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Mobile Surveillance Spheroid Robot with Static Equilibrium Camera, Leaping Mechanism and KLTalgorithm based Detection with Tracking

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ABSTRACT

The project is based on complex design yet simple implementation of robotics, analog electronics, image processing, mechanics and circuit making. Project consists of rolling ball (receiver part) and a controlling unit (transmitter part). The robotic ball consist of auto stabilized camera, leaping and rolling mechanism and the transmitter part houses analog sticks, buttons, processor. Robotic ball wirelessly with the help of RF trans-receiver module present at the controlling unit. The locomotion of the ball, camera and jumping is controlled with the help of joysticks and switches present at the controlling unit. It also contains an onboard processor which processes the real time feed coming from the receiver camera for face detecting and tracking.

Keywords: Beagleboard xM, Piccolo C2000 Launchpad, APC-220, Spheroid, Autodesk Inventor, IMU GY 80+, Jumping Mechanism, Energia, Arduino IDE, Facedetection, Auto-Stabilized Camera, Locomotion, Surveillance, Gear system.

1. INTRODUCTION

The idea of the project came to our senses after watching the horrifying tragedies in fire disasters, terrorist attacks and earthquakes etc. These incidents gave us an idea to build a robot resembling a ball type structure that can alert the authorities, help in rescue operations and also provide knowledge about the circumstances present at that location. We call our project as "RAVHEN – Reconnaissance Advanced Vehicle for Hostile Environment", significant research is carried by Boston Dynamics (Jump Flea)[1] and Recon Robotics (Recon Scout) [2] which actually inspired us. So the main goal of our project was to develop a robot that has all the features of other competitors and save as many lives as possible in the worst case scenario, keeping in mind the cost and efficiency of the robot.

1.1. Technical Background

RAVHEN comprises of various functions such as auto-stabilized camera, jumping mechanism, rolling mechanism, inbuilt face detection and various sensors such as IMU (Inertial Measurement Unit)[24] and temperature sensor. All these functions constitutes very important role in real time scenario such as when an hurdle has to be crossed then jumping mechanism would help the robot to overcome it, auto stabilization helps the robot to focus on a particular image even when the robot is undergoing jerks while rolling in rough terrain.The robot has inbuilt real-time multiple face detection ability. Sensors help the robot to acquire data from the environment thus making it work more efficiently, temperature sensor helps the robot to

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determine the accurate temperatures of the environment which helps in cases like fire disasters also IMU provides the orientation the robot which further helps in providing auto stabilization for the camera.

1.2. Proposed Solution

Presently various robots similar to RAVHEN have the ability to jump, roll and very few robots have ability for face detection but none of them has the ability to stabilize their camera as well as their sizes are too large. When the hurdles are encountered during their motion on the rough terrain then their camera destabilizes. RAVHEN is specially designed for surveillance and rescue missions. Due to its multiple face detection technique, it can easily detect the needy where rescue team can't reach and thus notifying the squad becomes easier. This feature provides an edge to our robot over the other conventional robots. Also, our robot can be controlled accurately over a distance of 1km; this range is very large as compared to other robots available today. Due to RAVHEN's small size and weight it provides the flair to move into remote locations such as debris and small pipes thus providing extra advantage over other robots.

1.3. Organization of the Paper

The paper is organized as follows: Section II constitutes the design methodology of RAVHEN – both transmitter and receiver. Each of the blocks has a detailed description in section III with its implementation. Section IV contains the results of the experiments performed to show the performance and analysis of the various blocks of the system. Section V has the concluding remarks of the project.

2. PROPOSED SOLUTION

Fig 1 and Fig 2 shows the two major parts of RAVHEN.

First figure determines the controlling unit for the ball. Here, controller deduces the input from analog sticks and switches. This data is processed and sent to the receiver side with the help of RF transmitter. Controlling unit or the transmitter also contains the provision for face detection with the help of microcomputer.

Fig. 2 constitutes the receiver part of the RAVHEN, here the processed data is received by the RF receiver and sent to controller for controlling the locomotion of ball, camera and jumping mechanism. Also here camera sends the real time images to the transmitter part either wirelessly or wired.

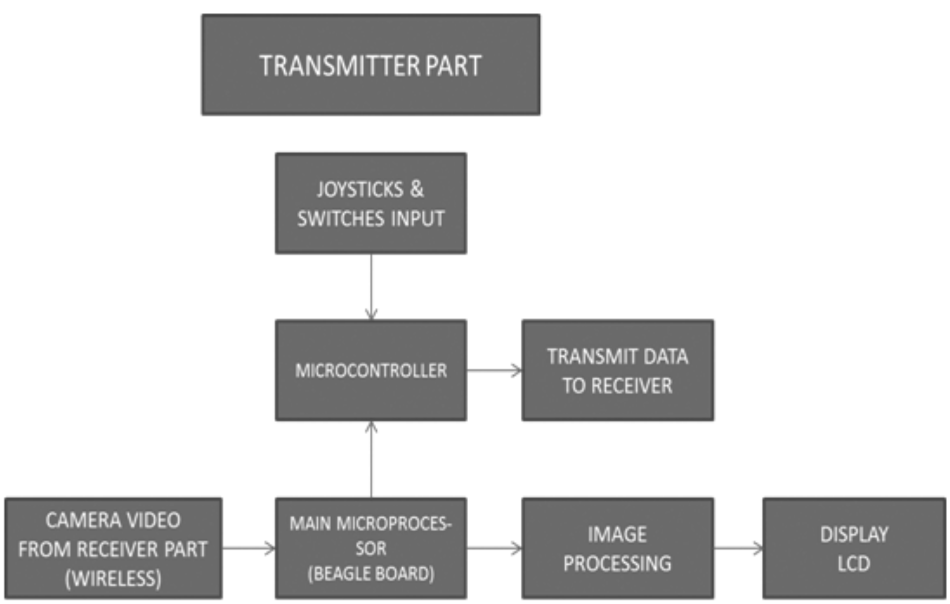

Figure 1: Controller Transmitter

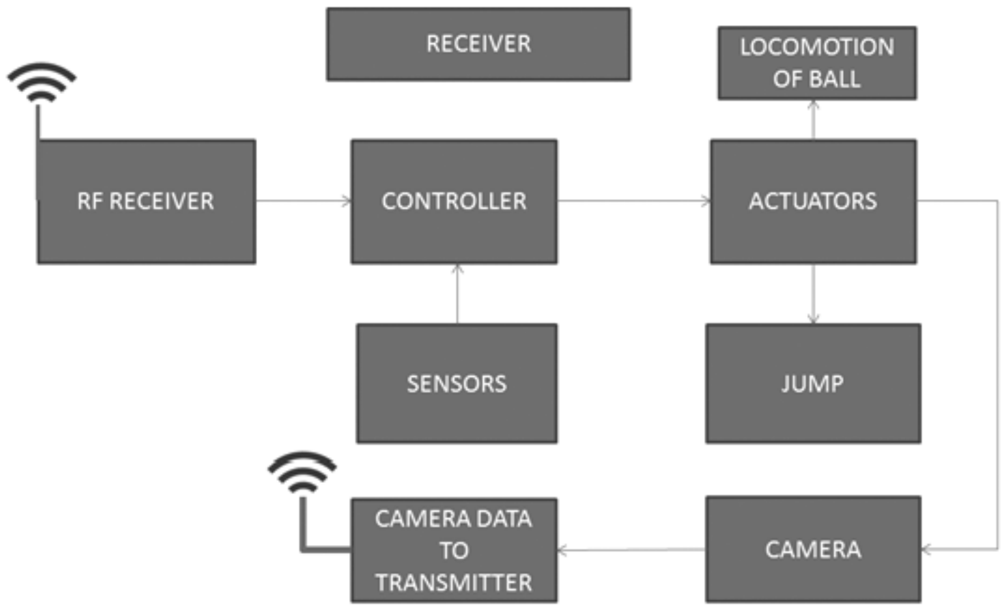

Figure 2: Robotic Ball

3. IMPLEMENTATION

3.1. Hardware Implementation

RAVHEN hardware comprises of 2 major parts Circuit Designing and Mechanical structure as shown in Fig. 3 and Fig. 4 respectively.

