Introduction

The spherical robot has a ball-shaped outer body that houses entire electronics inside it. The robot is controlled in autonomous and manual modes. The camera mounted on the robot provides visual feedback, which is then transmitted to the operator, thereby enabling better control of the robot's movement. The inexpensive and throwable robot can be used for autonomous applications such as indoor mapping, detection of sound and fire sources, etc. The current prototypes have the facility to view 360 panorama in real-time.

The teleoperated robot may be deployed at hazardous, difficult, and enemy intruded areas and controlled from a safe region. The structure of the spherical robot has many advantages over conventional mobile vehicles or humanoids. The ball shape of a spherical robot enables rolling in any direction on planar surfaces. Sensors and other electronics are entirely inside the shell. It is robust to collisions and can maneuver in any direction. The camera mounted on the robot provides a real-time panoramic 360 visual feedback that provides awareness to the situation. The visual feedback transmitted to the operator also enables him/her to control the robot's movement. A manually operated spherical robot has been designed that provides visual feedback for reconnaissance and search. The robot's design can be easily modified to add sensors for collecting application-specific information to the operator. It has applications in surveillance, STEM education, interactive toy for kids, and a home assistant.

Overview



Description	BOM ID	Qty
Hull_lower	2	1
Hull_upper	1	1
Left Pendulum	4	1
Right Pendulum	3	1
Yoke_lower	6	1
Yoke_Upper	5	1

The spherical bot consists of the following main components Hull, Yoke, and Pendulum. The design overview is shown in the above illustration. Each of the main components has upper and lower halves. The hull is transparent and throwable to be deployed in critical areas for surveillance and reconnaissance. The yoke consists of Pan 360 vision system for monitoring placed on the yoke. It carries the necessary electronics and actuators for maneuvering. The pendulums are made of brass. The bob is 25g, which steers the bot by shifting the center of mass. The spherical bot has a symmetrical design along with the pendulums.

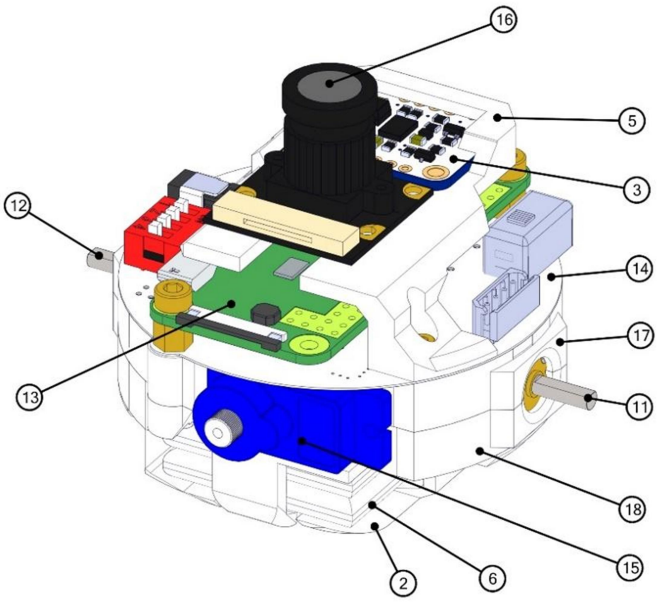
Technical Specifications:

i. Size 100mm (10cm)
ii. Max speed 20cm/s.
iii. 40 min run time.
iv. WiFi communication with the android app.
v. Fisheye vision sensors 200 FOV.
vi. Orientational sensors.

Assembly and Connections

Yoke assembly

Spherical Bot Yoke Sub assembly



Description	BOM ID	Qty
Yoke_Upper	17	1
Yoke_lower	18	1
Waveshare_Camera J 220 FOV	16	1
SP_PCB	14	1
Servo_motor	15	2
Pi_Zero_W	13	1
N20_Gear_Box	12	1
N20_DC_Motor	11	1
KP053450_Lipo Battery	6	2
IMU_Camera_mount	5	1
Bosch_IMU_Adafruit_BNO055	3	1
Battery_cover_mount	2	1

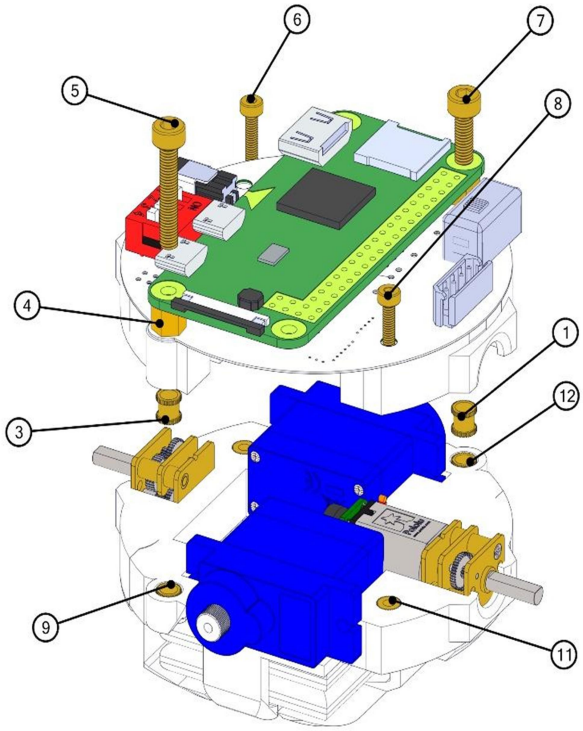
Turn over for Bolt/Heat insert/Brass Spacer

- The yoke comprises of the significant components of the system. It carries the Utility PCB with SBC (Rpi) and the actuators along with IMU and Pan 360 vision system.

