Doppler Direction Finder
(Di-Fi)

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in partial fulfillment for the requirements of B.E Degree in Electrical (Telecom) Engineering.

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IN THE NAME OF ALLAH, THE MOST BENEFICENT, THE MOST MERCIFUL.

CERTIFICATE OF CORRECTNESS AND APPROVAL

This is to officially state that the thesis work contained in this report

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under my supervision and that in my judgement, it is fully ample, in scope and excellence, for the degree of Bachelor of Electrical (Telecom.) Engineering in Military College of Signals, National University of Sciences and Technology (NUST), Islamabad.

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Date: ____________

DECLARATION OF ORIGINALITY

No portion of work presented in this t thesis has been submitted in support of another award or qualification either in this institution or anywhere else.

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Allah Subhan'Wa'Tala is the sole guidance in all domains.

Our parents, colleagues and most of all supervisors, Lt. Col. Hasnat Khurshid without your

guidance.

The group members, who through all adversities worked steadfastly.

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ABSTRACT

Doppler Direction Finder (Di-Fi) systems have previously been used for aerial navigation and were a critical technology in use during the First and Second World Wars. Today, the applications of Direction Finders are in pirate radio detection and stolen vehicle localization. The project aim is to design functional hardware and a Software-based system to estimate the direction of arrival of an electromagnetic wave using the doppler effect.

Currently, in Pakistan, the only solution to estimate the location of the illegal transmitter is considerably expensive and comes with huge equipment and infrastructure. We propose the design of an indigenous and cost-effective system to locate pirate FM transmitters. It consists of 4 antenna arrays connected to the RF switch and UHF receiver. Using Doppler effect and phase difference of the signals, angle of arrival of the signal is calculated.

The final deliverable holds a compass module that will point in the direction of signal and GPS module that will give current location of the system. Display will be on google maps API for localization of the detected signal using triangulation.

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Chapter 1: Introduction

This chapter supply comprehensive introduction of project “Doppler Direction Finder, Di-Fi”.

1.1 Overview

The Radio Direction Finder is the device that can find and identify the Angle of Arrival of an electromagnetic signal or the bearing of radio frequency. In the recent years, the devices to find radio frequency bearing has acquired immense importance. The world has advanced and developed portable and accurate solutions to estimate the direction of arrival of EM waves. Unfortunately, In Pakistan the currently used systems are expensive, bulky, and limited.

The Doppler direction finder is a hardware and a software-based system that is used to estimate the direction of arrival of EM-wave using doppler effect. The system is low cost, portable and Indigenous. The investigation techniques for direction of arrival estimation includes Pseudo Doppler and Time Difference of Arrival (TDOA).

Raspberry Pi and Arduino are used as single board computer SBC and programmed accordingly to obtain correct results for localization. The whole equipment is consoled in a casing and mounted on drone. Using the triangulation technique, the area is narrowed down, and ariel surveillance is obtained.

1.2 Problem Statement

Pakistan is an underdeveloped country struggling to support the economy and keep up with the ever changing and advancing world. Pakistan has been facing huge problems over years related to terrorism where people were using unlicensed and unauthorized transmitters to communicate.

Each organization is allocated a particular frequency band for the transmission and reception of radio signals. However, if someone transmits a signal on frequency without license, it is considered illegal and unauthorized. Use of unlicensed product is not only a threat to national security, but it can also disrupt the communication of licensed clients.

To estimate the direction of arrival of electromagnetic waves, an extremely sensitive, precise, high scanning speed and portable system is required. However, in Pakistan, the only such equipment is available to FAB and PTA. The systems to locate pirate EM signal is bulky, expensive, and Indigenous. To narrow down area and to locate the pirate transmitter, triangulation technique is used in which the system needs to be deployed on three vehicles.

Figure 1-1: Triangulation Technique

1.3 Proposed Solution

The major goal of our proposed solution is to provide a low cost, Indigenous, portable, and accurate equipment to estimate the direction of arrival of EM-wave using Doppler effect.

The estimation technique we used for EM-waves' direction of arrival is Phase Difference Method using Pseudo Doppler Effect, which is commonly known as Time Difference of Arrival, TDOA. The working will involve bearing computation and triangulation technique. This proposed solution will eradicate the limitations of the existing system to locate pirate transmitters.

1.4 Working Principle

The project mainly works on the principles of Electromagnetic signal processing and Digital Signal processing. The main working is dependent on Time difference of Arrival TDOA and Triangulation technique which will be discussed later in detail.

1.4.1 Time Difference of Arrival:

It is one of the most famous and widely used techniques for estimating the direction of arrival of EM wave. It is based upon the time at which the signal is received and speed of propagation of signal. It is also known as Phase Difference Method.

1.4.2 Triangulation Technique:

The triangulation technique is used by major law enforcement organizations in Pakistan like Frequency Allocation Board (FAB) and Pakistan Telecommunication Authority (PTA). It requires heavy equipment consist of three vehicles with high power direction finders to narrow down the area having suspected illegal transmitter.

1.5 Objectives

1.5.1 Academic Objectives:

- To employ our knowledge and practical skills in the field of Electromagnetic waves.
- To obtain complete command on using Raspberry PI, Arduino and RF switch.
- To develop a complete system for localizing and monitoring of pirate transmitters.

1.5.2 Industrial Objectives:

- Support law enforcement and strategic organizations by locating the pirate and illegal radio transmitters.
- The existing system requires 3x vehicles. Proving access to unreachable areas by using drone and ariel surveillance service.

1.6 Scope

The scope of the project includes:

- Development of radio receiver antenna array with RF switch
- Algorithm development for angle of arrival computation
- Implementation of Raspberry Pi on SBC (single board Computer)
- Integration of Compass module
- Integration of GPS module and google maps API for localization using triangulation.
- Determining accuracy of localization.

1.7 Deliverables:

1.7.1 Phase Difference:

In this method, using a sine and a square wave as input the phase difference is calculated. During the process, the antennas keep switching due to doppler effect. This phase difference will indicate the currently active antenna during switching. The deliverable for the project is the display containing the phase difference and phase angle of a sine and square wave.

1.7.2 Compass:

Once the phase angle is calculated, using a code compass is firstly integrated and then calibrated. After this, it will indicate the direction of incoming signal.

1.8 Relevant Sustainable Development Goals:

The project aligns with following United Nation Sustainable Development goals:

- Industry, Innovation, and Infrastructure
- Law enforcement /Justice

1.9 Thesis Structure

Chapter 2 contains the review of literature, the background and analysis study this thesis.

Chapter 3 contains the design and development of the project.

Chapter 4 introduces detailed evaluation and analysis of the code.

Chapter 5 contains the conclusion of the project.

Chapter 6 highlights the future work needed to be done for the commercialization of this project.

Chapter 2: Literature Review

A new product is launched by modifying and enhancing the features of previously launched related products. But with a fresh and efficient approach. As radio-wave communication technology becomes more common, the possibility of its illegal exploitation has also become a reality.Hence the need to make spectral monitoring systems ubiquitous is now. We all understand that theliterature review is the foundation step for the development and grooming of an idea into an all- new product. Therefore, for the development of the product and its implementation as a replacementto the existing detection system in the spectral network, a detailed study regarding all similar projects and concepts is compulsory. Our literature review mainly consists of the study of several distinct direction-finding techniques and the mythology we picked for our proposed design along with all supporting factors. Our research is mainly classified into the following particulars:

- Commercial and operational background
- Direction Finding Methods
- Current systems and their backdrops
- The applaudable conclusion

2.1 Commercial & Operational Background

In today's era, spectral hijacking has become a fundamental problem around the world. The spectral congestion of illegal traffic has led to rise of different problem, as discussed in Problem Statement, which increases need for smarter systems. Ultimately, this results as a big marketplace opportunityfor industrial level development.

