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# GPS based Automatic Antenna Management System and Satellite Tracking

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*Our project is to develop a low cost, automatic, smaller and portable Satellite Tracker and Antenna management system useable for Satellite communication. We are using programmable microprocessor and embedded technology to develop this project. This project is based on GPS so that we can calculate, track and communicate with almost all the satellites orbiting the earth from anywhere of the globe. Now it is possible to develop complete portable satellite Ground Station using this technology.*

**Field of Research:** Electrical and Electronic Engineering

## 1. Introduction

In the present era, many researchers have studied on satellite communication (Didactic 2015; Hudson and Martin 2007; Tllford et al 1999; Ragland et al 2013; Cho et al 2004; Benjamin et al 1999; Radov 1987). Satellite communication has three basic parts; Space segments (The satellite), Control segment and Ground segment. Here we are concerned about Ground segment. Satellite Ground station consists of three basic parts: Satellite tracking, Radio & Transmission control and Antenna control. In our project we are focusing on satellite tracking and antenna control (McGuire and Tilden 1990). In a senior design project paper known as “Amateur Satellite Tracking Communication System” (Cho et al 2004), they published about a design of an antenna/transmitter module for communicating with LEO amateur satellite using direction controlled antennas. Another senior design project paper known as “Amateur radio Satellite Ground Station” (Ragland et al 2013) proposes a design for a communication satellite ground station operating on ham radio frequencies using software controlled, motor operated antennas. There is another United States Patent, “Two axis satellite antenna mounting and tracking assembly” (Benjamin et al 1999) which relates to a low-cost mounting and tracking assembly for satellite antenna. It consists of two support sub systems for adjusting two axis angles.

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Here, different researchers tried to find easy and sophisticated solution for satellite communication. But there is no other device or system that can provide the complete solution for satellite communication.

We tried to find an easy and cost efficient solution. In this study we found some device that requires putting the location of the device manually, another device needed to fix direction orientation of the antenna (Wilson, 1987) manually. Previous published papers uses systems that cannot display the graphical movement of the satellite antenna and most other device cannot operate in moving condition (Sherwood and Wagner 1996). Another important issue is the size and power consumption of the device. Most of the devices or systems in the previous or published research are larger in size and requires high power compare to our device. We used Raspberry Pi microprocessor as our main board to develop the system. An Arduino microcontroller is also interfaced with Raspberry Pi. The system is operated by Raspbian OS. Together this system is called Raspduino, which gives us much required flexibility for developing this project. It is also very easy to transport and assemble in a short period of time with less complexity (Wang et al 2003). This device has GPS module so that it can get the location coordinates automatically. It also shows the direction by digital compass and able to fix up the direction orientation of the antenna. This device can track almost all the satellites orbiting the earth from anywhere of the globe. Some researchers from Georgia Institute of Technology develop a reference ground station for University satellite missions to control multiple satellites from a single ground station (Choi et al 2017). This tracking system is also able to track multiple satellites. Their tracking system is limited to a smaller number of satellites where our system can track larger number of satellites compare to their system; the number is above 1800 satellites. Their system is not providing all those services what we are able to provide by our device. Our research is an extension of their project but within a limited interval. Here we have focus on tracking and antenna control system but we did not work that much on radio control and communication system as they have done in their system. To operate this device, any online or data connection is not required as it is completely an offline based system. In the above research papers within our literature review, no other research paper uses this system for satellite tracking. We did not find any other research project that is providing this exact set of solution. The main advantage of this device is that, it has very low development cost, compared to the other devices mentioned on the other papers.

The following paper is organized through different sections.Section1 deal with introduction of the research. Section 2 focuses on the methodology, by which the device is operated. Section 3 introduces and describes the various hardware and software components used for the construction of the device, finishing with a detailed description of the completed device and the results obtained from a successful run of the device. Section 4 outlines the final conclusion with explanation of limitations we had to face while developing the device. Finally, section 5 discusses further research prospects that can be explored for further development of the device.

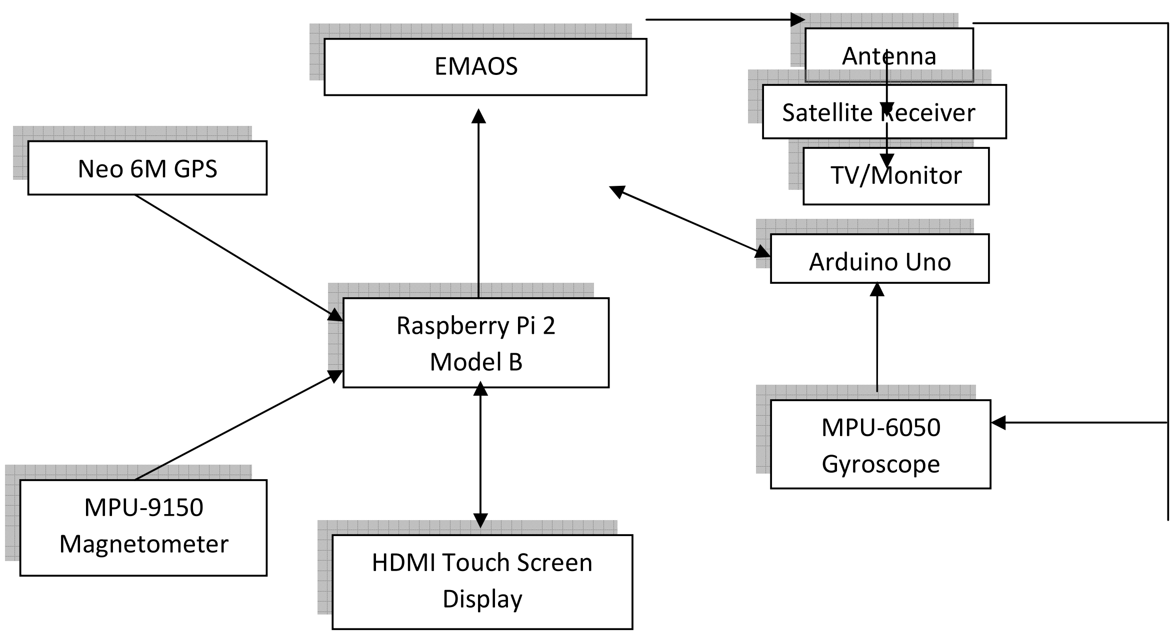
## 2. Methodology

We have combined several components and systems to build our system which is designed to be completely autonomous. Raspberry Pi 2 is our main Microprocessor board. Arduino Uno is connected with Raspberry Pi as slave. MPU6050 (Gyro) module is connected with Arduino Uno analog input port. Magnetometer (MPU9150) is connected with Raspberry Pi I2C Bus. GPS module is connected with UART port of Raspberry pi. The servo motor's PWM control cable of Azimuth rotator is connected with GPIO 4 (Pin-7) and Elevation rotator is connected with GPIO 17 (Pin-11). And the display is connected through HDMI port.