Sr. No.	Component	Specification
1.	Fisheye camera	Waveshare 220 FOV
2.	IMU	Adafruit Bosch BNo055 9 axis IMU
3.	Servo Motor	Tower Pro SG90; Stall Torque 1.2 Kg-cm
4.	DC N20 Motor	Polulo #2386 150:1 Gear ratio 210 RPM @6v
5.	SBC	Raspberry Pi Zero W
6.	Battery	Lipo 1s x 2; 1500 mAh each.
7.	Chassis	FDM 3D printed PLA
8.	Weight	310g

Yoke Internal Assembly and Connections

Yoke Upper Nut Bolt/ Spacer Placement

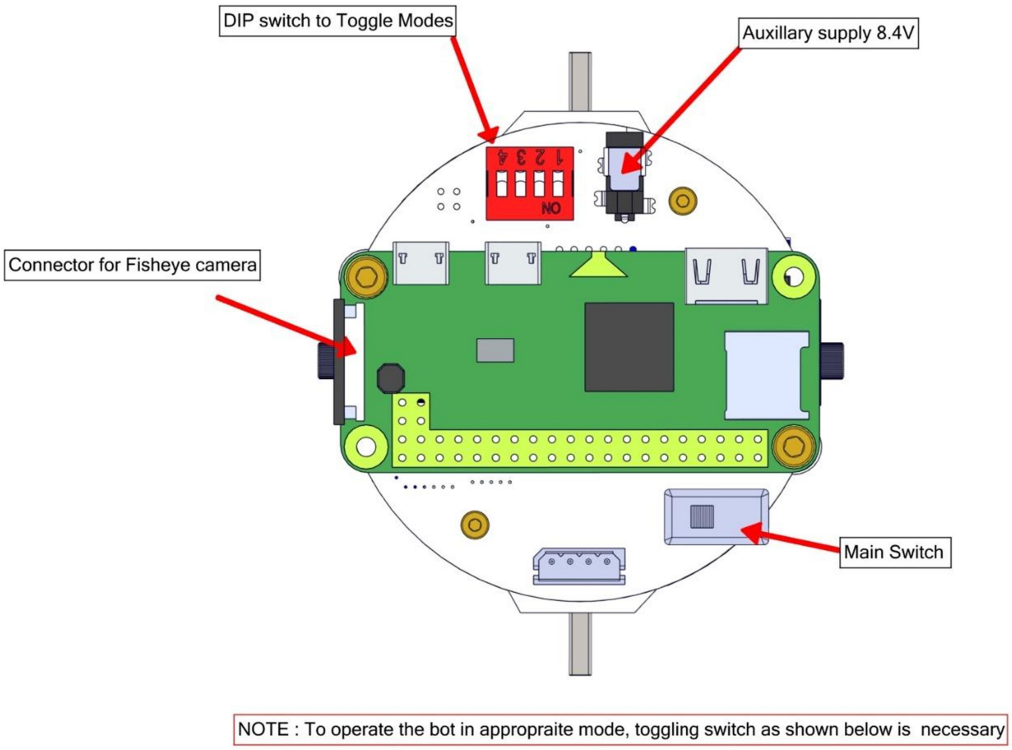


Description	BOM ID	Qty
Brass Spacer M3x6mm	4	1
M2 x 0.4mm Thread 16mm Bolt	6	1
M2 x 0.4mm Thread 16mm Bolt	8	1
M2x6 Heat insert	11	1
M3 x 0.5mm Thread 18mm Bolt	5	1
M3 x 0.5mm Thread 18mm Bolt	7	1
M3x4 Heat insert	1	1
M3x4 Heat insert	12	1
M3x4 Heat insert	3	1
M3x4 Heat insert	9	1

- Above are various Nuts bolts that need to be considered for assembly of the spherical bot.
- The above illustration shows the internal configuration of the yoke and the placement of various components.

Utility PCB

Utility PCB for the spherical bot facilitates internal peripheral connections, power regulations, and placing the SBC (Raspberry Pi) in a minimal design for the handy ergonomic prototype. The system has two Lipo batteries, each 1s 3.7v 1500 mAh in series connection. The total battery supply is 8.2v or approx. 8.4v at its max capacity. The raspberry pi requires a 5v constant for operation and considering the current requirement wrt the torque provided by the N20 motors, and such series configuration was implemented.



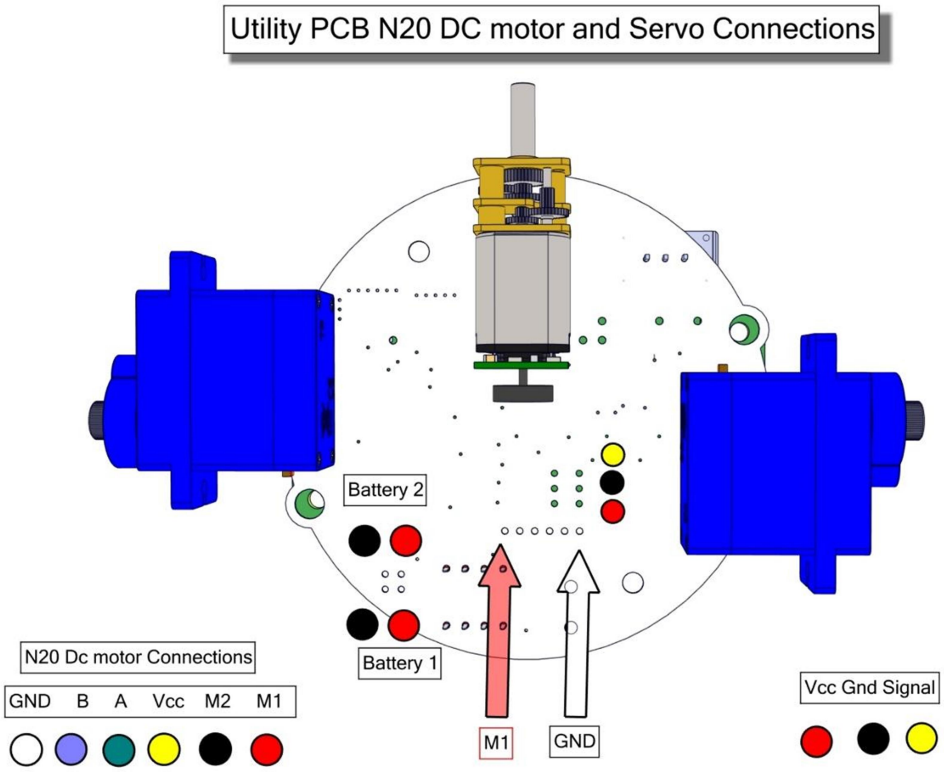
NOTE : To operate the bot in appropraite mode, toggling switch as shown below is necessary

PCB Connections Topside

- The spherical bot has two modes of usages:
- Run Mode: In this, the bot can be operated on its battery supply.
- Auxillary supply: It can be used for debugging and development by directly supplying 8.4v via DC barrel jack using any adapter. The battery connections are entirely cut off in auxiliary mode, and the system gets the external supply