Initially, industries in Pakistan were backwatered and outdated. But then, they started exploring new innovative ways to improve their products and techniques under liberal policies resulting in increase in industrial growth due to the rapid expansion of domestic demand and encouragement for export. Despite of declination of domestic growth rate, Pakistan managed to make progress and grow in the new century. And now companies are moving towards smart industries which are based on innovations such as Machine Learning, IOTs and Artificial Intelligence. Hence, our direction finder fits very well in this age of smart devices, making way for greater market growth potential. In this time of information technology where the electromagnetic radiations have become an integral part of our lives, unlicensed usage of spectral frequencies is a criminal offense. As the assailant can frame a valid user of excess resource usage which results in lager compensation on the user end to the network company. Our proposed compact solution is a hand carriable device that can be further customized to be more autonomously maneuverable.

2.2 Direction Finding Methods

Different solutions have previously been provided for the for this purpose. Some of these solutions are given below.

- Time of Arrival (TOA)
- Time Difference of Arrival (TDOA)
- Angle of Arrival (AOA)
- Received Signal Strength (RSS)

2.2.1 Time of Arrival (TOA):

Time difference of arrival is a simple and a commonly used direction-finding technique. It is also used in GPS. This method requires the exact (synchronization) with the departure of the signal from the target and the exact time of arrival of the signal at the reference point and the speed of the propagation of the signal which is the speed of light.

2.2.2 Time Difference of Arrival (TDOA):

TDOA is also one popular method of direction finding and ranging techniques and more versatile than Time of arrival technique. It requires only the time at which the signal is received unlike TOA which also needed the time at which the signal was released. It also requires the speed of the propagation of the signal which the speed of light. If we record the difference in the arrival time of the signal at two different reference points, the difference in the distance of the target and two reference points can be determined.

2.2.3 Angle of Arrival (AOA):

Angle of arrival works on the principle of triangulation. In this approach array of antenna is required at the receiver. At the receiver side, angle of arrival other signal is estimated by multiple receivers. Combining the results of the signal with respect to the known location of the multiple receivers gives an intersection point of the transmitter. AOA is used for many applications including beamforming, tracking and localization.

2.2.4 Received Signal Strength (RSS):

In this method, the location of radio transmitter is localized based on the power or strength of the transmitted signal. The locator will move in the direction where maximum strength of the signal is observed. Our proposed approach uses the RSS method of direction finding

2.3 Current systems and their backdrops:

The Triangulation technique is currently used by the FAB (frequency allocation board) to locate the source of the transmission. In this method, 3 heavy vehicles with high power direction finders are used. A particular area is specified by each of the three direction finders and based on the signal strength received. This is done by intersecting each of the device's direction of signal reception. The method may have to be repeated numerous times to discover the approximate location of the transmitter. These bulky systems cause such a ruckus that the assailants pack up ahead of time and can escape. Thus, in view of practicality, these systems are outdated and need replacement.

But apart from the direction-finding strategies one also needs to be aware of band plans and spectrum information before locating the radio transmitter.

2.3.1 RF Band Distribution:

In the electromagnetic wave spectrum, the RF band is, the lowest known portion, used to transmit analogous and digital signals in modern day communication system. It has a frequency range of 3KHz to 300 GHz. Nearly all the present-day transmission systems operate within radio frequency band spectrum including aircraft navigation, analogue radio, amateur radio, mobile networks, satellite systems and marine radio etc.

2.3.2 Spectrum Planning & Management:

The radio spectrum in Pakistan is divided, managed, and distributed by the FAB. After obtaining permits from the PTA / PEMRA / Govt, the Frequency Allocation Board provides radio-compatible radio waves to all wireless networks. These include technical analysis of spectrum control tools, development / revision of the National Frequency Spectrum Plan and recommendations for ways to improve spectrum utilization, international cooperation and agreements with other authorities regarding various satellite and global communications networks, fulfilling national obligations as set out in agreements international. ITU countries, etc. Monitoring Spectrum to detect illegal wireless channels, as well as site removal of all wireless installs in the country. FAB ensures that the use of spectrum complies with ITU radio rules, guidelines, decisions, and recommendations. Ongoing revisions are followed by spectrum belts in accordance with ITU rules and re-invested spectrum where its current use does not have the best social and economic uses, is used sparingly, improperly used or its use conflicts with international norms. FAB is also actively involved in the development of frameworks for re-cultivation / use of spectrum, spectrum sharing and trade, exploration and development licenses, SRDs etc. by providing relevant feedback to the Pakistan Telecommunication Authority.

2.4 The Applaudable Conclusion:

The project concept is unique. As no such project has successfully used Software Defined Radio and yielded results in MCS. The conception of the project revolves around the technique of Received Signal Strength to detect transmitters. Through localization but having following merits over the existing method.

The hardware & equipment used in the product is quite easy to acquire in bulk. It far more economical as compared to machinery used in the current method.

In terms of dimension and size, it is small & portable. The light weight is another bonus. All these factors contribute to reducing the relative operation time.

An integrated GPS & compass system give the exact coordinates of the transmission source while the existing system can only manage to give an approximate location of the transmitter. With further modifications, the mobility of the device can be increased and access to live location is also possible.

Chapter 3: Technological Requirements

This chapter contains in-depth information regarding our project's technical requirements such as, operating System, hardware and software.

3.1 Hardware Requirements:

The Hardware required for the implementation of the project includes:

3.1.1 Raspberry Pi 3b+:

Raspberry Pi 3b+ is a quad core processor with 64 bits and 1.4 GHz processing power. All other components are directly connected to the Pi and results from the compass, GPS and received signal are processed at Raspberry Pi.

3.1.2 Arduino UNO:

Pseudo Doppler affect is achieved by the switching of antennas at microseconds interval of time. Arduino is programmed to switch between the antennas connected to RF switch.

3.1.3 RF Switch:

RF switch is directly connected to Arduino and 4 antennas are connected to the 4 ports of the switch. One antenna is functional at a single instant of time with the virtue of the RF switch.

3.1.4 Compass Module:

Compass module is integrated with Pi, and it estimates the direction of the received signalat Pi.

3.1.5 GPS Module:

GPS also goes integrated with Pi and it provides the exact location of the equipment where it has been used.

3.1.6 Transceiver SA-828:

This module functions as a transmitter and receiver for test purposes, the direct application of the project however requires only the receiver as signal for which direction is to be estimated will already be transmitted by an unknown source.

3.1.7 1 KHz Bandpass Filter:

The tone that receives because of the doppler effect produced by switching of antennas and hence causing a phase difference between the waves incorporates a certain level of noise. Bandpass filter is therefore used in a circuitry to eliminate or reduce the noise.

3.1.8 Antennas:

4 Antennas are placed at a certain distance from each other when they are switched one by one distance between the transmitter and the receiving antennas keep on changing. With changing distance from source to the destination produces a doppler effect. For our project the effect rather is pseudo doppler as antennas are not being displaced physically rather switched one by one.