When we turn on the system it will boot up the Raspberry Pi with Raspbian OS. Then GPS module will get the device location, tracking software will track the satellites, Magnetometer shows the direction orientation, Gyroscope shows the graphical representation of antenna movement and servo motor rotates the antenna using mechanical system (Benjamin et al 1999) to make the alignment with the desired satellite. There is also a radio interface to communicate with satellites. This time we are using satellite receiver only.

In our study we found some devices that require putting the location of the device manually, another device needed to fix direction orientation of the antenna (Wilson, 1987) manually. Another research paper uses systems that cannot display the graphical movement of the satellite antenna and most other device cannot operate in moving condition (Sherwood and Wagner 1996). In a recently published article (Wang et al 2017), the authors discusses the estimation of antenna position determined through camera and mobile data, but lacks the antenna control mechanism entirely and does not include satellite communications.

**Figure 1: Block Diagram of the Proposed System**



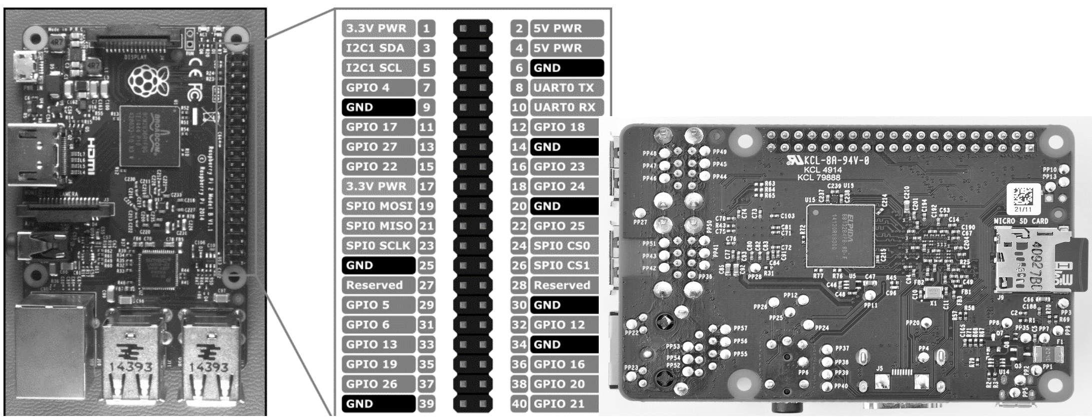
## 3. Discussion

### 3.1 Hardware Components Used in the Proposed System

#### 3.1.1 Raspberry Pi 2 Model B Microprocessor Board

Raspberry Pi 2 Model B is a micro controller which is equipped with a quad core ARM processor and 1GB of RAM. It comes with its own OS with entire set of free open-source programs and system development tools in its libraries. It has 40 digital input/ output pins, analog inputs, UARTs (hardware serial ports), 4 USB connections, a LAN connector and a micro USB power port. This was chosen for the proposed system design due to its excellent interfacing capability with different sensors and the built in availability of satellite tracking software in its libraries.

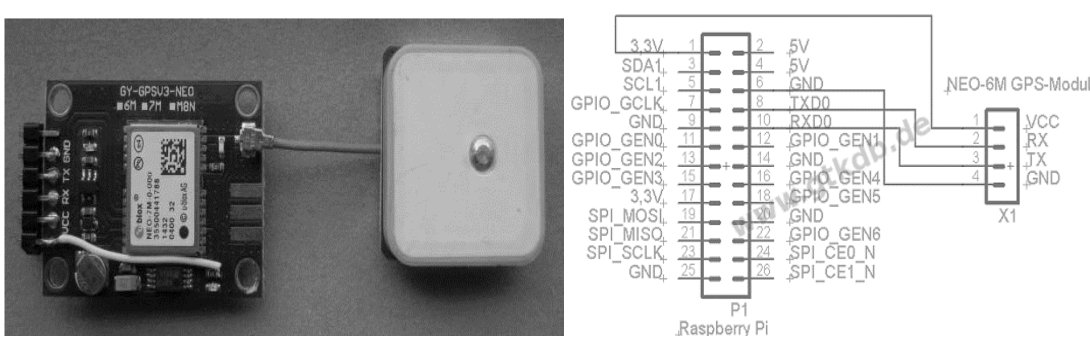
**Figure 2: Raspberry Pi 2 Model B Front & Back Side**




#### 3.1.2 Neo 6M GPS Sensor

Neo 6M GPS module is a GPS receiver that can be used with Raspberry Pi 2. This GPS module uses the latest technology to give the best possible position information such as longitude and latitude without being online using mobile network or the internet. It has very high refresh rates and very low power consumption making it ideal for use for the proposed system.

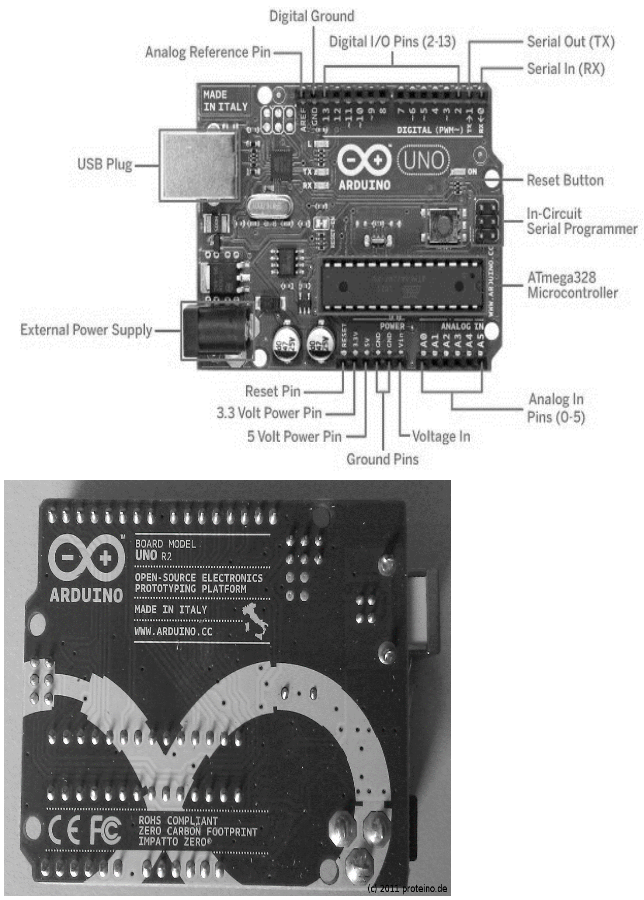
**Figure 3: Neo 6M GPS Sensor Front & Back Side**



### 3.1.3 Arduino Uno Microcontroller Board

Arduino Uno is a microcontroller board. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It has been used as a slave to the Raspberry Pi 2. This particular board was used because of its excellent compatibility with the MPU6050 sensor as compared to the Raspberry Pi 2.