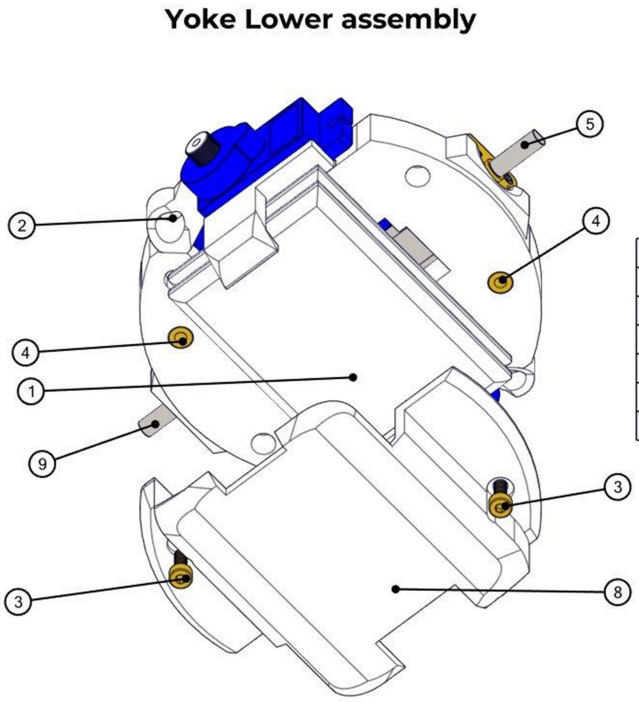
Mode	Switch 1	Switch 2	Switch 3	Switch 4
Run	ON	ON	OFF	OFF
Auxillary supply	OFF	OFF	OFF	OFF

PCB Bottom Side Connections



- Dc N20 Motor connections are as shown above from GND to M1. Please check the Pololu N20 Motor datasheet for further reference.
- The Battery connectors are as shown in the illustration. JST 2mm Lipo Battery connectors are used. Please check for BOM reference.
- SG90 standard servo motor is connected as above. Please check for GND on PCB with DMM before connecting.

Yoke Lower Assembly

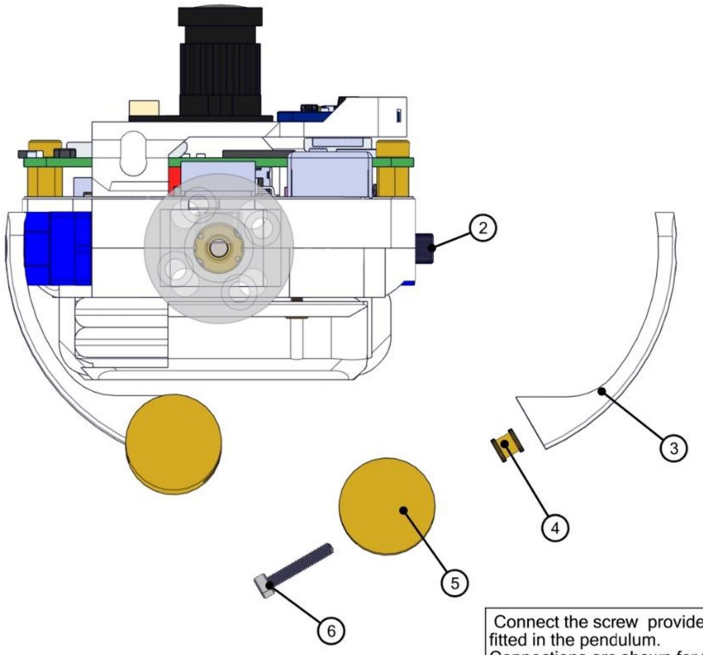


Description	BOM ID	Qty
battery_cover	8	1
KP053450_Batt	1	2
M2 x 0.4mm Thread 6mm Bolt	3	2
M2x6 Heat insert	4	2
N20_motor_magnetic_encoder	5	1
only_gear_N20	9	1

- The lower assembly of the yoke carries the Lipo Batteries and actuators like DC Motor and Servo.
- Various Bolts that need to loosen are shown in the above illustration.

Pendulum Connections

Pendulum sub asembly and connections

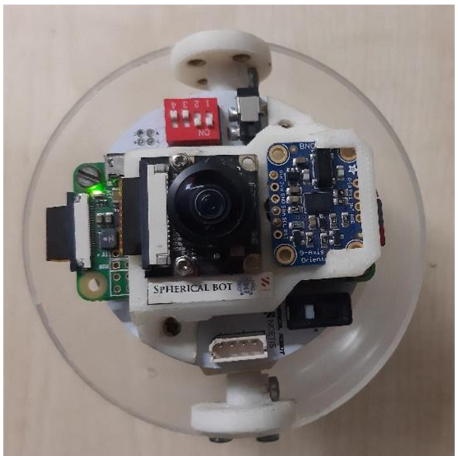


Description	BOM ID	Qty
Brass Bob	5	1
M2_x_12mm_bolt	6	1
M3x4 Heat insert	4	1
Pendulum	3	1
Servo_motor	2	1

Connect the screw provided with servo along its axis with the servo hand press fitted in the pendulum.
Connections are shown for the RIght pendulum same follows for left pendulum.

Standard Operating Procedures

Operating spherical Bot in **RUN Mode**

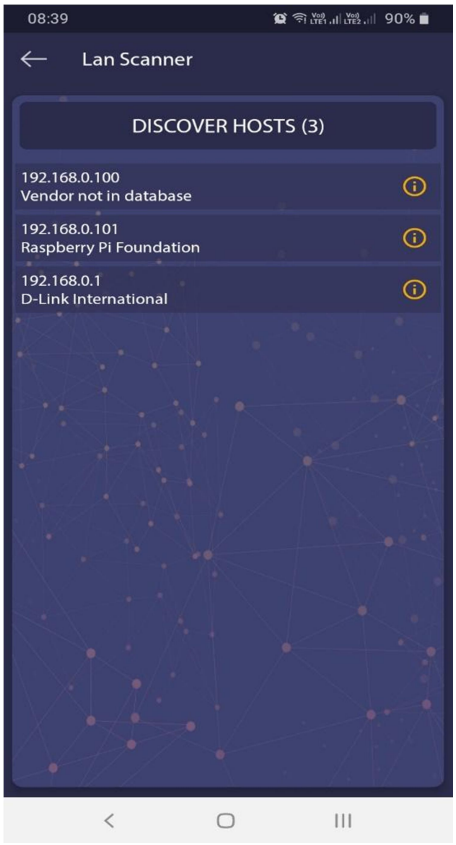


STEP 1 :

- Open the spherical bot hull and turn the switch 1 and 2 of the DIP switch to set the bot in run mode.
- Turn the main switch ON and let the spherical bot SBC boot.