(i) Circuit Implementation & Working

In this we have divided our circuit in two parts i.e. the transmitter and receiver.

3.1.1. Transmitter

Fig. 3(a) shows the block diagram and working of transmitter. Transmitter circuit works as a controlling unit which is used to control the receiver ball. The whole chassis of the transmitter is made from Laser cut Acrylic for better stability and control as shown in Fig. 6(b). Transmitter circuit comprises of Analog Stick, digital input buttons, C2000 Piccolo Launchpad, Beagle Board xM, APC 220-Module and some peripheral connected to Beagle Board xM such as Monitor/LCD, Keyboard-Mouse, and Camera etc.

C2000 is a 32 bit microcontroller providing real time data processing. It is acting as a main brain which processes the data coming from the analog sticks and digital buttons. Microcontroller then sends the data to the receiver with the help of wireless trans-receiver APC 220 Module. APC-220 is working on 450MHz frequency and has a range of up to 1km. Transmitter circuit also consists of Beagle Board xM which is currently running on Linux Shell. It has an inbuilt DSP processor which accelerates the image processing. Its main application is to provide the face detection [23] of a person. Real time feed is provided by the wireless or wired camera which is connected directly to Beagle Board xM. With the help of OPENCV library [20, 21] inside Beagle Board xM the data coming from the Camera get processed in real time and face detection is accomplished. The detected images are then sent to the Monitor/LCD with the help HDMI cable as shown in figure 3(a). The results of image detection are shown in Fig. 6(e) & Fig. 6(f).

3.1.2. Receiver

Fig. 3(b) shows the block diagram of receiver. Receiver part houses the circuits of Arduino Micro microcontroller, LM35 (temperature sensor), GY80+ IMU(inertial measurement Unit), L293D motor driver, LM7805 and LM7809 voltage regulators, XL6009 boost converter, TP4056, 2 DC motor actuators, 2 Servo

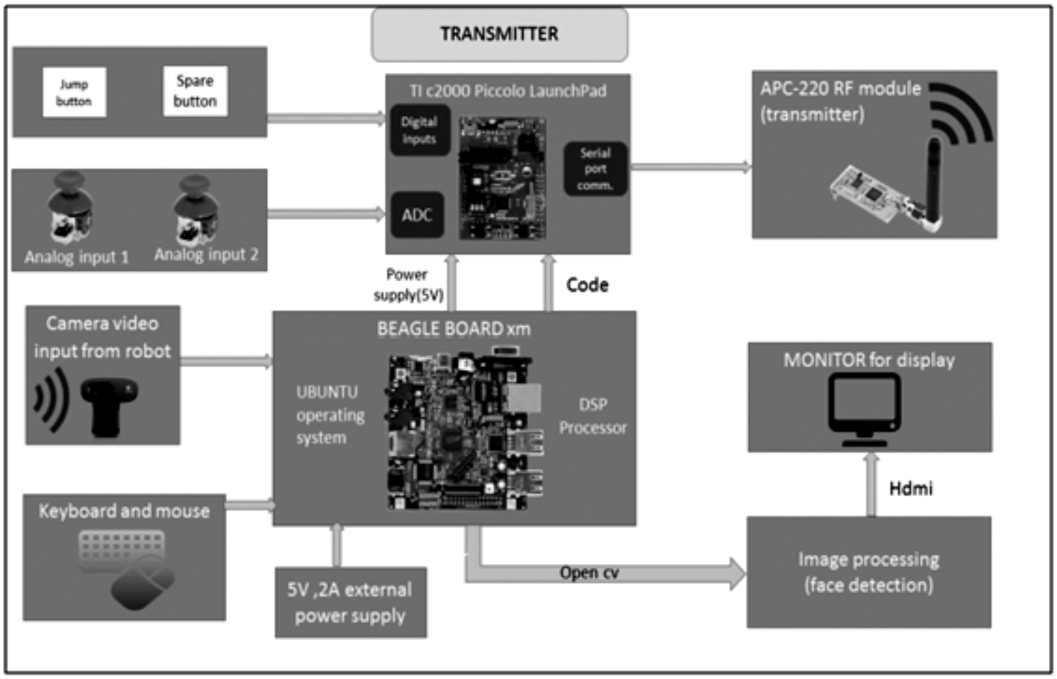

Figure 3(a): Transmitter Block Diagram

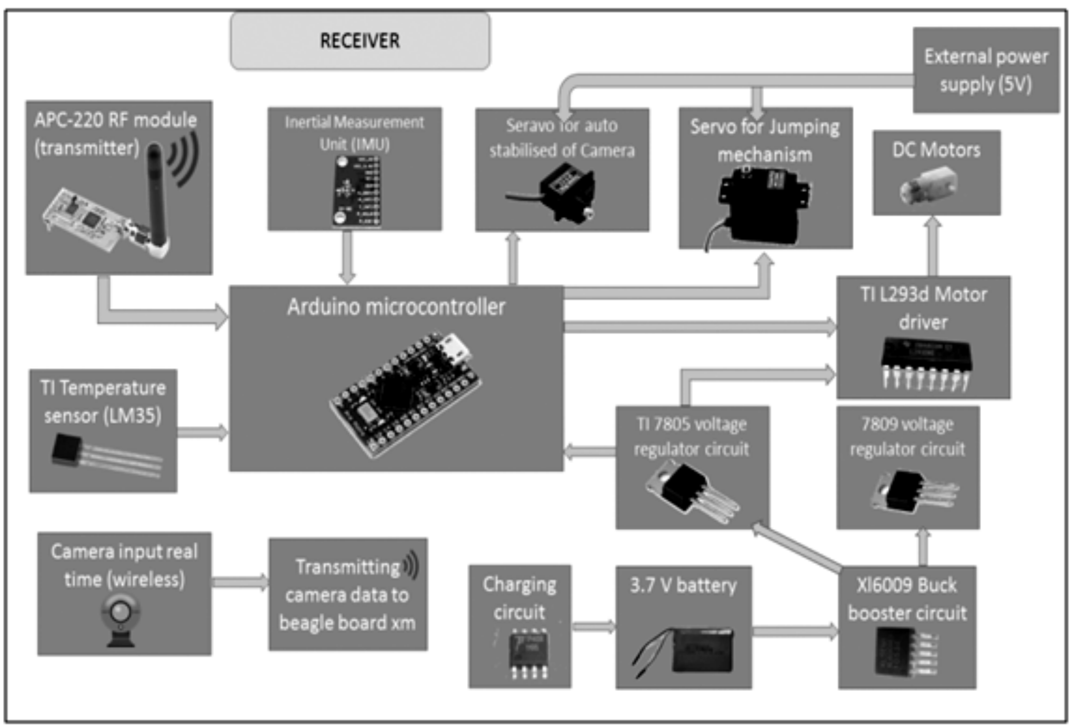

Figure 3(b): Receiver Block Diagram

motors and APC 220 module. The whole circuit is working with the help of 3.3V battery, only external power of 5V and supplied to servo motor and 9V to motor driver externally.