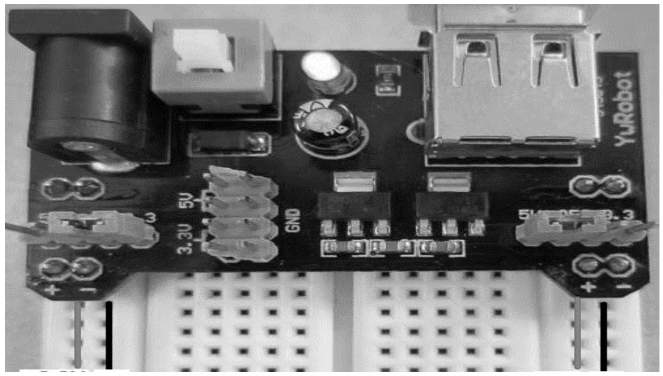
**Figure 4: Arduino Uno Front & Back Side**




### 3.1.4 YwRobot 545043 Power Controller Board

The YwRobot 545043 is a breadboard power supply module. It provides dual 5 V and 3.3 V power rails, and has a multi-purpose female USB socket. This module is used to equally distribute power to the different modules and sensors of the proposed system.

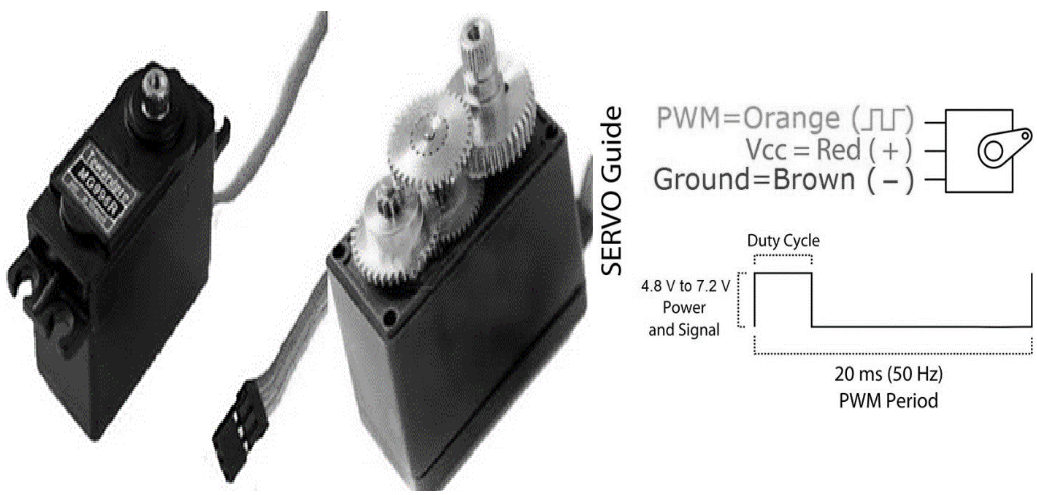
**Figure 5: YwRobot 545043 PCB**



### 3.1.5 MG996R Servo Motor

MG996R is a servo motor module that is connected with Raspberry Pi. The motor is used in this system to control and adjust the antenna. It has support from 0 to 180-degree rotational range. This is used in this system to adjust the angles, which can be adjusted very accurately and have very low power consumption.

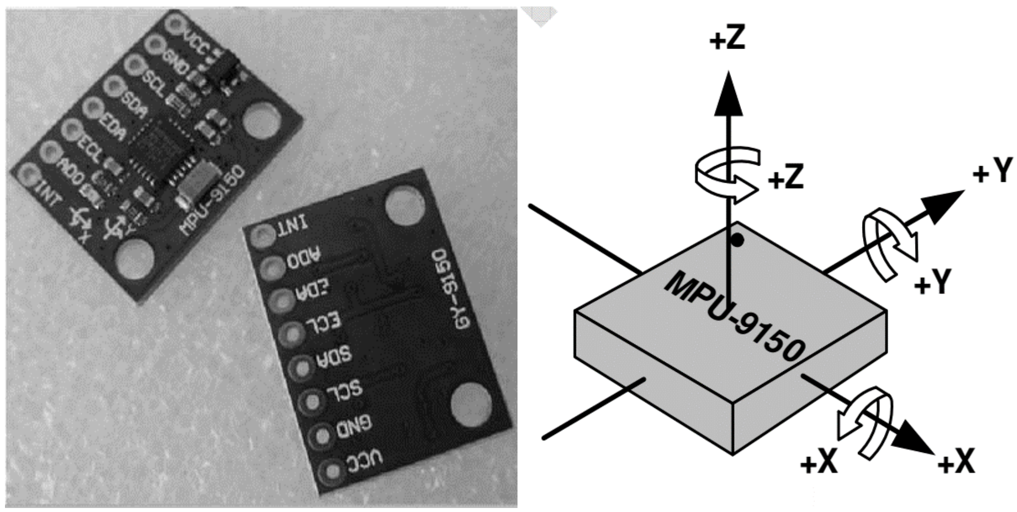
**Figure 6: MG996R servo motor**




### 3.1.6 MPU 9150 Sensor

The MPU-9150 is a System in Package (SiP) that combines two chips: the MPU-6050 contains a 3-axis gyroscope, 3-axis accelerometer, and an onboard Digital Motion Processor™ (DMP™) capable of processing complex Motion Fusion algorithms; and the AK8975, a 3-axis digital compass. This module is used in the proposed system for figuring the directional orientation of the antenna. It is used as a compass and is interfaced with the Raspberry Pi 2.