STEP 2 :

- Use any network scanner App (IP Tools) on your mobile to search for the active clients available in WLAN.
- Check for Raspberry Pi and note down its IP address.



STEP 3 :

- The IP address of the spherical bot is `192.168.0.101`.
- Now we will access the spherical bot via your laptop, which is in the WLAN using SSH.

```
ssh pi@192.168.0.101
```

- Now navigate to the sphericalbot folder

```
cd sphericalbot
```

- Execute the script for teleoperation

```
python3 sphericalbot.py
```

STEP 4 :

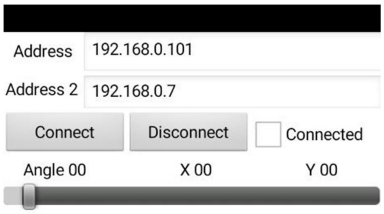
- Execute the script for the streaming camera feed.

`python3 stream.py` This provides the raw feed of spherical bot as seen by the fisheye camera

STEP 5 :

- In your host Laptop system. Navigate to Pan vision (Refer Pan 360 vision docs)

```
cd panvision/HostSystemFiles/flask-video-streaming
```



- Execute the Pan 360 conversion script.

  `python3 app.py`

STEP 6 :

- Enter the spherical bot IP address `192.168.0.101` and Host Laptop IP address `192.168.0.7`

- Connect you can operate the bot, and you can see the Pan 360 feed on your mobile by moving the slider.

Troubleshooting

1. Home is pressed in mobile phone, and the bot does not move. The script in Pi logs as socket already in use.

- `ps -ef` then `kill -9 <PID>`

Operating Spherical Bot in Debug/Development Mode

- Switch off 1 and 2 DIP switches.
- Connect 8.4v via adapter provided, and the battery is entirely isolated in this mode.
- Via ssh, scripts can be edited, and logs can be checked for debugging.

Charging the Spherical Bot

STEP 1 :

- **Disassemble the hull and loosen the bolts of the lower yoke**
- **Remove both batteries. For charging, batteries should be separately charged.**

- Following should be the mode of the balance charger for charging 1s Lipo Battery
- DO NOT LEAVE Battery unmonitored. If done, overcharging may damage the battery and cause a potential hazard.

DUAL-LAYER UTILITY CIRCUIT BOARD

DESCRIPTION

The Utility Circuit Board (UCB) is a dual-layer, surface mount technology-based board designed to combine 3+ functional blocks on a single PCB. The objective is to achieve modularity, minimize repair and diagnostic issues with a form factor optimum to the SPHERICAL BOT mechanical constraints.

FEATURES

The UCB features the following utilities:

- MP1584 - 3A, 1.5MHz, 28V Step Down Converter Logic.
- TB6612FNG – 4 mode Motor Driver Logic.
- Raspberry Pi Zero W compatibility.
- Charging Mode with Dual Series Battery input and External Supply Logic.
- Reverse current protection logic.

APPLICATIONS

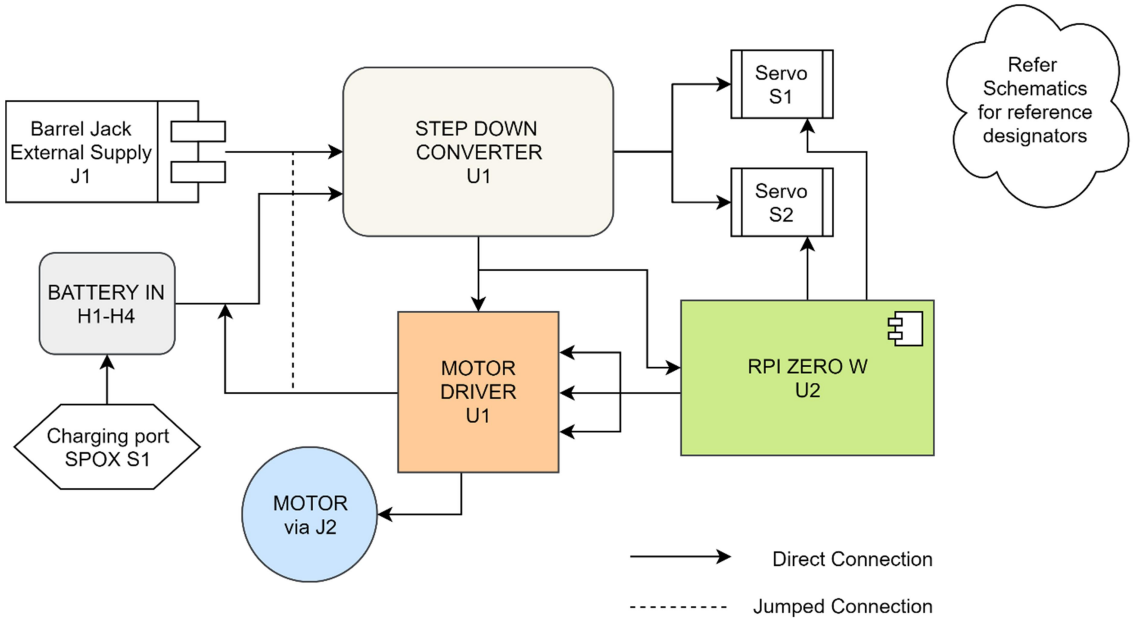
- Power Input.
- Battery Charging.
- Control In/Outs.
- High voltage conversion.
- Current Conversion.
- Reverse Input Protection.