Receiver circuit comprises of 2 parts i.e. the charging circuit and main circuit. The method for controlling the working of the two circuits depends upon the **DPDT** switch, when the switch is turned **ON** the circuit works as a charging circuit with the help of TP4056 charging chip and if the switch is turned **OFF** then the voltage from the 3.3V is converted to 12Volts with the help of Xl6009 boost converter. LM7805 and LM7809 provide constant voltages of 5V and 9V respectively. 5V are then provided to microcontroller and

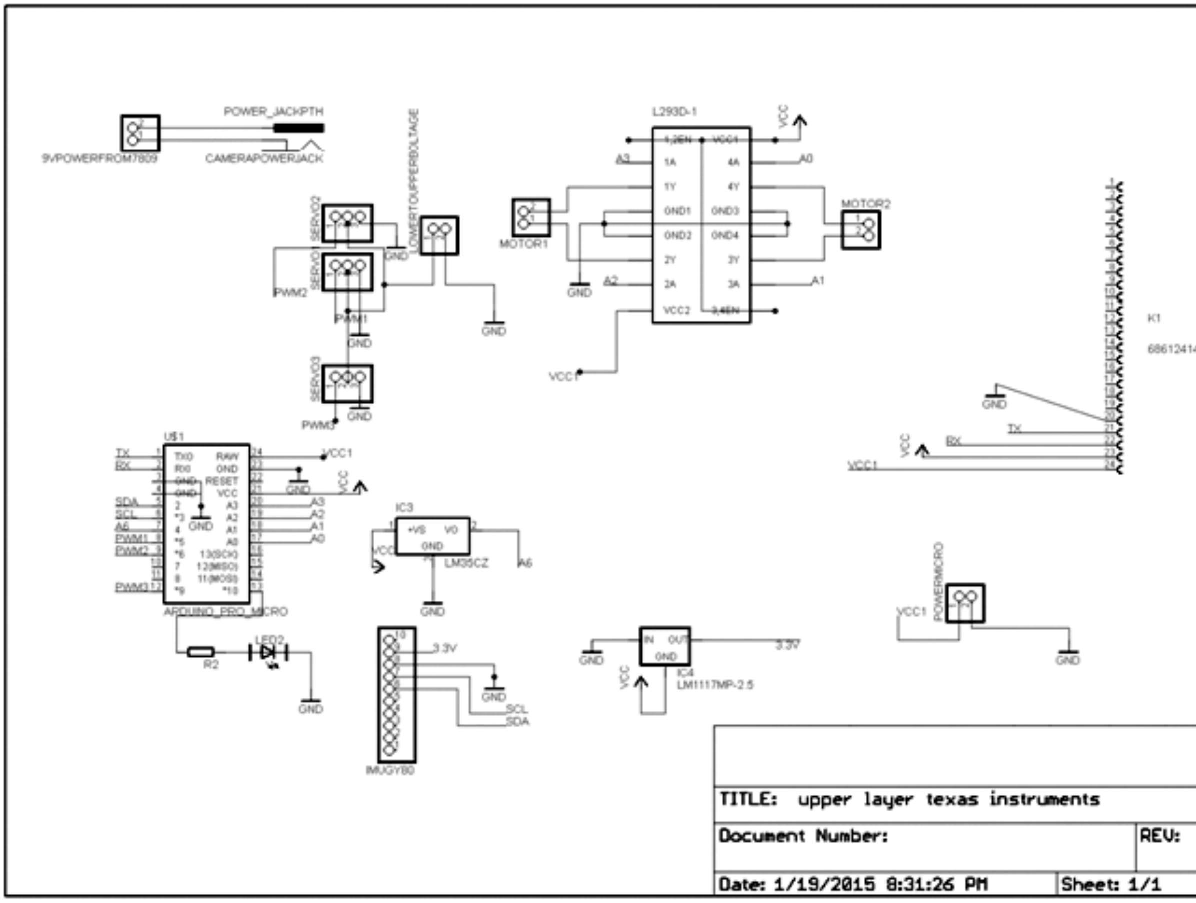

Figure 3(c): Receiver upper layer circuit

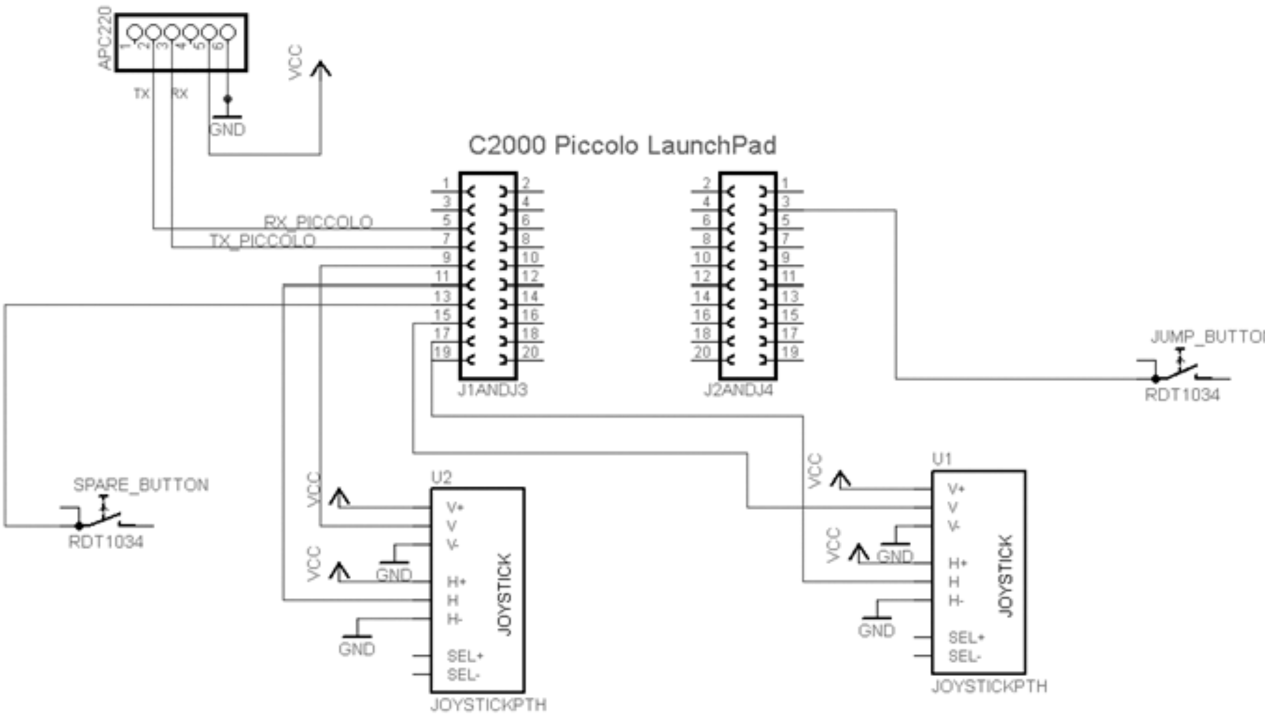

Figure 3(d): Transmitter Circuit

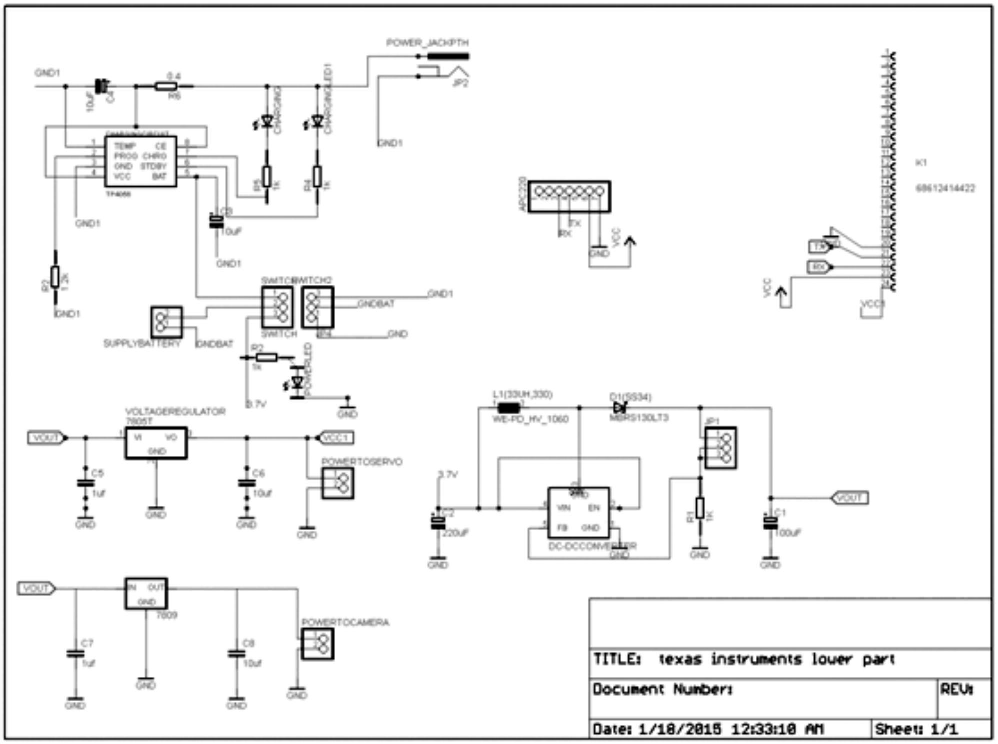

Figure 3(e): Receiver lower layer circuit

9V volts are provided to provisional wireless camera.L293D is an H bridge motor driver which is used here for controlling the DC motors connected the outer hemispherical structure of ball as shown in Fig. 4(a). LM35 is low power and high precision temperature sensor which is being used to attain the accurate temperature of the environment.

The data coming from the control unit is received by the APC220 module and sends the data to the microcontroller. Here microcontroller processes these values and provides constraints to it. After the data is processed; it then sends the signals to the DC motors to control the locomotion of the ball accordingly with the movement of analog sticks at the transmitter side. Microcontroller also controls the jumping mechanism of the robot with the help of servo motor as shown in Fig. 3(b). This servo motor is attached to the spring mechanism of the robot as shown in Fig. 4(b). Another servo is attached to the central part of ball so that it can provide the auto stabilization of the Camera as shown in Fig. 4(b). IMU GY80+ is working as a feedback mechanism, it determines the orientation of the robot and then the microcontroller processes the values. These values are then used as correction error for the servo motor which eventually controls the auto stabilization of the Camera.