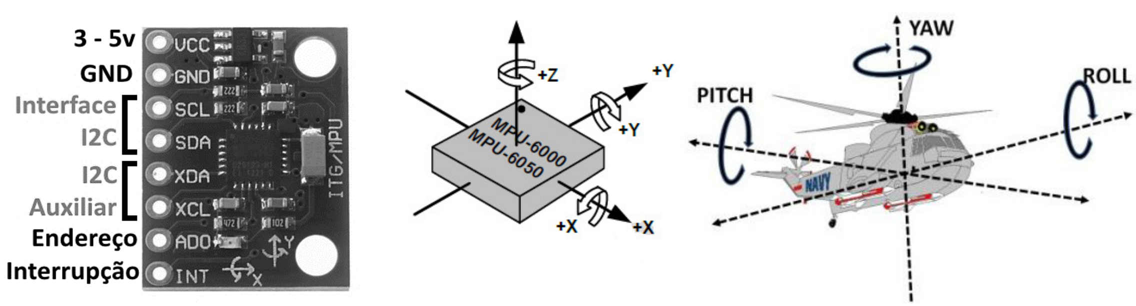
**Figure 7: MPU 9150 Sensor**




### 3.1.7 MPU 6050 Sensor

The MPU-6050 sensor contains a MEMS accelerometer and a MEMS gyro in a single chip. It is very accurate, as it contains 16-bits analog to digital conversion hardware for each channel. Therefore it captures the x, y, and z channel at the same time. The sensor uses the I2C-bus to interface with the Arduino.This module is used in this proposed system for visual representation of the antenna using Python programming. The module is interfaced with Arduino Uno.

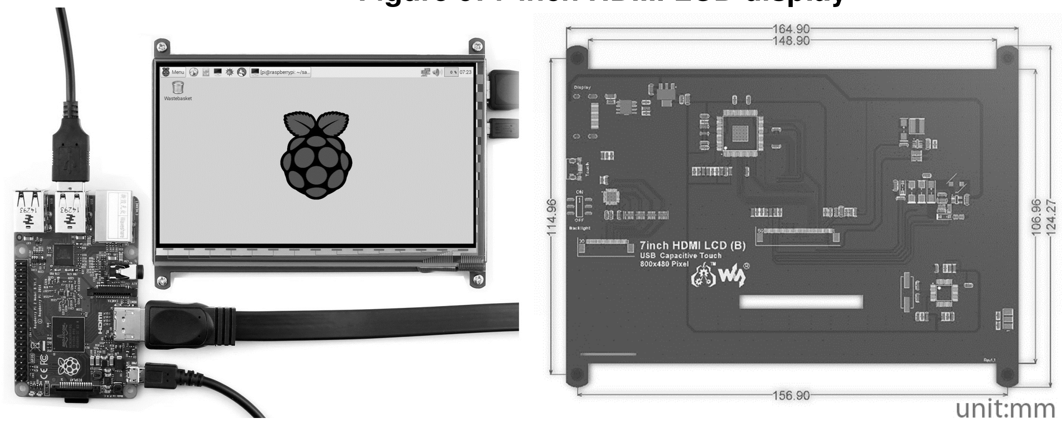
**Figure 8: MPU 6050 sensor**




### 3.1.8. 7 inch HDMI LCD Display

The 7 inch HDMI LCD display is used to display the OS and different satellite tracking software and programs that is used to operate the proposed system. It is connected and interfaced with the Raspberry Pi 2.

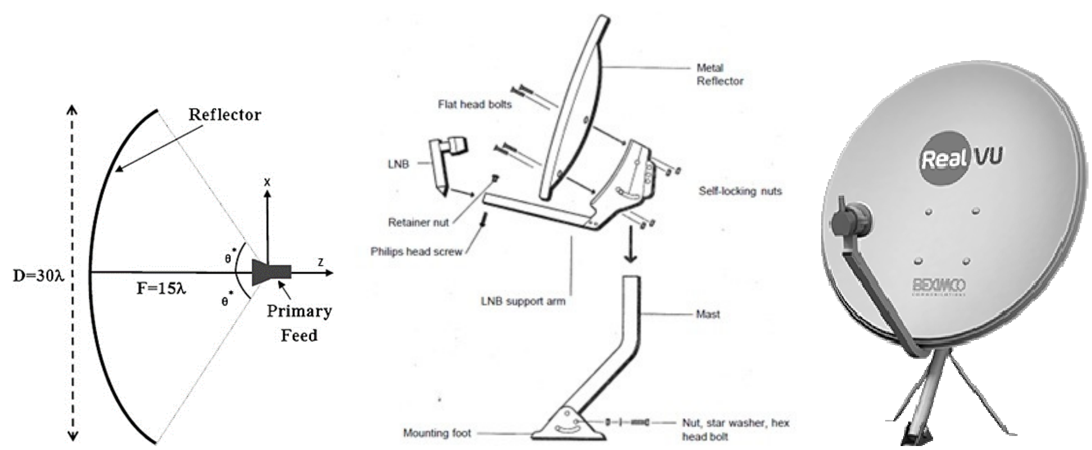
**Figure 9: 7 inch HDMI LCD display**




### 3.1.9 Parabolic Antenna Reflector

Reflector antennas are typically used when very high gain (e.g. satellite transmission or reception) or a very narrow main beam (e.g. secure communication) is required. It transforms an incoming plane wave traveling along the axis into a spherical wave converging toward the focus. It is used in this system to receive and transmit satellite transmissions through it for the system.

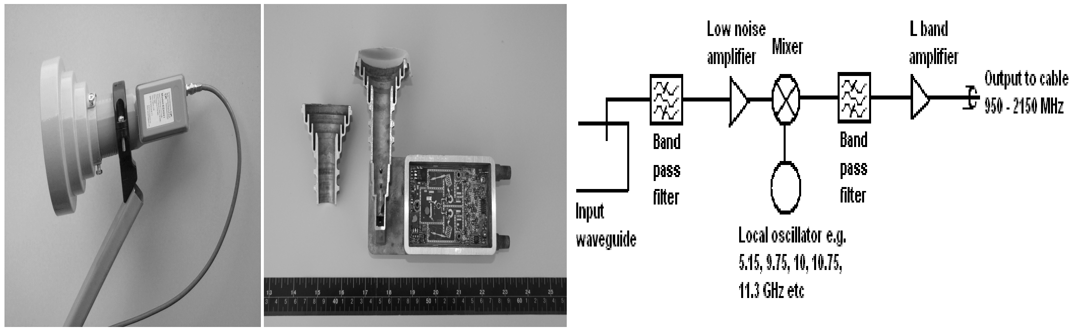
**Figure 10: Parabolic Antenna Reflector**




### 3.1.10 Antenna LNB

The LNB is a combination of low-noise amplifier, frequency mixer, local oscillator and intermediate frequency (IF) amplifier. It receives the microwave signal from the satellite collected by the dish, amplifies it, and down converts the block of frequencies to a lower block of intermediate frequencies (IF). This down conversion allows the signal to be carried to the indoor satellite TV receiver using coaxial cable, which is the purpose of this module in this system.