SOFTWARE

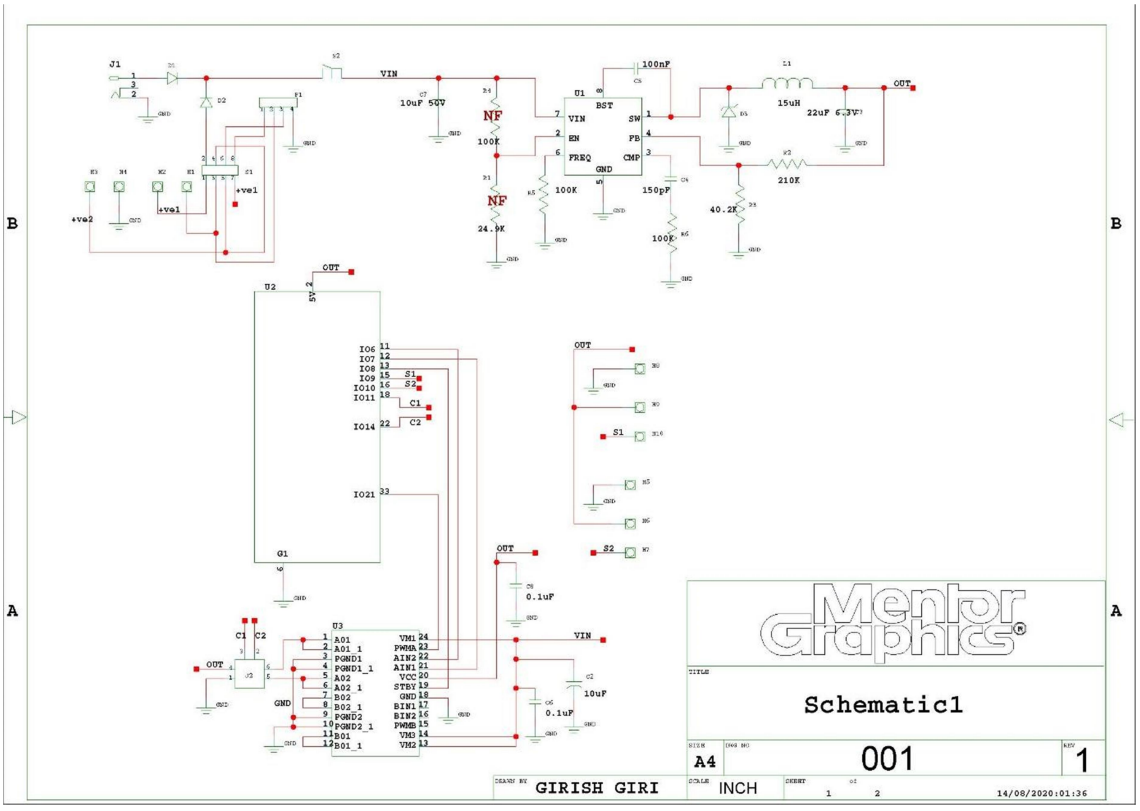
The schematic for PCB is designed on DxDesigner Software. The layout is designed and developed on PADS v9.5 and both these platforms are a part of software package tool suite from Mentor Graphics, Siemens. The schematic design is developed by implementing universal standard symbol library and can be used to migrate into decal layout libraries in PADS logic for layout designing. The foot print for each component is developed from scratch by referring to respective datasheet constraints for decal guidelines.

The routing for layout is developed with optimum designing rules for trace length and width. The board design ensures all requisite IPC standards and EMI, EMC considerations are met. All placements and routing are done with strictly referring to PCB layout Guidelines wherever needed and mentioned in components datasheets.