(ii) Mechanical Designing:

The Robot consists of three parts - Two Hemispherical Structures and a Centre cylindrical piece and together forms a spheroidal structure. The two outer hemispheres are made up of Polycarbonate material and act as wheels to the spheroid and provide locomotion to the system. This allows us to control the robot to move and spin bidirectional on its own axis. Each of the hemispheres is connected to the respective DC motor of the center piece via an axle. Also, the hemispherical structure is 15 cm in diameter and thus due to its shape, the structure makes it more robust against other environment. The center cylindrical piece consists of jumping mechanism[19], the anti-static circuit plate and actuator for auto-stabilized camera as shown in the Fig. 4(a).

For the jumping system to perform successfully, storage of spring potential energy was required to lift the entire system to a certain height[18]. So, for this mechanism to work, a combination of rack gear and

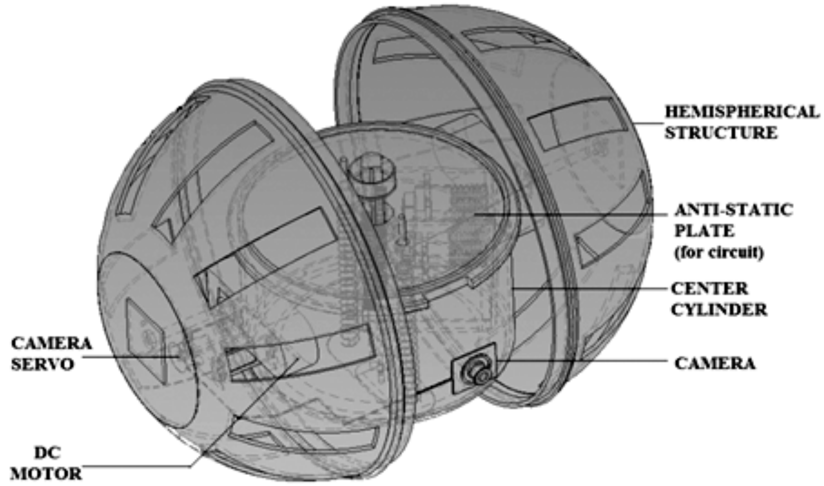

Figure 4(a): Overall Structure of Ball

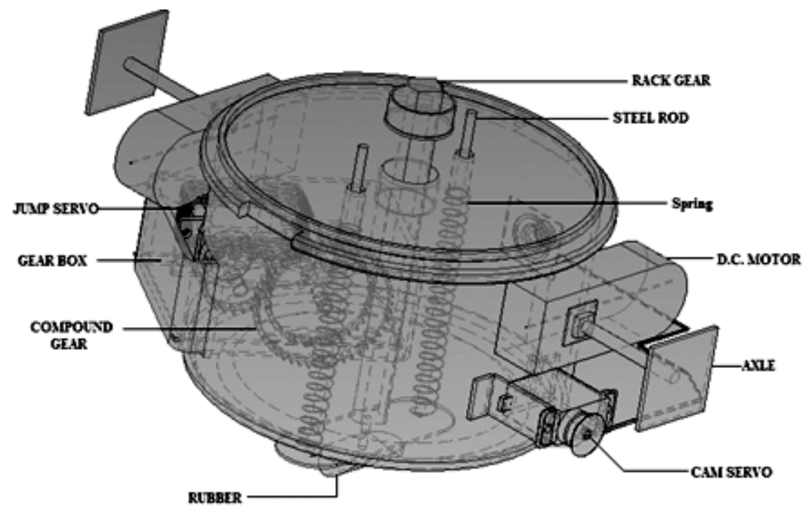

Figure 4(b): Detailed Structure of Centre Cylinder

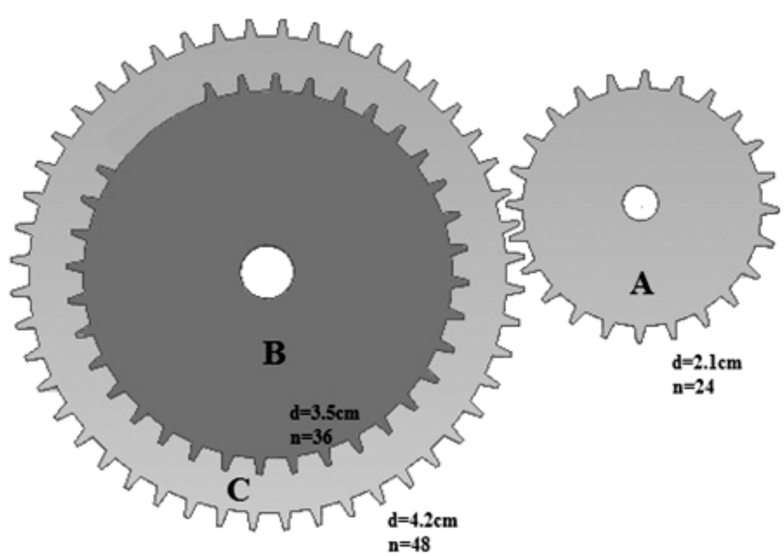

Figure 4(c): Compound Gear System

couple of compression springs were placed in parallel as shown in Fig. 4(d). Lifting the system of about 700gm was not enough even for a 10kg-m metal -geared servo motor. The system wasn't able to rise to the desired height. Thus, the increase in output torque for the system was necessary. Due to this, a gear box was developed so as to compress the springs even further.