3.2 Operating System Requirements:

Our project requires a minimum of 1 GB RAM, a 1.4 GHz processor, and a 32 Gb hard drive to store data. High performance controllers, on the other hand, can significantly improve performance. The minimum requirement is being filed by Raspberry Pi 3 B+.

3.3 Setting up working environment

This section offers information on how to install and configure software. To open raspberry pi on laptop, a wireless connection is established using Wi-Fi, allowing the view of the Raspberry Pi Graphic User Interface on the desktop monitor. A variety of software applications are available to connect a Raspberry Pi to our laptop. We used VNC software to connect the Pi to our laptop.

This also indicates that we can put our Pi wherever in our home and still control it. The VNC server is used to access the Pi on the desktop screen and is controlled by a keyboard and mouse.

3.3.1 Downloading Raspbian Image:

SD card is required with the OS installed before we can connect our Pi to our PC. There are many operating systems available for the Raspberry Pi, the most of which are based on Linux, although Raspbian is the most used one. This OS not only gives a fully working desktop environment with used apps like google chrome and word process, but italso has tools for programming. Raspbian, which is open source, has been designated as theprime OS for Pi by the Raspberry Pi Foundation since 2015.

To obtain this OS, go to https://www.raspberyrypi.com/software/ and download the most recent Raspbian from there.

There are other possibilities but to download the complete version, get the “Raspbian Pi OS with desktop and recommended software”. You can get the torrent or the ZIP file.

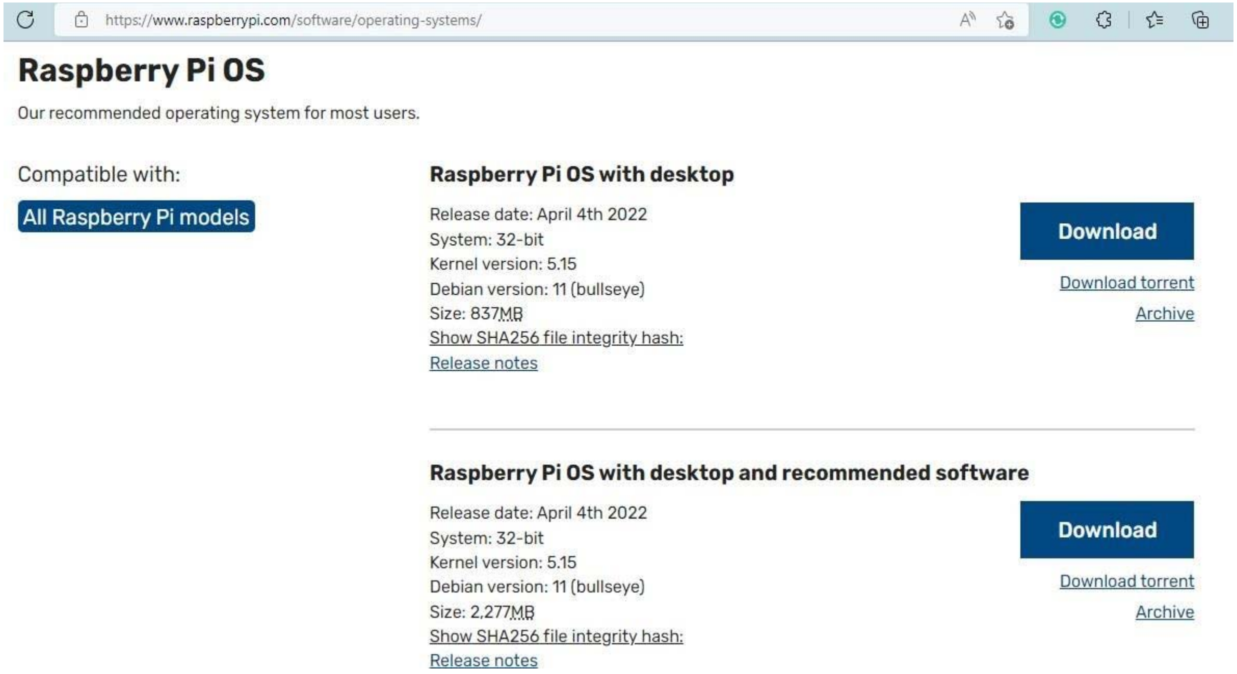

Figure 3-1: Raspberry Pi OS

3.3.2 To Write the Raspbian Image on SD card:

The Win32 Disk imager is required to write the image of raspberry on SD card. Firstly, install the win32 imager and run the setup. After downloading Raspbian, extract the file, launch https://sourceforge.net/projects/win32diskimager/ and download it.

Figure 3-2 Win32 Disk Imager

Check that the service selection box and the microSD card drive are both compatible. Use a card reader listed as 'F' drive and select it from the list in such case. Now that everything is in place, select "write" to save the image on SD card.

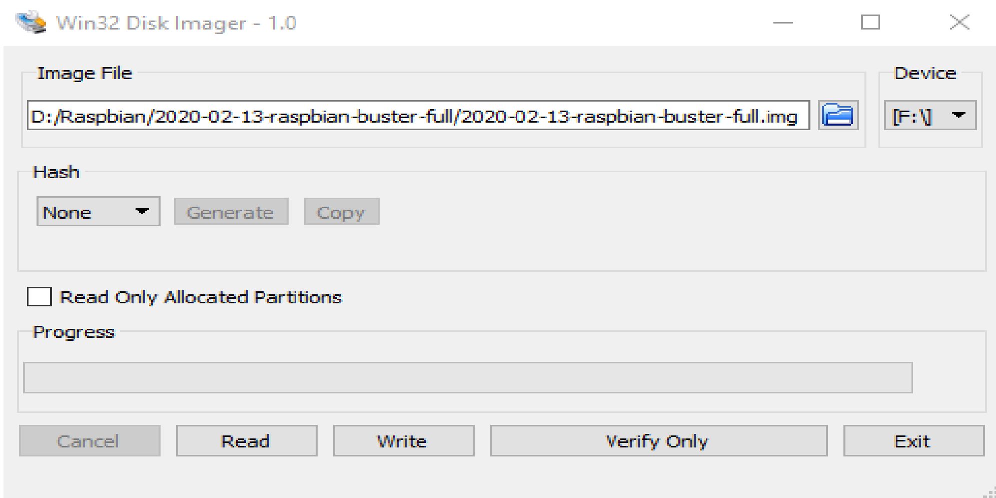

Figure 2-3: Win32 Disk Imager Environment

3.3.3 To Add additional file to enable and connect SSH to Wi-Fi:

Raspbian OS is installed when the image has been written. SD card needs to be updated new files to create SSH. The SSH file is required to connect with Wi-Fi. Create file "wpa supplicant.conf" change country enter the credentials of your Wi-Fi and connect to Wi-fi.