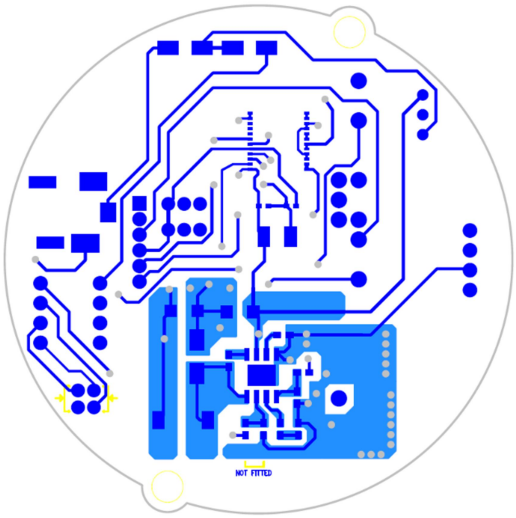
BLOCK DIAGRAM



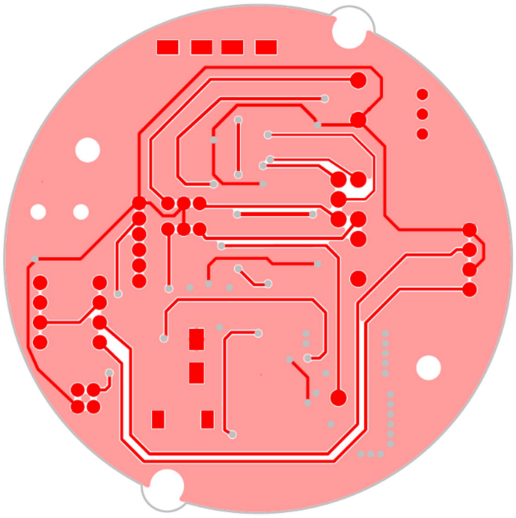
SCHEMATICS



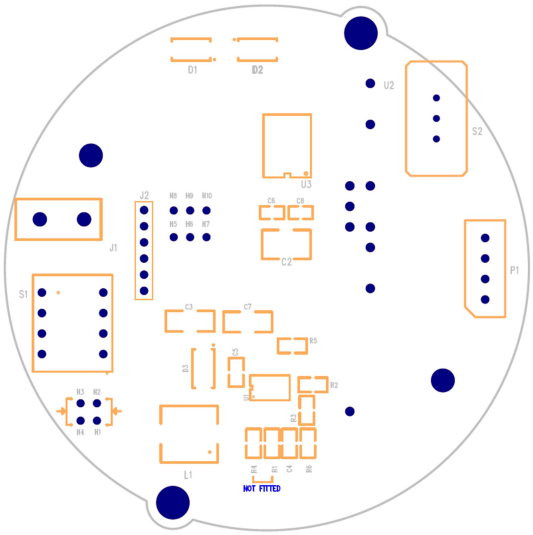
LAYOUT



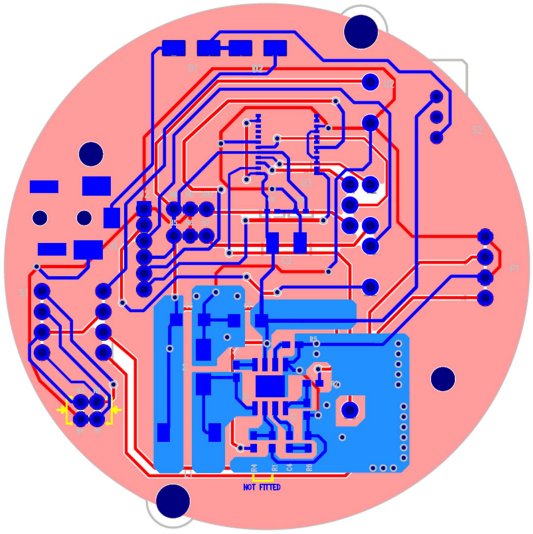
TOP-SIDE



BOTTOM-SIDE

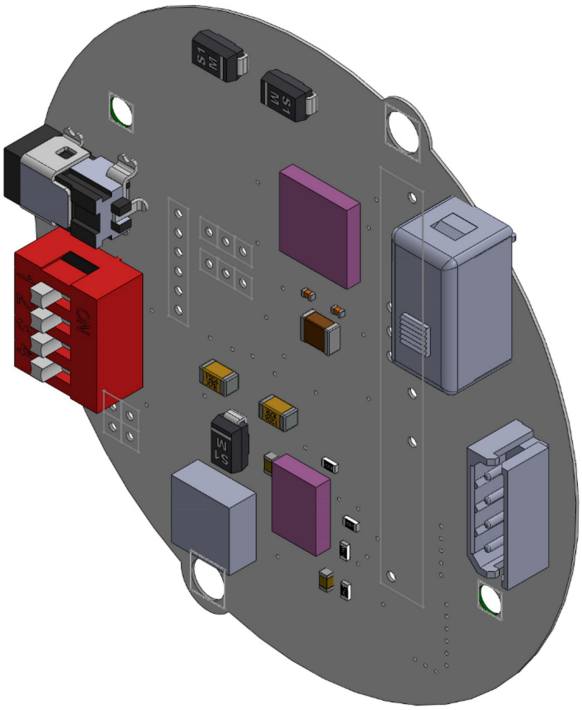


ASSEMBLY DRAWING



COMPOSITE

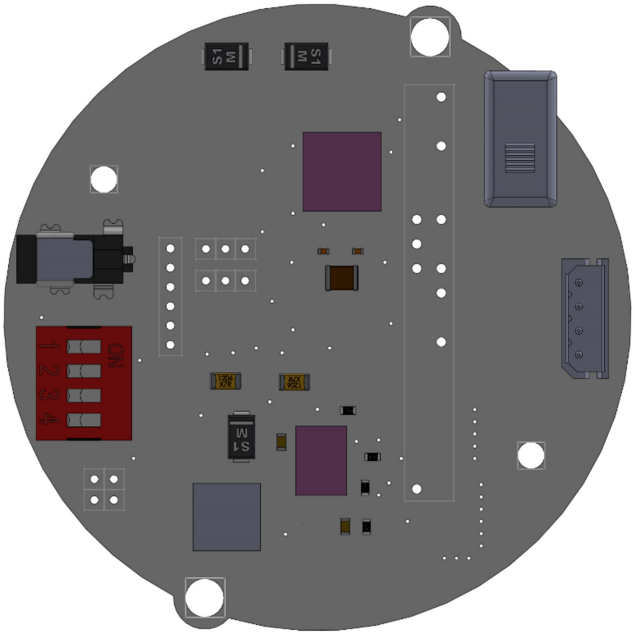
CAD MODELLING



The PADS layout file designed for the PCB is exported in CAM planes to generate GERBER files for PCB Fabrication. The same Layout File can be exported in .iso format supported in CircuitWorks, which is an extension available in SolidWorks 2017. CircuitWorks allows user to view the layout design into actual 3D phase and also features editable components library which can be updated by manually searching for the part files of each component online and adding it in the same. Once all components are added, the build command generates and assembly file with available components mounted on board as shown in figure above. The above process gives a very near perfect idea about the utility board before its Fabrication and assembly.

Almost all the components (SMD and Through Hole) are mounted on top side to maintain isolation with motors at the bottom. The utility board is designed to sustain permissible current and voltage ratings provided by manufacturers, considering all safe, positive tolerance values. The components selection is based on ratings, package availability and power Endurance.

The placement of each device is done to ensure compatibility with bot mechanics; keeping accessible terminals exposed. Thermal areas and isolations are provided wherever required for heat dissipation.



REFERENCES

Kindly refer to /PCBfiles folder for Datasheets, Schematics and Layout Docs and CAD drawings, design logic, component values/quantity, package types, Drill Holes, Board Outline, Components datasheet for PCB Layout Guidelines, Fabricator details, and other relevant information.

How to Fabricate Spherical Bot

Refer to the Introduction of the spherical Bot to understand the various parts. Each part, such as Hull, Yoke, Pendulum, comprises various components. Following is the list of Bill of materials.

- The spherical bot has significant 3D printed parts. For 3D printing, please refer to /Design/STL files. Provide the STL files to the fabricator. You can use software Flashprint by flashforge to get the estimate of the time taken ~approx quotation.
- For fabricating deadweight, provide the mechanical workshop with the drawing that would be used for Lathe machining.
- PCB fabrication, please prefer PCB POWER Gandhinagar Gujrat. Other leading international fabricators include JLCPCB.

Design Fabrication and Prototyping

Design

- Spherical Bot design is developed in SOLIDWORKS 2017.
- All the CAD files are available in `/Design/Spherical Bot CAD Part and assembly files.`
- Check for `Sphericalbot_March_2020.Sldasm`
- CAD Drawing for all parts are available at `/Design/Drawing files`
- STL files for prototyping are available in `/Design/STL files.`

Fabrication and Prototyping

Indus 3D printers – Prasad Kelaskar – 8291395105
Email ID sales@indus3dprint.com

- The spherical bot prototype was fabricated using FDM 3D printers using PLA material with high-resolution default ABS OFF white color.