Gears are not only used to transfer power but they can also adjust the mechanical advantage of a system. There are cases when motor itself is not powerful enough for an application. So, to increase the torque in our mechanism, a compound gear system was required as shown in Fig 4(b).

For the required level of jumping, the gears are to be placed in an order so as to increase the torque of the system. The increase in torque leads to decrease in angular velocity. The set of spur gears -2.1 cm, 3.5 cm and 4.2 cm in diameter were taken into accordance in the gear system, each having same pitch but different number of teeth. The smallest gear is connected to the servo at the axis and transfers the power to the gear with 4.2cm radius having 48 teeth as shown in Fig. 4(c). This is attached to another gear of 3.5 cm diameter with 36 teeth in parallel which acts a medium to transfer power to the rack gear. The gear ratio of the compound gear system is thus 2.5 which increase the output torque to 26.67 (kg-m). This increases the torque 2.5 times and decreases the angular velocity with the same ratio. This enables one to control the mechanism more precisely.

Thus when the power is supplied to the metal-geared servo motor that is attached to Gear A, the mechanical power is transmitted to the rack gear via the compound gear system. The vertical motion of the rack gear acts as a prismatic joint and enables the rack gear to move vertically and thus the springs are compressed [10, 16]. After a certain degree of rotation, the rack gear is released from the compound gear system due to absence of teeth on a certain arc of spur gear B.

Thus when the system is released, the rubber piece attached to the bottom of the system hits the ground. The spring potential energy is thus converted to the kinetic energy and finally to the potential energy of the spheroid.

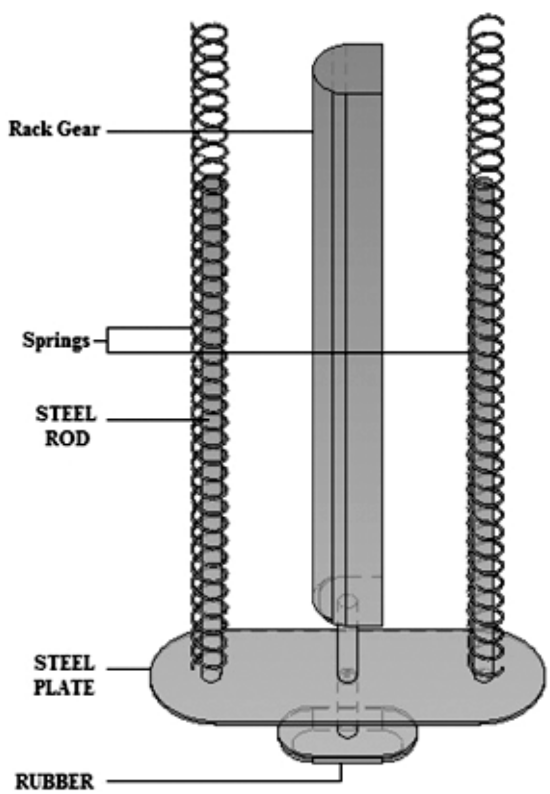

Figure 4(d): Spring-Rack Gear System

On Calculating, we have

$$h = \frac{25\tau_0^2 R_b^2}{8mgk}$$

where

h	$\rightarrow$	*Maximum height of jump*
τ_o	$\rightarrow$	*Output Torque of the servo motor*
R_b	$\rightarrow$	*Radius of the Gear B*
m	$\rightarrow$	*Mass of the robot*
g	$\rightarrow$	*Acceleration due to gravity*
k	$\rightarrow$	*Spring Constant*

3.2. Software Implementation

This section discusses the software implementation of the RAVHEN. The Hardware section of the RAVHEN robot was developed in AUTODESK™ INVENTOR 2014 3D CAD Software while the circuits are designed using EAGLE™ CAD Software. The Fig. 5(a) shows the flow diagram of transmitter circuit. The program of the transmitter circuit is developed in Energia™software to control the locomotion, jumping and auto stabilization of receiver ball. As you can see in the Fig. 6(b), the analog sticks and buttons are providing analog values and digital values respectively to the microcontroller C2000 Piccolo Launchpad. Microcontroller C2000 has inbuilt 12 bit ADC converter which helps it to read the values of analog sticks from 0-4095 then the values are mapped from 0-255 as shown in Fig. 6(c) to make it legible for the receiver. It also reads the digital Inputs in form of 0 and 1 as shown in Fig. 6(c).All the data is encoded and transmitted to receiver using an acknowledgement bit to prevent data loss and maintain 95% transmission efficiency.

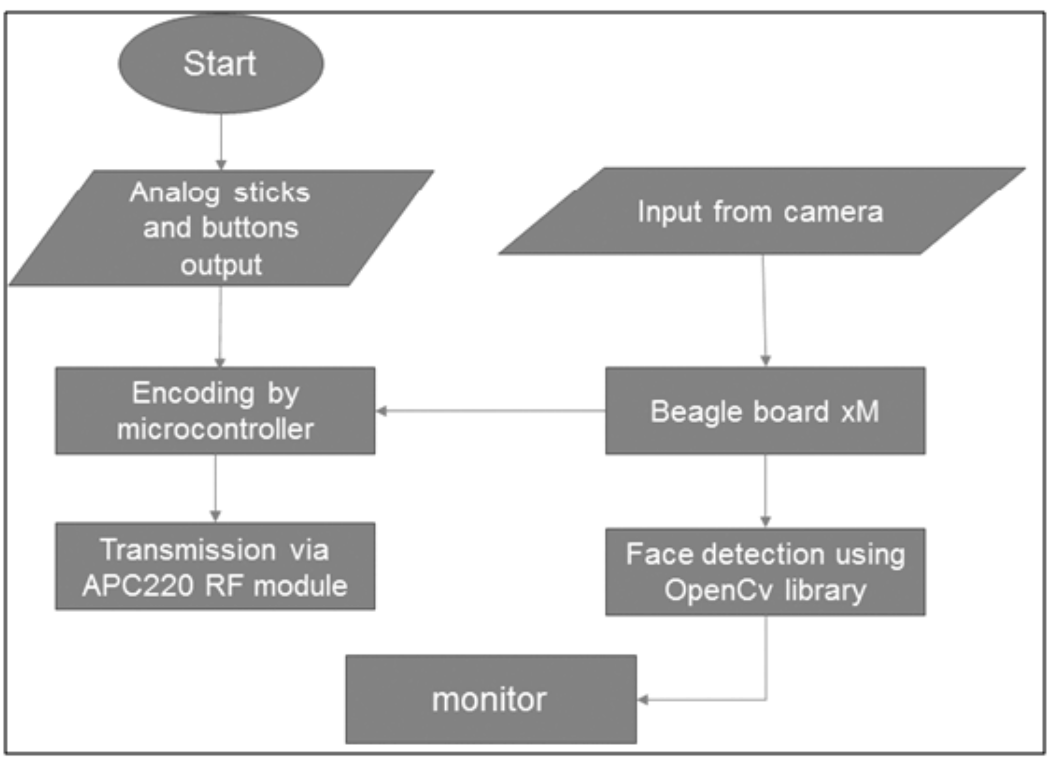

Figure 5(a): Transmitter Flow Diagram

For the face detection purpose, the powerful BeagleboardxM board is built with a Linux Shell of Ubuntu 14.04 console distribution.The program for detection is carefully written in PYTHON language and positive results were obtained.