Create file called "wpa supplicant.conf" and replace the country code in the program, name of the Wi-Fi, and password. This will enable your Pi to connect to the wi-fi.

```
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1
country=PK #Your country code

network={
        ssid="My_WiFi" #Your WiFi Name
        psk="123456789" #Your WiFi password
        key_mgmt=WPA-PSK
}
```

Figure 3-4: Setting up SSH File

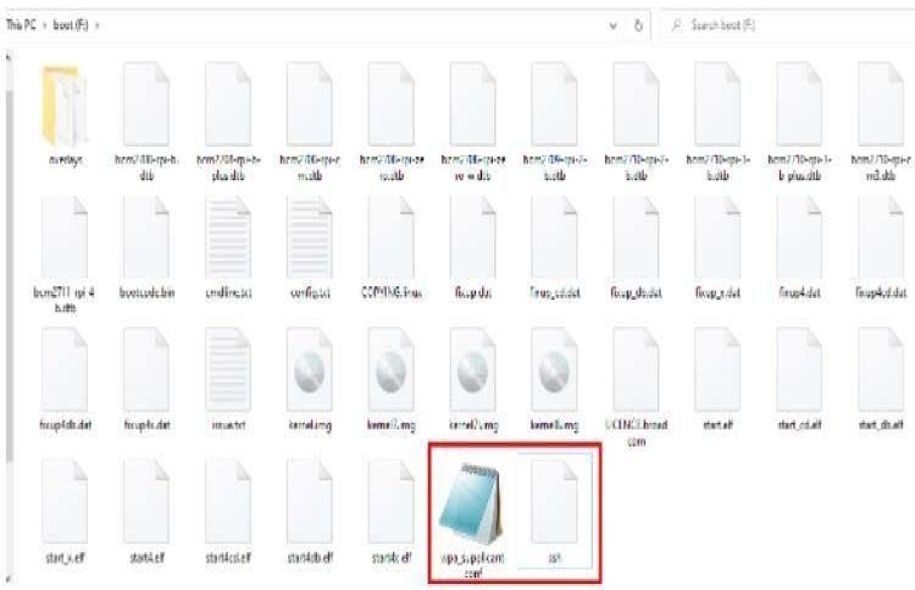

Figure 3-5: Setting SSH

On the SD Card, a file called "SSH" is generated with no extension. Your Raspberry Pi will be connected to the Internet. Now turn the Pi ON and insert the SD card.

3.4.4 Searching the IP Address of Raspberry Pi:

IP Scanner is used to determine Raspberry Pi's IP address in a professional way. Install and download the Advanced IP Scanner.

The Scan button will give a list of IP Addresses. Select the IP of your Pi from that list.

Copy this IP address to use it in the next step.

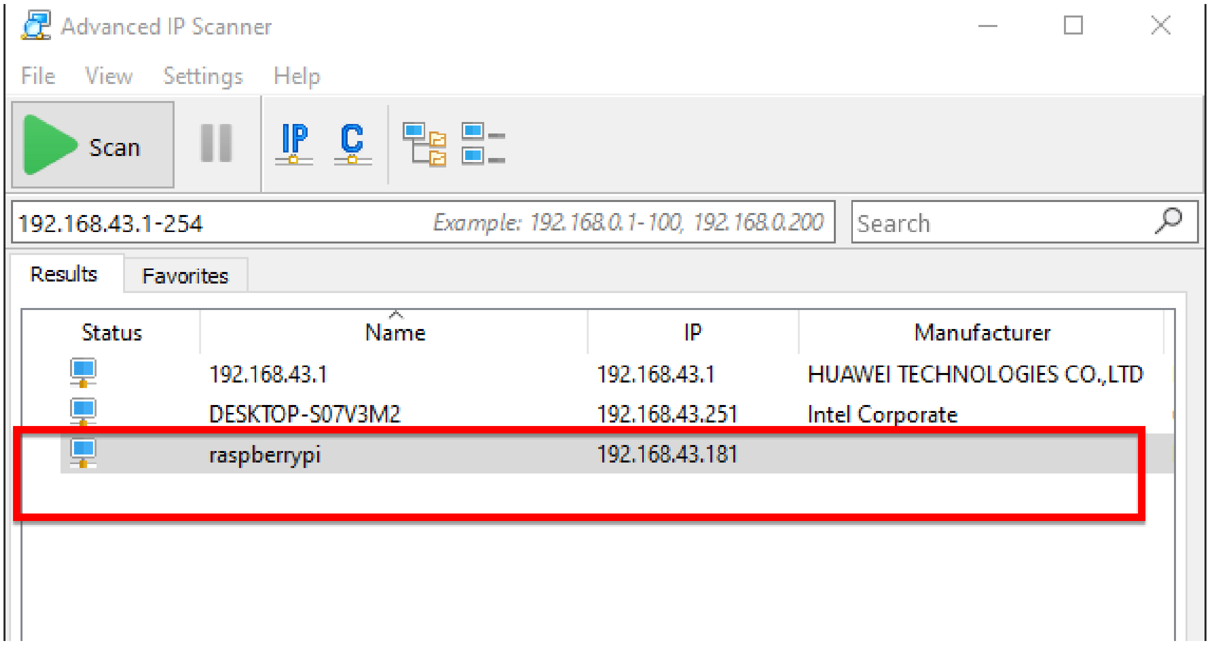

Figure 3-6: IP Scanner

3.4.5 Implementing SSH into Raspberry Pi:

We'll need the PuTTY program to SSH into the Raspberry Pi.

Install the PuTTY program on computer.

Open it, enter your Raspberry Pi's IP address (which we received in the previous step), and press the open button

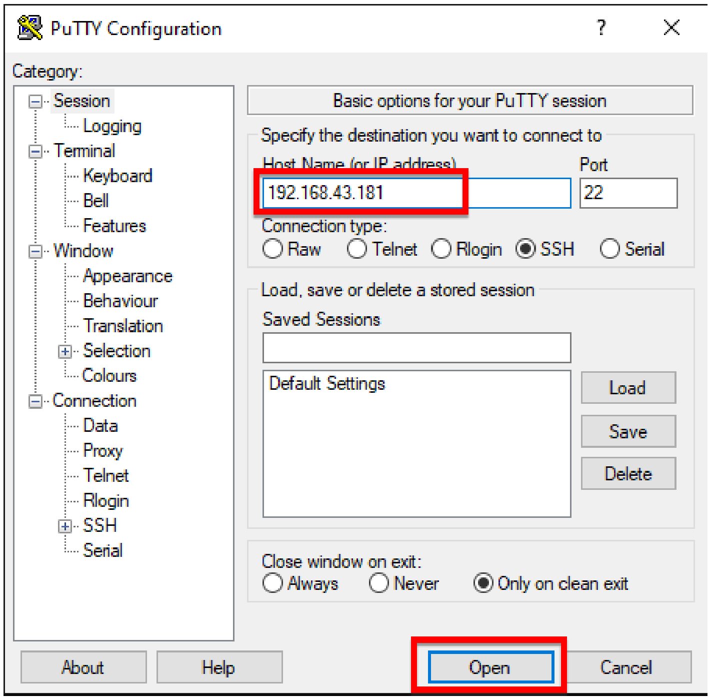

Figure 3-7: Putty Configuration

A security alert will be appeared because the connected host is unknown to us. Click 'Yes.'

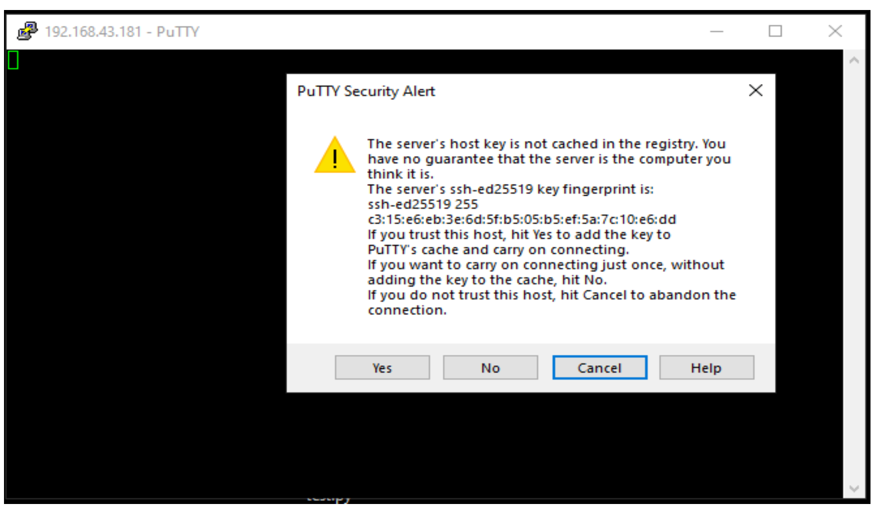

Figure 3-8: Putty Configuration

Following that, it will prompt you for your username and password. The username is ‘pi’ and password are 'raspberry', by default.