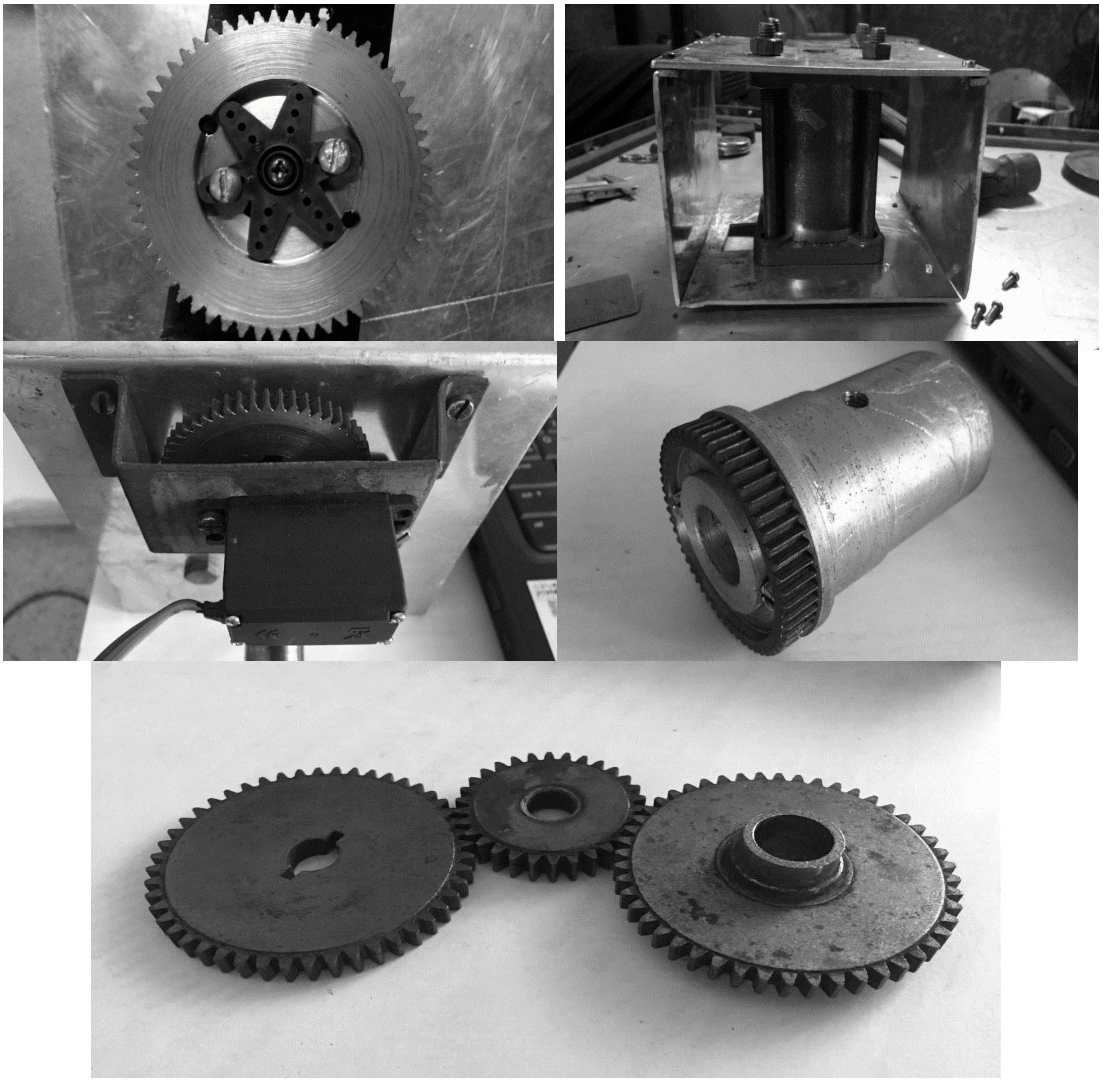
**Figure 11: Antenna LNB**




### 3.1.11 Electro-Mechanical Antenna Orientation System (EMAOS)

The EMAOS consists of a stand, two servo motors, a turn table, an antenna mounting and an antenna. The turn table rests on the stand. A spur gear with 360teeth has been attached to the top-end of the stand. The turn table consists of another spur gear. These spur gears are designed in a 1:1 ratio so that the rotation of the turn table is the same as the angular rotation of servo motor. The idea of this spur gear is that these gears are aligned in the same line so that when the motor starts to rotate, the whole turn table rotates. Actually, the gear on the top of the stand is fixed. It does not change its position. As another gear is attached to the shaft of the servo motor, this gear drives the whole turn table in the direction of its rotation. As the servo motor is mounted to the bottom of the turn table, it allows the whole turn table to rotate along the axis of the shaft which was mentioned earlier. So, this axial rotation defines the azimuth angle of the satellite. Another spur gear is connected with EMAOS to control the elevation angle which is same as the azimuth gear but perpendicularly positioned. The purpose of EMAOS in the proposed system is to precisely control and adjust the azimuth and elevation angles of the antenna. The picture of the EMAOS is shown in Figure 12.

**Figure 12: EMAOS**



## 3.2 Software Components Used in the Proposed System

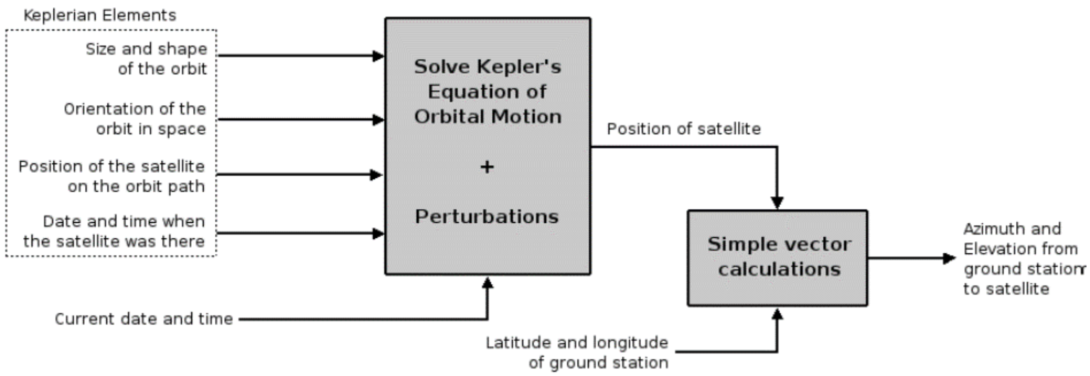
### 3.2.1 Operating System: Raspbian OS

Raspbian is a free operating system based on Debian linux optimized for the Raspberry Pi hardware. Raspbian provides more than a pure OS: it comes with over 35,000 packages; pre-compiled software bundled in a nice format for easy installation on Raspberry Pi.