At the receiver side, second flowchart i.e. Fig. 5(b) explains the complete algorithm of receiver ball. The whole algorithm is written in Arduino IDE.Incoming data from transmitter is stored in an array and then decoded to get the original data. Data from analog stick 1 controls dc motors, while data from analog stick 2 controls servo motor for camera movement. The forward and backward movement of motors is decided by comparing data from analog stick to a threshold (approx. 190).

$$\textit{If}\,(\textit{Data} > \textit{Threhold}) \rightarrow \textit{Move Forward}$$
$$\textit{Else If}\,(\textit{Data} < \textit{Threshold}) \rightarrow \textit{Move Backward}$$

Similarly, left and right movement of spheroid is decided. The jump button controls servo for jumping mechanism. The servo is made to rotate until rack gear is free, thus releasing springs in an instant [17, 18, 19].

IMU provides analog data to microcontroller using I^2C (Inter-Integrated circuit) communication [7, 8, 24]. I^2C is a multi-master multi-slave communication to which multiple devices communicates using only two pins or connection. Here microcontroller is master and IMU is slave. Data from IMU is processed to get angles about three axis using a complimentary (high pass plus low pass) filter [24]. Complementary filter [24] is as follows:

$$x_{angle} = \left(0.96 \times \left(x_{angle} + \left[DPS[0]_{gyro} \times 0.02\right]\right) + 0.04 \times x_{acc}\right)$$

$$y_{angle} = \left(0.96 \times \left(y_{angle} + \left[DPS[1]_{gyro} \times 0.02\right]\right) + 0.04 \times y_{acc}\right)$$

The above result calculates the position of camera as shown in figure 6(d) and stores it in a memory location (say current position). Error signal is generated by comparing pervious position and current position. The servo motor is rotated accordingly to achieve auto stabilization.

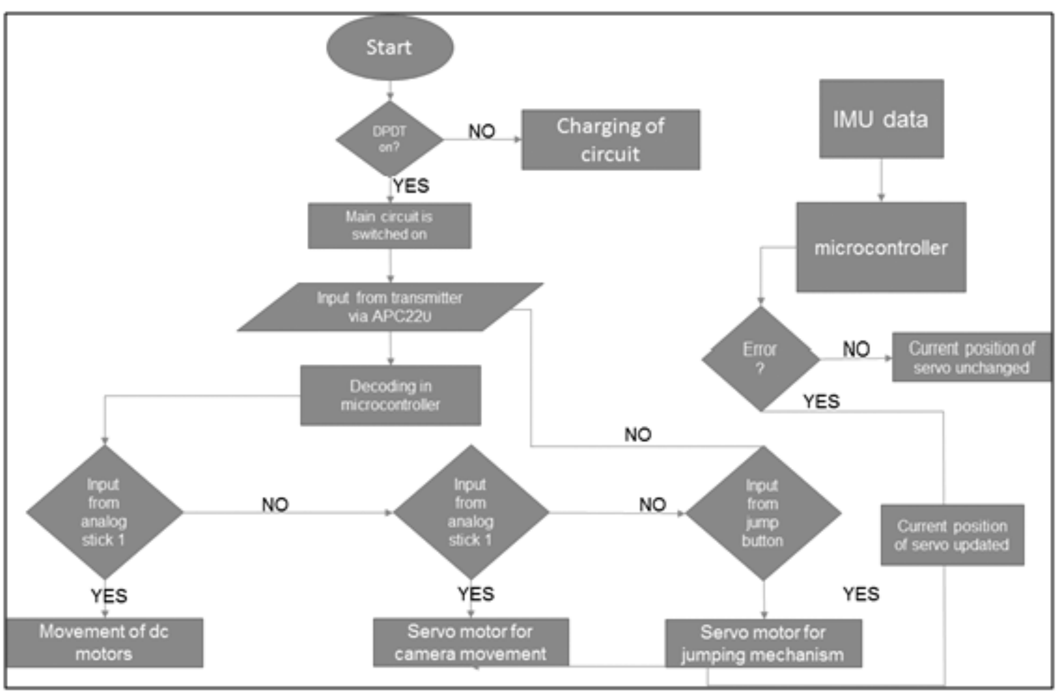

Figure 5(b): Receiver flow diagram

$$error = current_{position} - previous_{position}$$
$$new_{position} = previous_{position} - error$$
$$servo_{camera} . write(new_{position})$$
$$previous_{position} = current_{position}$$

Also the temperature sensor LM35 provides the analog values to microcontroller. By processing these values in microcontroller we determine the accurate the temperature of the environment as shown in figure 6(d).

4. RESULTS

This section visualizes the results obtained at the end of every section. The complete Spheroid was setup as clearly shown in Fig. 6(a). Also, the transmitter/controller is presented in Fig. 6(b).

Figure 6(a): Receiver Part full view

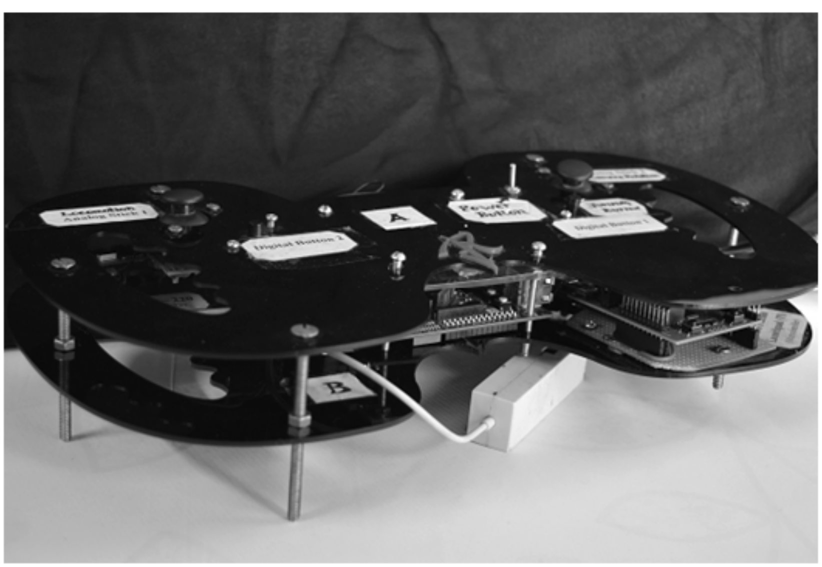

Figure 6(b): Transmitter full view

As we discussed in the earlier sections, the data is sent from the transmitter to the receiver and thus the locomotion and camera input output values can be seen in Fig. 6(c). Also, it controls the robot to jump whenever desired. As the Fig. 6(c) first column shows, the value of the function 'motor_l_r' increases to 254, the robot starts moving in forward direction.