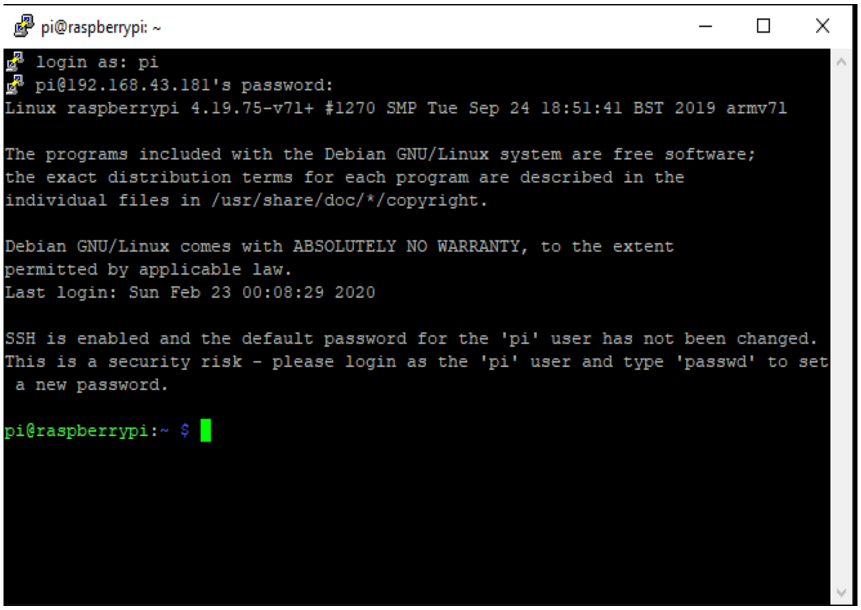

Figure 3-9: PI Configuration

3.4.6 Setting Up VNC Server:

Virtual Network Computing, VNC, is a desktop sharing technology that allows you to operate your Raspberry Pi from anywhere in the world via the internet.

The first step is to configure the Raspberry Pi's VNC server so that it could be controlled remotely. Open the terminal and type “sudo apt-get update” to configure the VNC server.

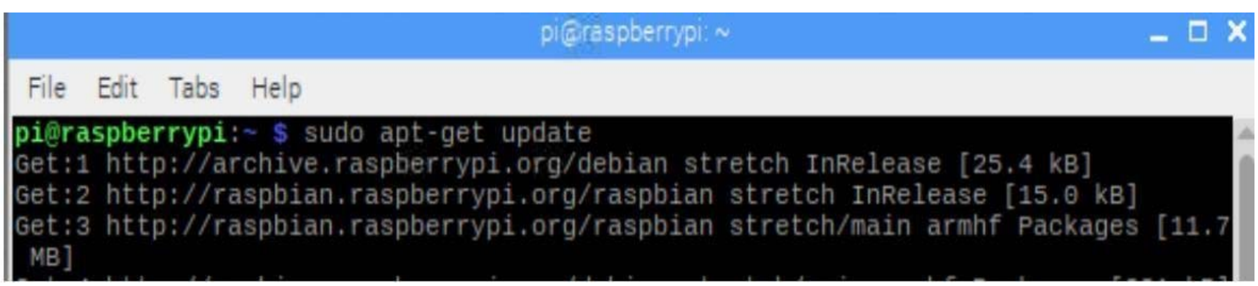

Figure 3-10: Setting up VNC Step 1

After the successful completion of update, type “sudo apt-get install realvnc-vnc-server realvnc-vnc-viewer”. It will install the real VNC server on Pi.

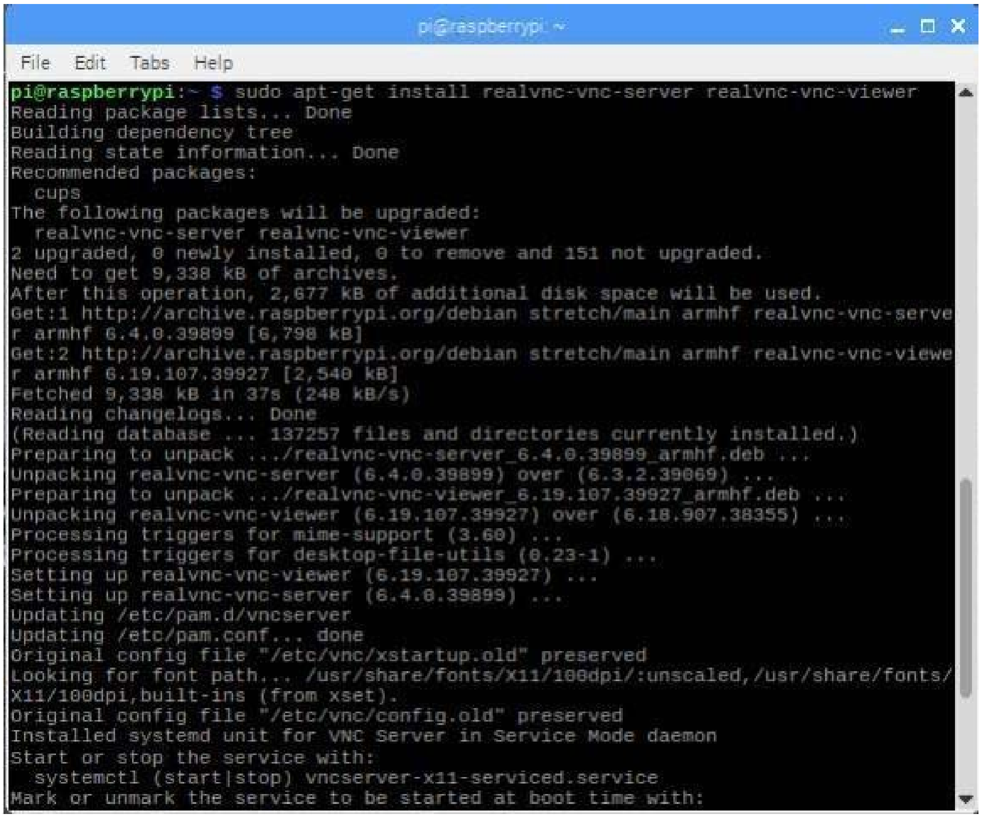

Figure 3-11: Setting up VNC Step 2

The next step is to enable the VNC server.