Hull Fabrication

- Small spherical bot - Hull fabrication was carried out with INDUS 3D printers
  Contact – Prasad Kelaskar 8291395105 sales@indus3dprint.com
  Karan Shah 7208175461 Email ID karan@nexmath.com
- Quotations for small spherical bot hull are available and provided in the `/Design/Fabrication/Quotation`

The CAD model drawing sheets are available for reference here

Bill of Materials

Sr. No.	Component	Quantity	Description	Link
1.	Upper Yoke	1	3D Printed	http://www.indus3dprinters.com/ FDM ABS Default white 0.1 resolution 100% infill
2.	Lower Yoke			
3.	IMU mount			
4.	Deadweight mount			
5.	Pendulum	2		
6.	Hull Mount	2		
7.	Vicon Marker Mount	2		
8.	Hull	1 pair	Plastic 100mm	Transparent Christmass Balls
9.	Pendulum Brass bob	2	Brass Machining	Any Machine shop with Lathe.
10.	Deadweight	1		
11.	Lipo Batteries Model KP-053450	2	3.7v 1500mAh	https://www.electronicscomp.com/3.7v-1500mah-lipo-battery
12.	Servo motor	2	TowerProSG90	www.Robu.in
13.	N20 DC motor	2	Polulu #2386 Mircomotor	https://www.pololu.com/category/141/micro-metal-gearmotors-with-extended-motor-shafts
14.	Magnetic encoder pair kit	1	Encoder 12 CPR	https://www.pololu.com/product/3081
15.	IMU	1	Bosch 9 axis IMU	https://www.mgsuperlabs.com/featured-brands/adafruit/168/adafruit-9-dof-absolute-orientation-imu-fusion-breakout-bno055
16.	Fisheye camera	1	220 FOV	https://www.evelta.com/
17.	M3 x 18mm Bolt	2		American Nuts and Bolts, Lamington
18.	M2 x 16mm	2		
19.	M2.5 x 6mm	4		Element14.com
20.	M3 x 6 mm	12		
21.	Heat insert M3x4mm	16		Robu.in
22.	Heat insert M2.5x6mm	2		American Nuts and Bolts, Lamington
23.	Spacer M3 x 5mm	2	Brass spacer	Mouser.in
24.	2 pin JST PH 2.0mm Through Hole Header Vertical Straight Top Entry	2	Battery connector male	https://www.sunrom.com/
25.	2 pin JST PH 2.0mm One side Female 30cm	2	Battery connector female	

Bill of Material for PCB Fabrication

Part Lister output for Board1
Generated on Monday, February 24, 2020

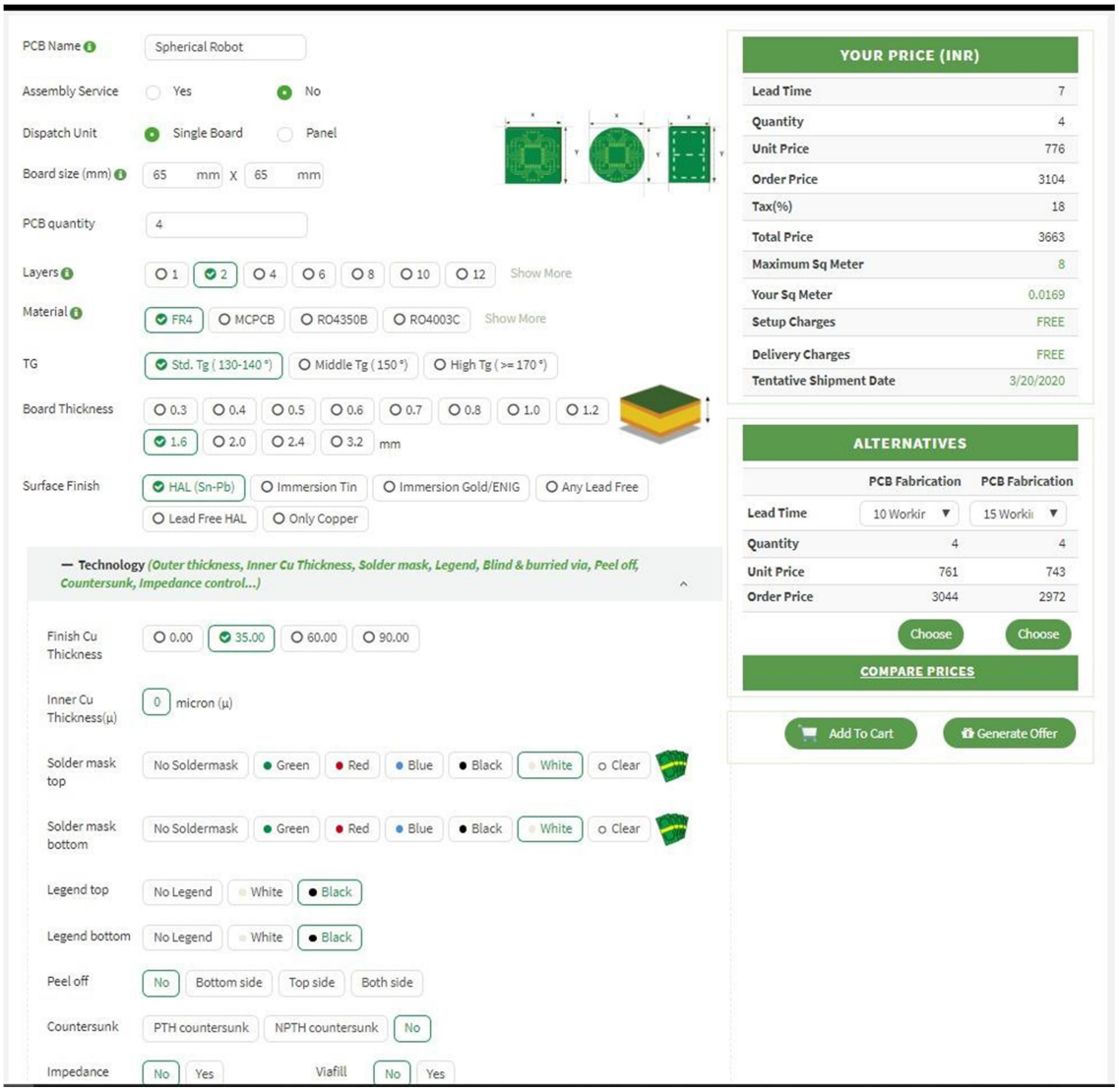
#	REFDES	PKG_TYPE	VALUE	QTY
1	C6,C8	0402,0402	0.1uF,0.1uF	2
2	R4-R6	0603,0603,0603	100K,100K,100K	3
3	C5	0603	100nF	1
4	C2	1210	10uF	1
5	C7	1206	10uF 50V	1
6	C4	0603	150pF	1
7	L1	4R7-7MM	15uH	1
8	R2	0603	210K	1
9	C3	1206	22uF 6.3V	1
10	R1	0603	24.9K	1
11	R3	0603	40.2K	1
12	U1	MP1584EN-LF-Z	-	1
13	U3	TB6612FNG-SSOP24	-	1
14	D1-D2	SMA-DO214AC	40V 3A	2
15	D3	SMA-DO214AC	SS34	1
16	J1	PJ-032H-SMT-TR	-	1
17	S1	4POS-DIP-SW	-	1
18	S2	25136N B	-	1
19	P1	Mini-SPOX 5264	M/F	1
20	H1-H60	Header-Male-2.54	-	2x40

I have labelled all the ref des for the given component.