Also, the room temperature and IMU Reading was calculated.The room temperature was found to be 24°C. The IMU readings were observed in real time and sent to as a feedback as to control the camera *servo*. Auto-stabilization was clearly observed during the jerks. Fig 6(d) shows, the change IMU readings during the change in orientation of the robot.

```
---> motor_l_r=169; motor_f_b=169; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=168; motor_f_b=170; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=167; motor_f_b=170; camera_l_r=176; camera_f_b=165; jump=0 <---
---> motor_l_r=168; motor_f_b=170; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=168; motor_f_b=170; camera_l_r=178; camera_f_b=165; jump=0 <---
---> motor_l_r=167; motor_f_b=170; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=168; motor_f_b=170; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=169; motor_f_b=170; camera_l_r=178; camera_f_b=166; jump=0 <---
---> motor_l_r=167; motor_f_b=170; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=168; motor_f_b=171; camera_l_r=178; camera_f_b=166; jump=0 <---
---> motor_l_r=168; motor_f_b=170; camera_l_r=177; camera_f_b=165; jump=0 <---
---> motor_l_r=168; motor_f_b=169; camera_l_r=176; camera_f_b=164; jump=0 <---
---> motor_l_r=168; motor_f_b=170; camera_l_r=177; camera_f_b=165; jump=0 <---
---> motor_l_r=177; motor_f_b=169; camera_l_r=178; camera_f_b=166; jump=0 <---
---> motor_l_r=192; motor_f_b=169; camera_l_r=177; camera_f_b=166; jump=0 <---
---> motor_l_r=215; motor_f_b=169; camera_l_r=178; camera_f_b=167; jump=0 <---
---> motor_l_r=241; motor_f_b=168; camera_l_r=176; camera_f_b=165; jump=0 <---
---> motor_l_r=254; motor_f_b=168; camera_l_r=176; camera_f_b=166; jump=0 <---
---> motor_l_r=254; motor_f_b=168; camera_l_r=177; camera_f_b=167; jump=0 <---
---> motor_l_r=254; motor_f_b=169; camera_l_r=178; camera_f_b=167; jump=0 <---
---> motor_l_r=254; motor_f_b=169; camera_l_r=177; camera_f_b=168; jump=0 <---
---> motor_l_r=254; motor_f_b=168; camera_l_r=176; camera_f_b=166; jump=0 <---
---> motor_l_r=254; motor_f_b=166; camera_l_r=175; camera_f_b=165; jump=0 <---
---> motor_l_r=254; motor_f_b=166; camera_l_r=175; camera_f_b=165; jump=0 <---
---> motor_l_r=254; motor_f_b=166; camera_l_r=175; camera_f_b=165; jump=0 <---
---> motor_l_r=254; motor_f_b=166; camera_l_r=175; camera_f_b=164; jump=0 <---
---> motor_l_r=254; motor_f_b=166; camera_l_r=175; camera_f_b=164; jump=0 <---
---> motor_l_r=254; motor_f_b=167; camera_l_r=174; camera_f_b=164; jump=0 <---
```

Figure 6(c): Analog Values of analog stick & Digital Input of Jump Button

```
< Temperature= 24(in Degree C) >        < IMU Reading= 29.64(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.43(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.23(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.24(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.12(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.33(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.54(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 29.89(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 30.39(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 30.87(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 31.53(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 32.25(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 32.97(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 33.91(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 34.97(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 36.07(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 37.20(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 38.37(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 39.73(angle in Degree)
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< Temperature= 24(in Degree C) >        < IMU Reading= 43.78(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 45.44(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 47.04(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 48.78(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 50.52(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 52.20(angle in Degree)
< Temperature= 24(in Degree C) >        < IMU Reading= 53.80(angle in Degree)
```

Figure 6(d): Values of temperature sensor and IMU.

Using BeagleboardxM, we were successful in detecting any random human face with a time lapse of less than 50 milliseconds and a boundary around the face was observed as shown in Fig. 6(f). As the xM board has a powerful dedicated DSP processor, it was easier to detect multiple number of faces in the same frame in real time.