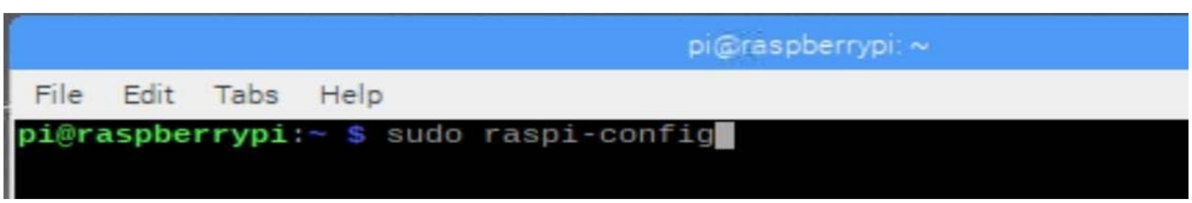

Figure 3-12: Enable VNC Server

To enable the VNC server on Pi type "sudo raspi-config".

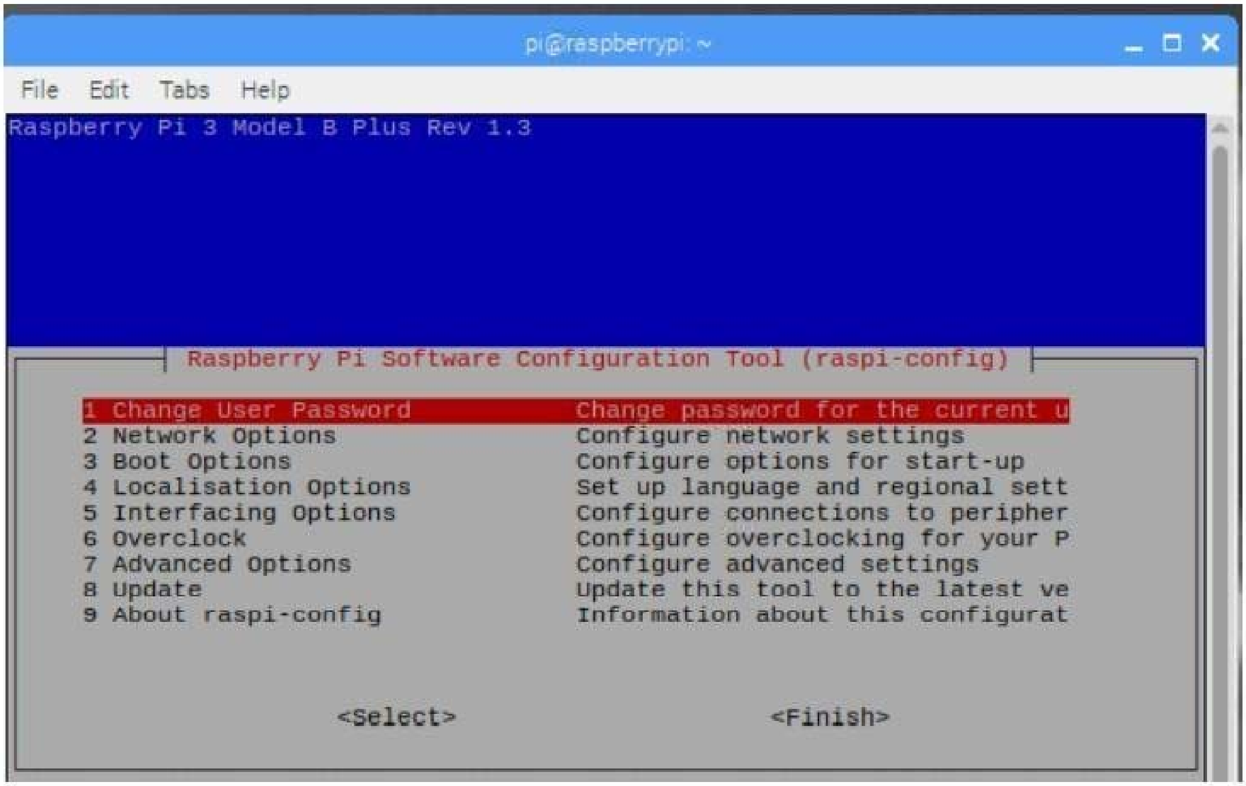

Figure 3-13: Setting up VNC Step 4

Scroll down to the "Interfacing Option" and press Enter.

Figure 3-14: Setting up VNC Step 5

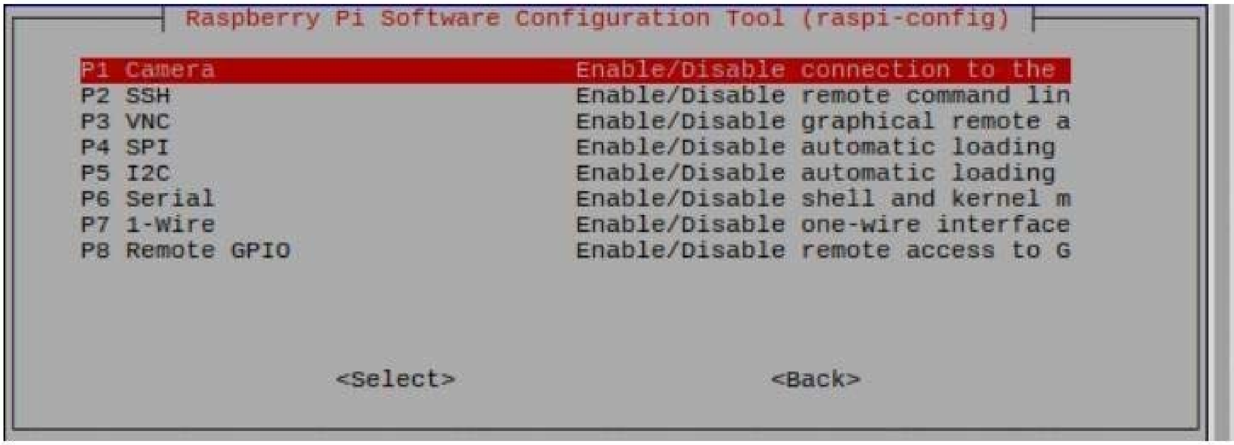

Figure 3-15: Setting up VNC Step 6

In the next window scroll down to "P3 VNC" and press Enter.

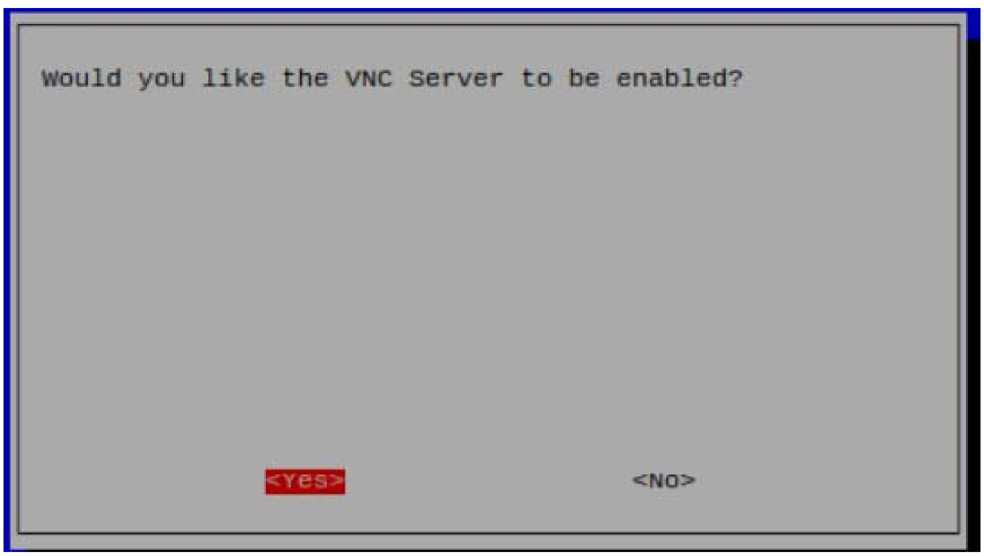

Figure 3-13: Setting up VNC Step 7

This option asks for enabling the VNC Server by Entering on "Yes"

Figure 3-14: Setting up VNC Step 8

After Entering on “Yes” the new window will appear which will be validating that the VNC Server has been Enabled. Press “OK” to continue and the first initial window will appear again.