### 3.2.2 Tracking Software: GPREDICT

GPREDICT is a real-time satellite tracking and orbit prediction program that predicts the position and velocity of a satellite at a given time using a mathematical model of the orbit. Once the position and velocity of the satellite is known other data can be calculated, for example bearing, distance, footprint, and visibility just to mention a few. The figure below shows a diagram of the core functionality of a satellite tracking program.

**Figure 13: Working mechanism of GPREDICT software**



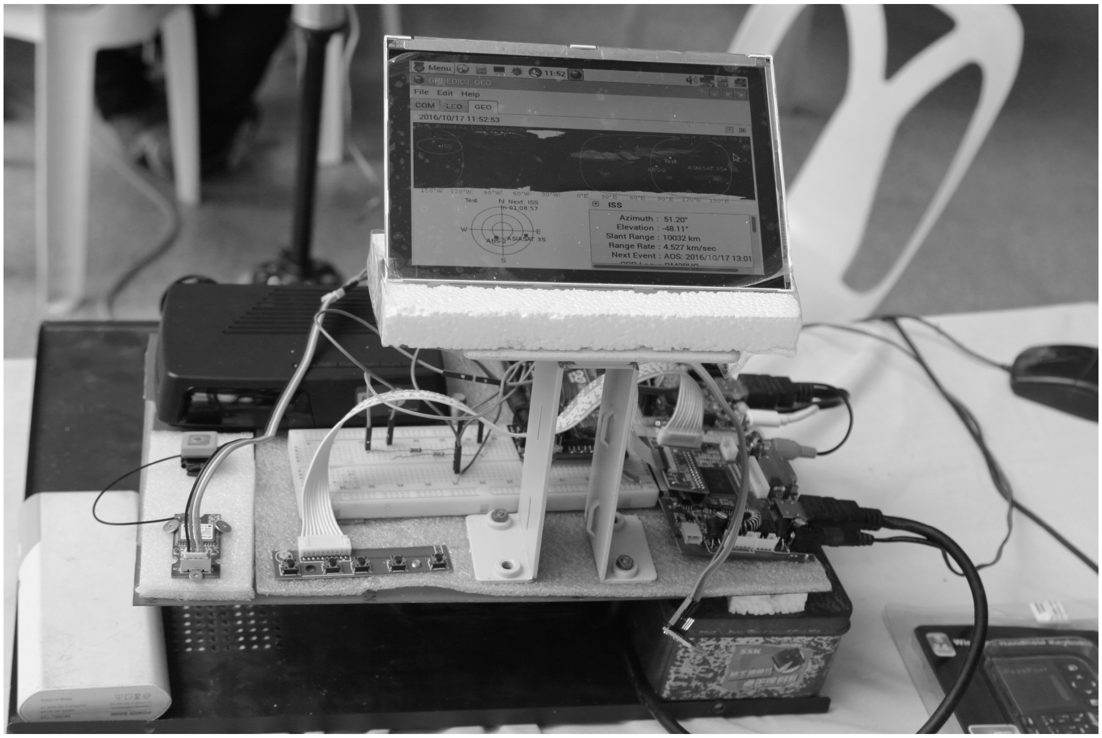

### 3.2.3 Arduino Software (IDE)

The Arduino Integrated Development Environment - or Arduino Software (IDE) - contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them.

## 3.3 Prototype of the Proposed System

When we plug in the power to the Raspberry pi, it will boot up with Raspbian OS. An Arduino Uno is interfaced with Raspberry Pi as a slave. MPU6050 module is connected with Arduino Uno that is placed in back side of the antenna reflector. When we input the Gyroscope code to the Arduino IDE or Python programming software, the Raspberry Pi will show the graphical display of the Antenna's angular movement (shows in Figure 18). In this device we are using GPREDICT software for satellite tracking. This software can track all the satellites orbiting the Earth and give us the graphical representation of satellites in maps (shows in Figure 15) with almost all the necessary data required for satellite communication. GPS module gives the present coordinate of the device that is the input for GPREDICT software. We are using hamlib antenna library and driver for Antenna rotator control (shows in Figure 16). When we select the desire satellite and push the 'Track' & 'Engage' button of antenna interface control, the servo motor will get command and it will start tracking the satellite. A Magnetometer (MPU9150) is also connected with Raspberry pi for direction orientation of the antenna. 0 degree Azimuth is the true North of the device. When it fix up the direction orientation of the antenna and get the command from rotator control, it will make the alignment of the antenna to the desire satellite. It can also operate in moving condition. Magnetometer will check the direction and fix the antenna orientation by rotating the servo motor. In this prototype we are using Real VU satellite receiver for receiving satellite signal and it connected with TV and we can watch the TV by receiving the satellite signal. The hardware design of the proposed system is shown in Figure14.

**Figure 14: Prototype of the Proposed System**




## 4. Results

The proposed device requires 2 power inputs with 5volt input voltage to function. The voltage source can be a USB powered brick or a battery pack that can deliver the functioning voltage. The system consists of one microprocessor boards and one microcontroller board which is plugged with all the sensors and EMAOS, which consist of two servo motors. All the individual components function distinctively and produce their own outputs. The entire device works as a perfect satellite tracking system and the EMAOS motors works in rotating and adjusting the various angles. Once the device is powered on, the sensors will be turned on and it starts generating location data as well as the present orientation of direction the antenna module. The GPREDICT software lists all the available satellite data and when one is selected, it sends signals to the EMAOS motors, which rotates and adjusts the antenna according to the data from GPREDICT. The outputs seen from the display of the system are shown below in Figure 15 & 16.Figure 17 shows the output of GPS. Figure 18 shows the output data and graphical display of gyro (MPU-6050) module. Figure 19 shows the output display of digital compass.

The device can be placed anywhere in the world and any satellite can be tracked from anywhere. We are able to track above 1800 satellites with an option of putting any satellite in the tracking module manually, if we know Keplarian element data of that satellite. We are getting almost all the information related to the satellite communication of any of those satellites. This system shows the graphical representation of satellites on the map. It also shows the location of the device on the GPS map. Additionally, this also shows the graphical representation of antenna angular movement and direction by displaying the compass. It gives us the ability to track satellites in steady position and as well as in moving conditions.