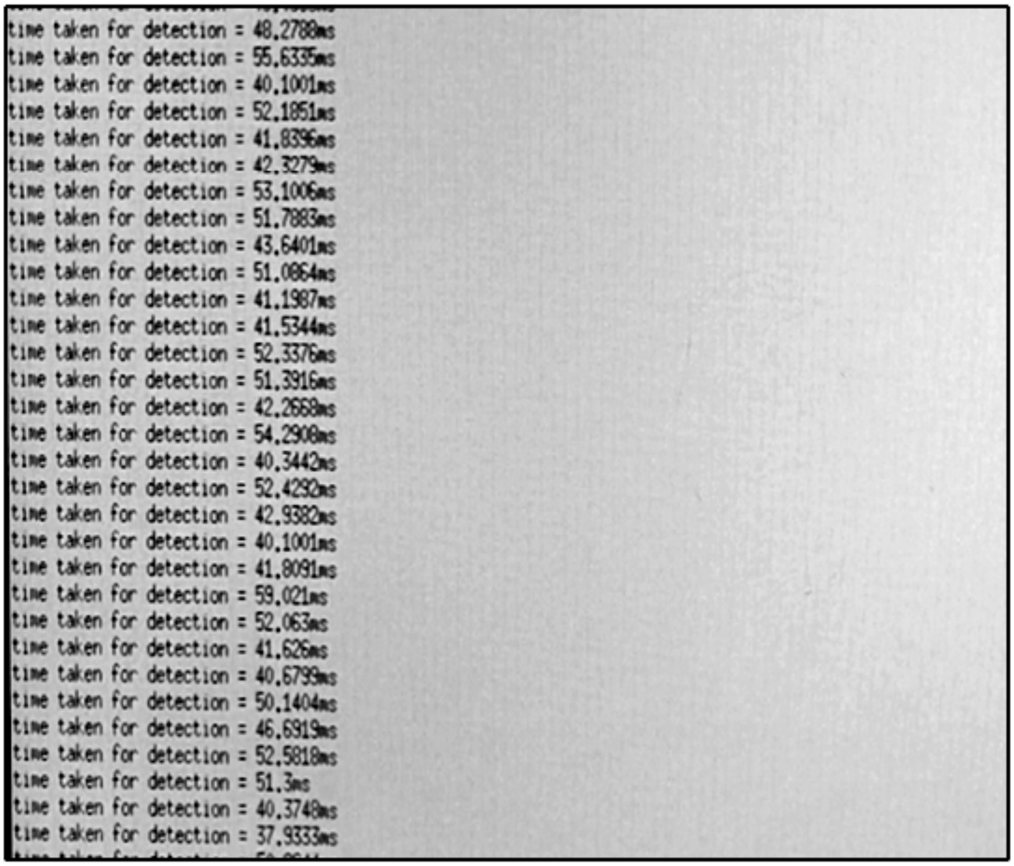

Figure 6(e): Delay for face detection

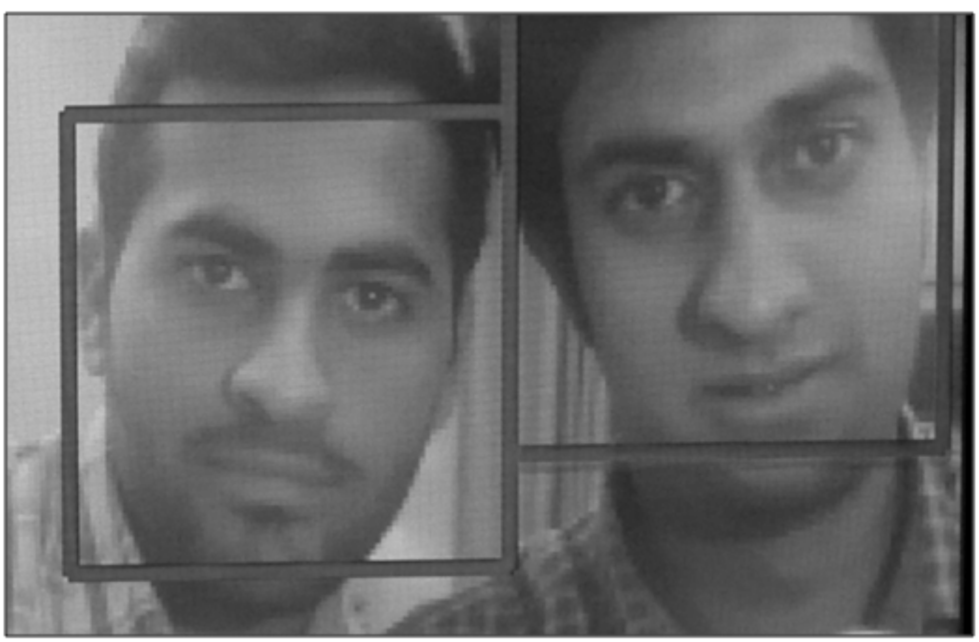

Figure 6(f): Multiple face detection of people

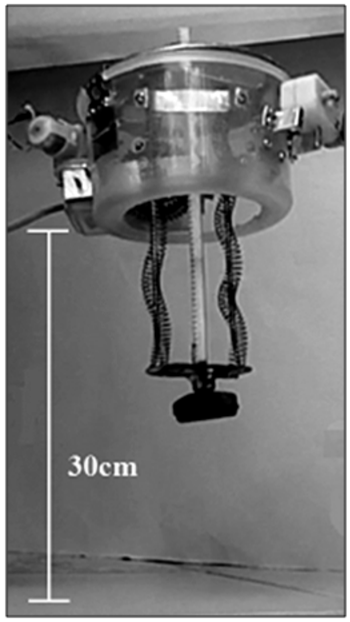

Figure 6(g): Jump Slow Motion Capture

The locomotion of the robot was very precise depending upon the input voltage (from 5V to12V). We were successful in jumping the robot up to 30cm from ground level after the jump button was pressed from the transmitter as shown in Fig 6. (g).

5. CONCLUSIONS

Thus,our robot was successfully controlled wirelessly over a long range by the controller in terms of locomotion, jumping mechanism and camera control with auto-stabilization as an addition. One of the most important features of our robot is its ability to avoid obstacles using the jumping mechanism. Another major feature is its Real time face detection, auto-stabilized camera. The spheroid isn't robust enough and may not be ready for very harsh terrains. This limitation can be overcome once the project reaches a production stage. The reduction in size and weight of the spheroid will nullify the present limitations. The spheroid in future may include the wireless camera, GPS module for tracking and Bluetooth module for controlling the RAVHEN from a Bluetooth enabled phone. The device has scope for a higher frequency and a higher resolution camera for better real time video feed.

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APPENDIX A (PCB DESIGN & MODULES)

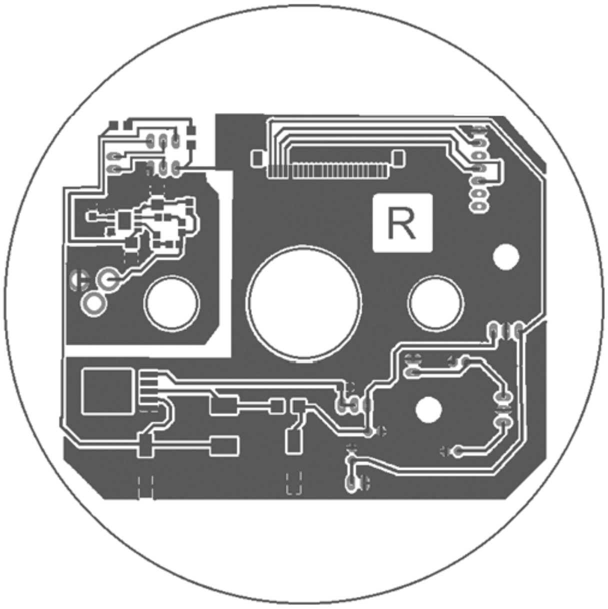

Figure 6(h): Receiver lower layer circuit (Receiver)

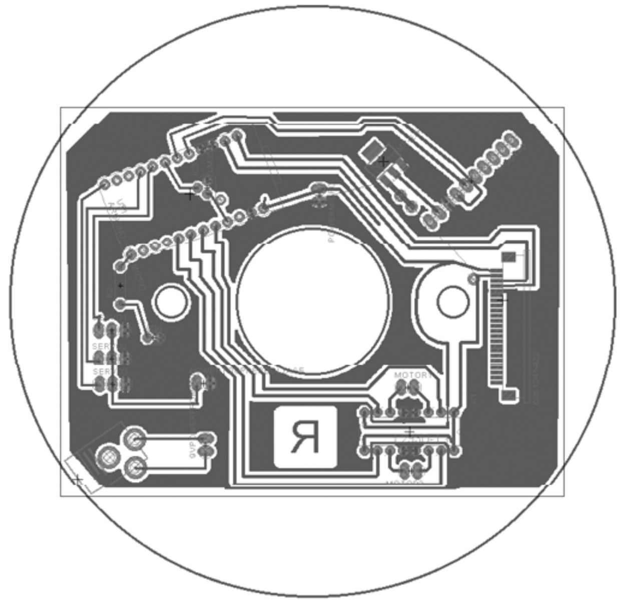

Figure 6(i): Receiver upper layer circuit (Receiver)

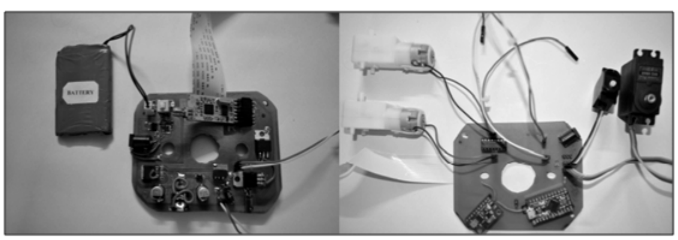

Figure 6(j): Receiver PCB modules of the circuit

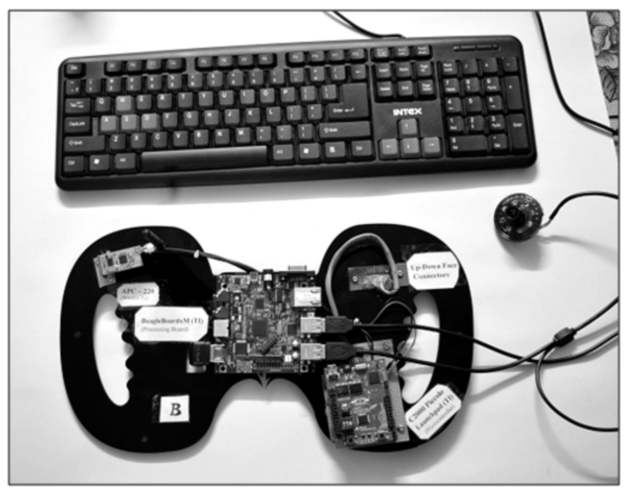

Figure 6(k): Lower Portion of Circuit of transmitter

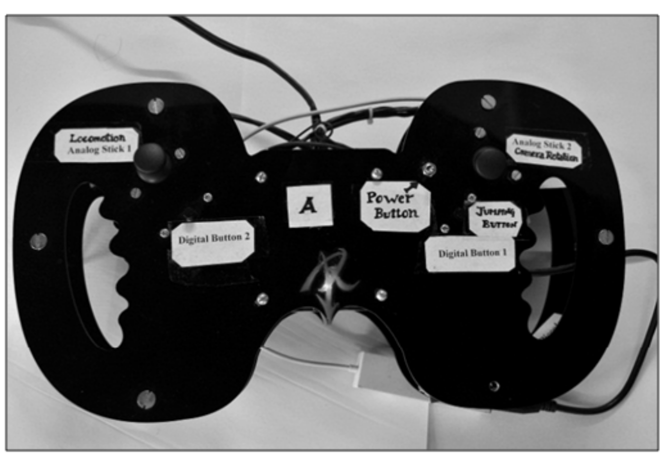

Figure 6(l): Upper View of Transmitter/Controller