Figure 3-15: Setting up VNC Step 9

Use “Tab” to scroll down to the “Finish” button and press “Enter”. And the VNC Server is Enable. Now open the VNC Server by clicking on the icon of VNC on the top right corner.

Figure 3-16: Setting up VNC Step 10

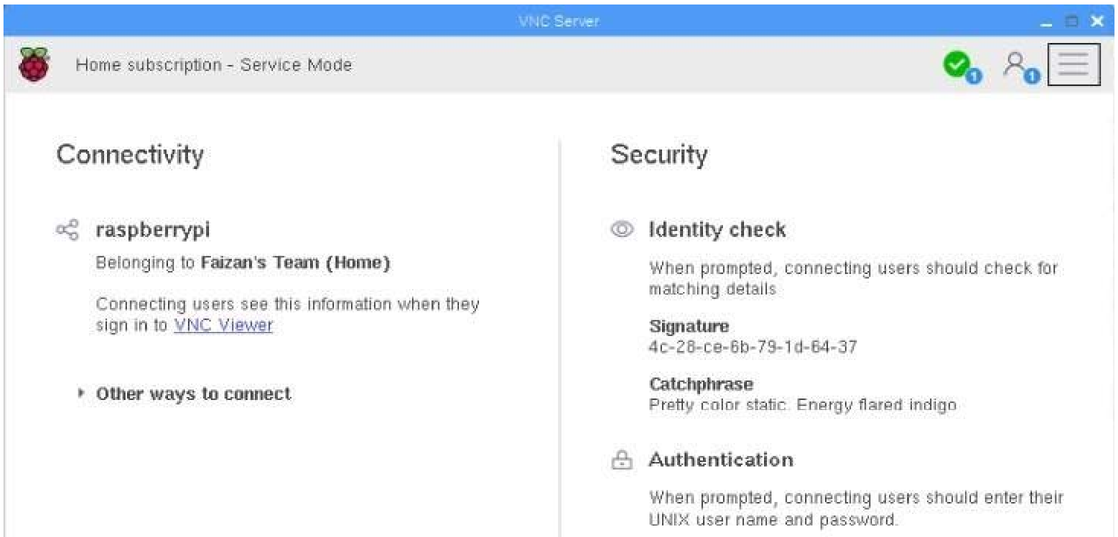

Figure 3-17: Setting up VNC Step 11

Sign in to the VNC server using a valid Gmail account by selecting "Other methods to connect" and then clicking Sign in.

VNC Server allows a maximum of 5 people to connect to the Raspberry Pi.

After that, the user must simply install the VNC Server on his laptop and sign in with his credentials.

the same account to remotely access the Raspberry Pi.

Chapter 4: Code Analysis

Following are the codes used at different stages in our project.

4.1 GPS & Raspberry Pi Integration:

```
import serial
import time
import string
import pynmea2

while True:
        port="/dev/ttyAMA0"
        ser=serial.Serial(port, baudrate=9600, timeout=0.5)
        dataout = pynmea2.NMEAStreamReader()
        newdata=ser.readline()

        if newdata[0:6] == "$GPRMC":
                newmsg=pynmea2.parse(newdata)
                lat=newmsg.latitude
                lng=newmsg.longitude
                gps = "Latitude=" + str(lat) + "and Longitude=" + str(lng)
                print(gps)
```

4.2 Phase Difference & Phase Angle:

```
void PrintVector(double *vData, uint16_t bufferSize, uint8_t scaleType)
{
  for (uint16_t i = 0; i < bufferSize; i++)
  {
    double abscissa;
    /* Print abscissa value */
    switch (scaleType)
    {
      case SCL_INDEX:
        abscissa = (i * 1.0);
  break;
      case SCL_TIME:
        abscissa = ((i * 1.0) / samplingFrequency);
  break;
      case SCL_FREQUENCY:
        abscissa = ((i * 1.0 * samplingFrequency) / samples);
  break;
    }
    Serial.print(abscissa, 6);
    if(scaleType==SCL_FREQUENCY)
      Serial.print("Hz");
    Serial.print(" ");
    Serial.println(vData[i], 4);
  }
  Serial.println();
}
```

```
  PrintVector(vReal1, samples, SCL_INDEX);
  Serial.println("Signal 1 IMG Value: ");
  PrintVector(vImag1, samples, SCL_INDEX);
  Serial.println("Signal 2 Real Value: ");
  PrintVector(vReal2, samples, SCL_INDEX);
  Serial.println("Signal 2 IMG Value: ");
  PrintVector(vImag2, samples, SCL_INDEX);

  FFT.ComplexToMagnitude(vReal1, vImag1, samples); /* Compute magnitudes */
  FFT.ComplexToMagnitude(vReal2, vImag2, samples);
  Serial.println("Computed magnitudes signal 1:");
  PrintVector(vReal1, (samples >> 1), SCL_FREQUENCY);
  Serial.println("Computed magnitudes signal 2:");
  PrintVector(vReal2, (samples >> 1), SCL_FREQUENCY);
  double x = FFT.MajorPeak(vReal1, samples, samplingFrequency);
  Serial.println("Dominant Frequency Signal 1");
  Serial.println(x, 6); //Print out what frequency is the most dominant.
  double y = FFT.MajorPeak(vReal2, samples, samplingFrequency);
  Serial.println("Dominant Frequency Signal 2");
  Serial.println(y, 6);
  delay(2000); /* Repeat after delay */
}
```

```
void loop()
{
  /*SAMPLING*/
  microseconds = micros();
  for(int i=0; i<samples; i++)
  {
      vReal1[i] = analogRead(CHANNEL1);
      vImag1[i] = 0;
      vReal2[i] = analogRead(CHANNEL2);
      vImag2[i] = 0;

      float phaseDiff1 = atan2(vImag1[i],vReal1[i]);
      float phaseDiff2 = atan2(vImag2[i],vReal2[i]);

      Serial.println("Phase Difference of Signals:");
      Serial.print(phaseDiff1 - phaseDiff2);
      while(micros() - microseconds < sampling_period_us){
        //empty loop
      }
      microseconds += sampling_period_us;
  }
  /* Print the results of the sampling according to time */
  FFT.Windowing(vReal1, samples, FFT_WIN_TYP_HAMMING, FFT_FORWARD); /* Weigh data */
  FFT.Windowing(vReal2, samples, FFT_WIN_TYP_HAMMING, FFT_FORWARD);
  FFT.Compute(vReal1, vImag1, samples, FFT_FORWARD); /* Compute FFT */
  FFT.Compute(vReal2, vImag2, samples, FFT_FORWARD);
  Serial.println("Signal 1 Real Value: ");
```

```
#include "arduinoFFT.h"

arduinoFFT FFT = arduinoFFT(); /* Create FFT object */
#define CHANNEL1 A0
#define CHANNEL2 A1
const uint16_t samples = 64; //This value MUST ALWAYS be a power of 2 //64
const double samplingFrequency = 100; //Hz, must be less than 10000 due to ADC

unsigned int sampling_period_us;
unsigned long microseconds;

double vReal1[samples];
double vImag1[samples];
double vReal2[samples];
double vImag2[samples];

#define SCL_INDEX 0x00
#define SCL_TIME 0x01
#define SCL_FREQUENCY 0x02
#define SCL_PLOT 0x03

void setup()
{
  sampling_period_us = round(1000000*(1.0/samplingFrequency));
  Serial.begin(115200);
  while(!Serial);
  Serial.println("Ready");
}
```