**Figure 15: Output of GPREDICT Real-Time Satellite Tracking**

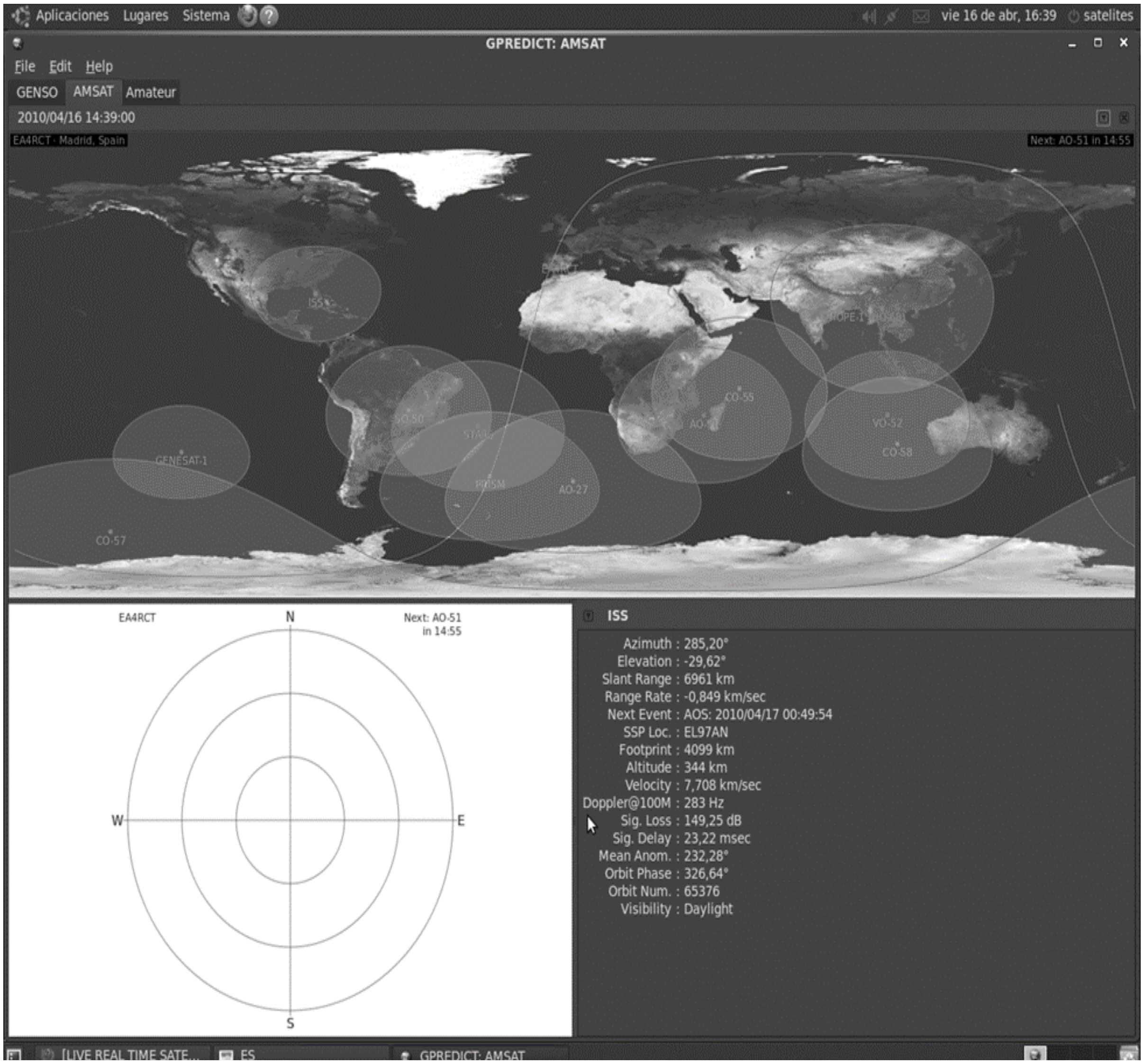


**Figure 16: The Rotator Control Interface**

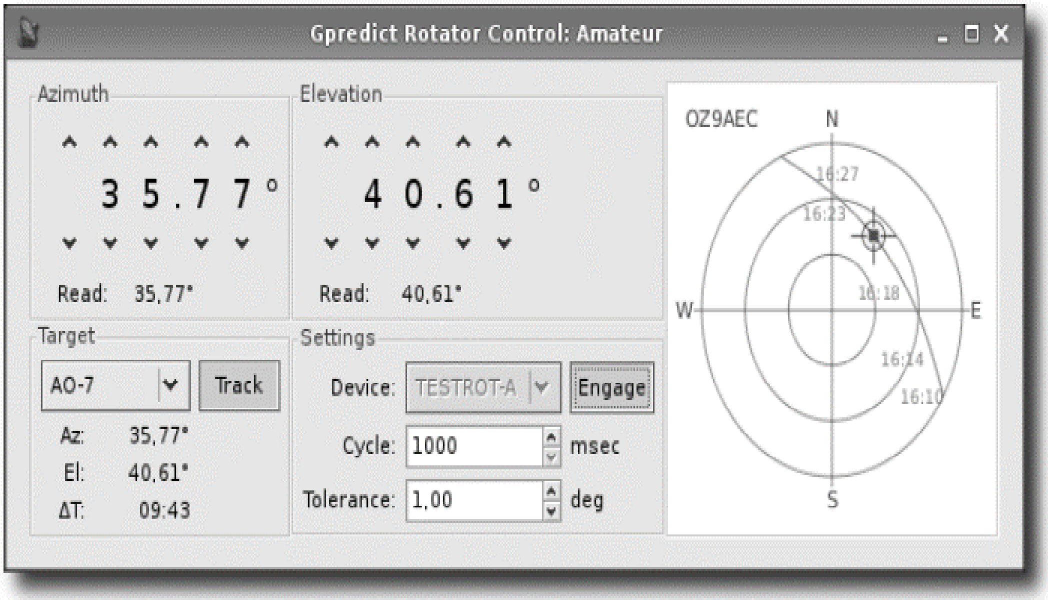



**Figure 17: Output Seen of u-center Software for Neo 6M GPS**

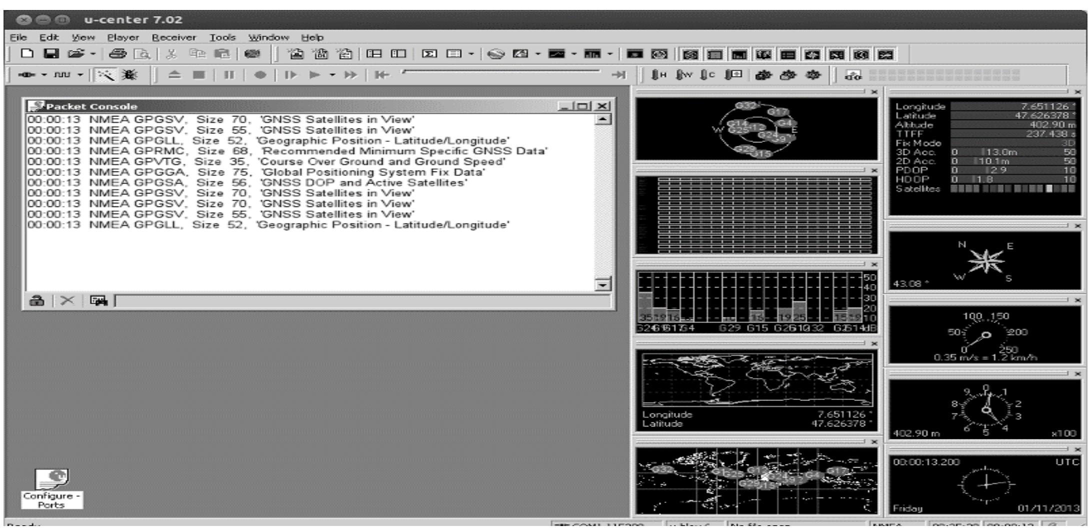


**Figure 18: Output Seen for MPU6050 Gyro Sensor**

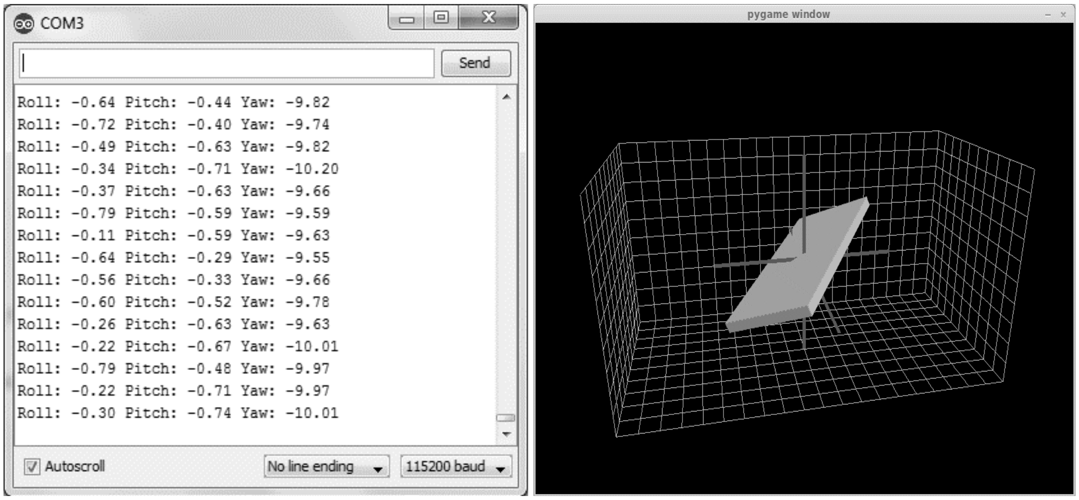
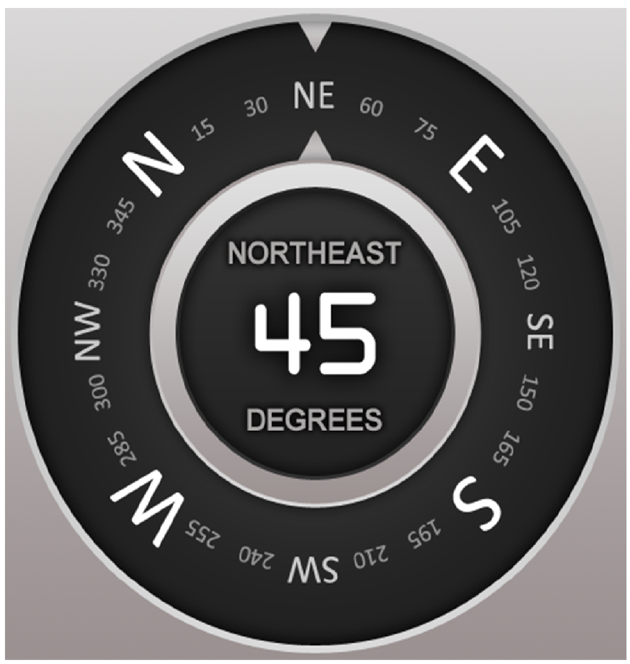



**Figure 19: Output Seen for MPU9150 Digital Compass**




## 5. Conclusion

In this paper, Automatic Antenna Management system and Satellite Tracking has been studied. The operating system, a set of sensors, gyro, magnetometer, GPS and the controller gives us much needed flexibility for the project; this unique combination of instruments and systems helped us to provide specific solution with important features that are reliable for satellite communication. We did not find any other research that is providing this set of solutions. It can be used to track and communicate with any satellite from anywhere. Moreover, this system has the ability to correct the direction orientation of the antenna, as well as, it shows the antenna movement graphically. This system is portable and less power consuming, automatic location tracking makes it ideal for establishing emergency satellite communications in remote areas and at natural disasters management. It is also useful for military purposes as it can provide faster alignment and service. Also, this device can be used for live telecasting of TV channels by using additional radio and communication devices. It is also possible to provide quick and easy satellite communication for moving vehicles such as automobiles, locomotives and water vessels. This device is affordable, easy to use, and definitely much cheaper than the available devices in the market. Finally, this system can be used as a portable mobile ground station for satellite communications with some additional instruments and as it is fully automated and does not required any highly skilled engineers to operate. While developing this prototype, we came across various issues and limitations that we faced. First issue