#7 L1 desolder 4R7 inductor from given breakout board.

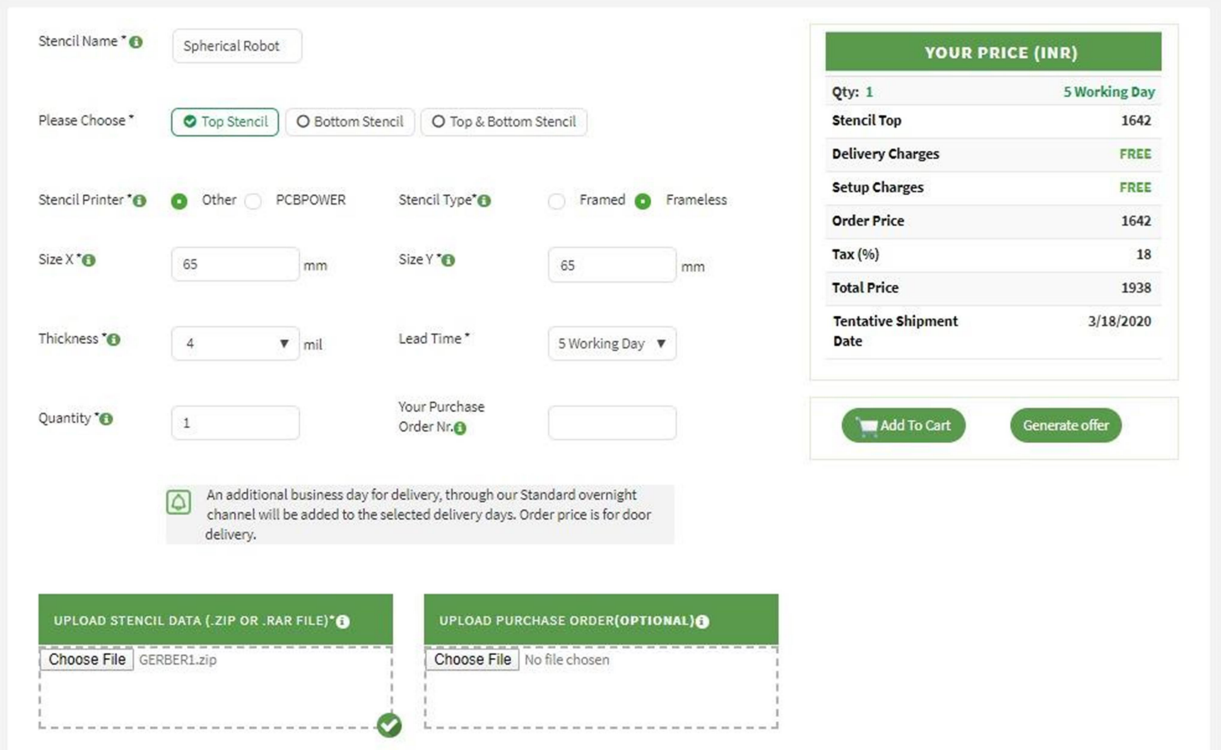
#20 H1-H60 do not solder leave it as it is

How to order PCB for Fabrication



The above image shows the details of how to place an order for PCB fabrication at PCB POWER Gujrat. The PCB files can be found in `/PCB files.` The Gerber file for Fabrication can be found `at /PCB files/Gerber.zip`

How to order PCB Stencil



Stencil is used for soldering the SMD components and apply the solder paste. PCB soldering person will ask this.

Amruta Enterprises Bhandup – 8286667494

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SIMULATION

Spherical Bot is simulated in MATLAB Multibody simulation to understand its nonlinear dynamics and its motion.

- For simulation CAD – mesh files (.STL) files are imported from solidworks.
- Open MATLAB. Go to `/Simulation/Matlab Multibody simulation/Simulink basics/self_gen_sp/`
- Run `sp_new_Datafile.m` This file consists of all simulation parameters for Spherical bot simulation. For eg. The mass properties, Inertia matrix etc.
- Run Spherical_bot_working.slx Simulink file. Here you could see all Simulink blocks connected.
- Press CTRL+D to build and CTRL+T to run simulation.
- Make sure you add `simulink_basics` folder and sub folder to the path of MATLAB files.
- Spherical bot uses `multibody_contact_forces` library.

SOFTWARE

Spherical robot Hardware interfacing

- ACTUATORS DC motor and Servo

  The spherical bot has Raspberry Pi zero W on PCB board. The sensors and actuators need to be interfaced via RPi. For DC Motor and servo control PiGPio library is used. Please find relevant code at `/Software/Control.`

1. `For testing servo motor use following command.`
   a. `$ python3 servo_test.py`
2. `For testing DC motor use following command.`
   a) `$ python3 pi_mot.py`

- Inertial Measurement Unit BNO055

  The system orientation feedback is sensed by IMU (Inertial Measurement Unit) `BNO055` Bosch IMU 9 DOF adafruit breakout board. The sensor is interfaced with RPi via I2C communication protocol in Master slave configuration with RPi.

1. To interface `BNO055` we need to assign software I2C to the SDA SCL pins. RPi directly does not communicate via i2c with `BNO055`
2. After software i2c it can be interfaced via PiGPiO library on SDA and SCL pins.
   a) $ python3 imu_test.py
3. Similarly, ROS package also can be used found here

- Fisheye camera

1. Fisheye camera is interfaced with Raspberry Pi via FPC connector cable. Opencv is used to access the image/video stream of the camera.
2. More over to stream the video in IP_Addresss Flask is used.
3. Please check `/Software/Vision`

```
$ cd small_spherical_bot
$ python3 stream.py
```

- Teleoperation of spherical bot
  1. Check /Software/Teleoperation/SphericalBot_teleop.apk to install android app on phone.
  2. To develop android app MIT app inventor is used. Use sphero.aia on MIT app to edit