4.3 Compass Integration & Calibration:

```
        ax = lib.lsm9ds1_getAccelX(imu)
        ay = lib.lsm9ds1_getAccelY(imu)
        az = lib.lsm9ds1_getAccelZ(imu)

        mx = lib.lsm9ds1_getMagX(imu)
        my = lib.lsm9ds1_getMagY(imu)
        mz = lib.lsm9ds1_getMagZ(imu)

        cgx = lib.lsm9ds1_calcGyro(imu, gx)
        cgy = lib.lsm9ds1_calcGyro(imu, gy)
        cgz = lib.lsm9ds1_calcGyro(imu, gz)

        cax = lib.lsm9ds1_calcAccel(imu, ax)
        cay = lib.lsm9ds1_calcAccel(imu, ay)
        caz = lib.lsm9ds1_calcAccel(imu, az)

        cmx = lib.lsm9ds1_calcMag(imu, mx)
        cmy = lib.lsm9ds1_calcMag(imu, my)
        cmz = lib.lsm9ds1_calcMag(imu, mz)

        print("Gyro: %f, %f, %f [deg/s]" % (cgx, cgy, cgz))
        print("Accel: %f, %f, %f [Gs]" % (cax, cay, caz))
        print("Mag: %f, %f, %f [gauss]" % (cmx, cmy, cmz))

        calculate_heading(cax, cay, caz, cmx, cmy, cmz)
```

```
    print("Heading: %f [deg/s]" % (heading))
    print("Roll: %f [Gs]" % (roll))
    print("Pitch: %f [gauss]" % (pitch))

if __name__ == "__main__":
    imu = lib.lsm9ds1_create()
    lib.lsm9ds1_begin(imu)
    if lib.lsm9ds1_begin(imu) == 0:
        print("Failed to communicate with LSM9DS1.")
        quit()
    lib.lsm9ds1_calibrate(imu)

    while True:
        while lib.lsm9ds1_gyroAvailable(imu) == 0:
            pass
        lib.lsm9ds1_readGyro(imu)
        while lib.lsm9ds1_accelAvailable(imu) == 0:
            pass
        lib.lsm9ds1_readAccel(imu)
        while lib.lsm9ds1_magAvailable(imu) == 0:
            pass
        lib.lsm9ds1_readMag(imu)

        gx = lib.lsm9ds1_getGyroX(imu)
        gy = lib.lsm9ds1_getGyroY(imu)
        gz = lib.lsm9ds1_getGyroZ(imu)
```

```
lib.lsm9ds1_calcGyro.argtypes = [c_void_p, c_float]
lib.lsm9ds1_calcGyro.restype = c_float
lib.lsm9ds1_calcAccel.argtypes = [c_void_p, c_float]
lib.lsm9ds1_calcAccel.restype = c_float
lib.lsm9ds1_calcMag.argtypes = [c_void_p, c_float]
lib.lsm9ds1_calcMag.restype = c_float

def calculate_heading(ax, ay, az, mx, my, mz):
    float roll = atan2(ay, az);
    float pitch = atan2(-ax, sqrt(ay * ay + az * az));

    float heading;
    if (my == 0)
    heading = (mx < 0) ? PI : 0;
    else
    heading = atan2(mx, my);

    heading -= DECLINATION * PI / 180;

    if (heading > PI) heading -= (2 * PI);
    else if (heading < -PI) heading += (2 * PI);

    // Convert everything from radians to degrees:
    heading *= 180.0 / PI;
    pitch *= 180.0 / PI;
    roll  *= 180.0 / PI;
```

```
lib.lsm9ds1_readAccel.argtypes = [c_void_p]
lib.lsm9ds1_readAccel.restype = c_int
lib.lsm9ds1_readMag.argtypes = [c_void_p]
lib.lsm9ds1_readMag.restype = c_int

lib.lsm9ds1_getGyroX.argtypes = [c_void_p]
lib.lsm9ds1_getGyroX.restype = c_float
lib.lsm9ds1_getGyroY.argtypes = [c_void_p]
lib.lsm9ds1_getGyroY.restype = c_float
lib.lsm9ds1_getGyroZ.argtypes = [c_void_p]
lib.lsm9ds1_getGyroZ.restype = c_float

lib.lsm9ds1_getAccelX.argtypes = [c_void_p]
lib.lsm9ds1_getAccelX.restype = c_float
lib.lsm9ds1_getAccelY.argtypes = [c_void_p]
lib.lsm9ds1_getAccelY.restype = c_float
lib.lsm9ds1_getAccelZ.argtypes = [c_void_p]
lib.lsm9ds1_getAccelZ.restype = c_float

lib.lsm9ds1_getMagX.argtypes = [c_void_p]
lib.lsm9ds1_getMagX.restype = c_float
lib.lsm9ds1_getMagY.argtypes = [c_void_p]
lib.lsm9ds1_getMagY.restype = c_float
lib.lsm9ds1_getMagZ.argtypes = [c_void_p]
lib.lsm9ds1_getMagZ.restype = c_float
```

LSM9DS1_Basic_I2C.py

```python
#!/usr/bin/env python
# coding: utf-8

#import ctypes
from ctypes import *

path = "../lib/liblsm9ds1cwrapper.so"
lib = cdll.LoadLibrary(path)

lib.lsm9ds1_create.argtypes = []
lib.lsm9ds1_create.restype = c_void_p

lib.lsm9ds1_begin.argtypes = [c_void_p]
lib.lsm9ds1_begin.restype = None

lib.lsm9ds1_calibrate.argtypes = [c_void_p]
lib.lsm9ds1_calibrate.restype = None

lib.lsm9ds1_gyroAvailable.argtypes = [c_void_p]
lib.lsm9ds1_gyroAvailable.restype = c_int
lib.lsm9ds1_accelAvailable.argtypes = [c_void_p]
lib.lsm9ds1_accelAvailable.restype = c_int
lib.lsm9ds1_magAvailable.argtypes = [c_void_p]
lib.lsm9ds1_magAvailable.restype = c_int

lib.lsm9ds1_readGyro.argtypes = [c_void_p]
lib.lsm9ds1_readGyro.restype = c_int
```

Chapter 5: Future Work

Future milestones that need to be achieved to commercialize this project are the following.

5.1 Locating the Mobile Phones and Ariel Automation:

The Mobile phones also works on the radio frequency. So, if we introduce a feature that can enable the tracking of mobile phones it will be an enormous success. The tracking of mobile phones is a highly tedious tasks as they use multiplexing techniques like TDMA, FDMA, CDMA which changes their frequencies.Hence locating a particular frequency becomes difficult job. Making the mobile phones trackable using this equipment will be a huge achievement which will open more ways for commercial use and applications.

Another improvement that can be made is the automation of ariel surveillance. As we are using drone for locating the pirate transmitter it needs to be operated manually. But the automation will allow the drone to move towards the transmitter based upon the signal strength.

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