was that the EMAOS has less powerful servo motors, which is not capable of adjusting the heavy antenna modules such as the Cassegrain antenna. These servo motors have the ability to rotate only within 0º -180º, so this tracking system becomes limited within 180º. As a result this system has the ability to track most of the satellites, not all the satellites. The Servo motors we used have angular error of around 2 degree and it is not completely stable, as the vibration effects the smoother operation of the device. This system may not work properly with the needed precision in the higher latitude (›70º) areas near the polar region. Another limitation we came across is that it has no central Graphical User Interface (GUI) or stand-alone program. Lastly, the EMAOS module has some mechanical error and it is not 100 percent accurate. Despite the limitations, all other functions of the device were tested and worked perfectly. This device can be used for providing fast and mobile satellite communications, at a fraction of the cost of present devices. We believe our design could significantly be useful for the field of satellite communications in Bangladesh and maybe even lower the cost of satellite communications in the world.

## 6. Further Research Prospect

The technology and design is still yet to be applied in the commercial market today as the applications or uses are still not present. Research on the EMAOS module can be studied to develop single usable module for mounting multiple types of antennas such as reflector antenna and VHF or UHF Yagi-uda quad antenna. A further research in developing military grade encryption can be done to enhance the device for secured military communications. In consumer use, it can also be used for live telecasting for the TV channels. Therefore, additional research in minimizing the response time and the mechanical movement can be conducted. Also, research in making the device perfectly stable can be conducted. Furthermore, implementing a smart antenna design with real time signal strength measurement can effectively make this design more future proof and efficient.

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