

Developing a mesh network in a wooded area



A Final year project Submitted Towards Consideration
for a Bachelor of Engineering

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Glossary

| | | | |
|--------------|--|--------------|--|
| APD | Avalanche PhotoDiode | MC | Multiple-Carrier |
| API | Application Programming Interface | MIMO | Multiple Input Multiple Output |
| ASK | Amplitude Shift Keying | MLSE | Maximum Likelihood Sequence Estimation |
| AWG | Agile Waveform Generator | MMF | Multi Mode Fiber |
| B2B | Back-2-Back | MSK | Minimum Shift Keying |
| BBP | Baseband Processor | MSO | Mixed Signal Oscilloscope |
| BER | Bit Error Ratio | MZI | Mach-Zehnder Interferometer |
| BL | Bandwidth-Length | MZM | Mach-Zehnder Modulator |
| BLAST | Bell Labs <u>L</u> ayered <u>S</u> pace <u>T</u> ime | NGPON | Next Generation Passive Optical Network |
| BT | Time Bandwidth Product | NLSE | Non-Linear Schrödinger Equation |
| CD | Chromatic Dispersion | NRZ | Non-Return to Zero |
| CDMA | Code Division Multiple Access | ODN | Optical Distribution Network |
| CPM | Continuous Phase Modulation | OS | operating system (OS) |
| CSI | Channel State Information | OFDM | Orthogonal Frequency Division Multiplexing |
| D | Dispersion Coefficient | OOK | On Off Keying |
| DD | Direct Detection | OSA | Optical Spectrum Analyzer |
| DECT | Digital Enhanced Cordless Telecommunications | OSNR | Optical Signal to Noise Ratio |
| DPO | Digital Phosphorous Oscilloscope | PAPR | Peak to Average Power Ratio |
| DPM | Digital Phase Modulation | PD | Photo Diode |
| DSP | Digital Signal Processing | P-i-N | P-doped Intrinsic N-doped Photodiode |
| EDFA | Eridium Doped Fiber Amplifier | PON | Passive Optical Network |
| FBMC | Filter Bank Multi-Carrier | PRS | Partial Response Signalling |
| FDM | Frequency Division Multiplex | QMDD | Quadrature Modulation Direct Dectection |
| FDMA | Frequency Division Multiple Access | RF | Radio Frequency |
| FEA | Finite Element Analysis | RIN | Relative Intensity Noise |
| FEC | Forward Error Correction | SCPI | Standard Commands for Programmable Instruments |
| FFT | Fast Fourier Transform | SISO | Single Input Single Output |
| FIR | Finite Impulse Response | SMF | Single Mode Fiber |
| FRS | Full Response Signalling | SNR | Signal to Noise Ratio |
| FTTx | Fiber To The x | SOA | Semiconductor Optical Amplifier |
| GASK | Gaussian Amplitude Shift Keying | SPM | Self Phase Modulation |
| GFDM | Generalised Frequency Division Multiplexing | SS | Spread Spectrum |
| GIPO | General Purpose Input/Output | SSFM | Split-Step Fourier Method |
| GLPF | Gaussian Low-Pass Filter | SSSFM | Symmetricised Split Step Fourier Method |
| GMSK | Gaussian Minimum Shift Keying | TCM | Trellis Coded Modulation |
| GSM | Global System for Mobile Communications | TDM | Time Division Multiplex |
| GVD | Group Velocity Dispersion | TDMA | Time Division Multiple Access |
| IFFT | Inverse Fast Fourier Transform | TFM | Tamed Frequency Modulation |
| IIR | Infinite Impulse Response | TIA | TransImpedance Amplifier |
| IMDD | Intensity Modulation Direct Detection | UFMC | Universal Filtered Multiple Carrier |
| ISI | InterSymbol Interference | USB | Universal Serial Bus |
| IVI | Interchangeable Virtual Intruments | VISA | Virtual Instrument Software Architecture |
| LAN | Local Area Network | WDM | Wave Division Multiplex |
| LD | Dispersion Length | | |
| LD | Laser Diode | | |
| LUT | Look-Up Table | | |

Chapter 1

Literature Review

[

1.1 Introduction

The following literature review explores mesh networks in a wooded area, when communicating from two devices across a network there are a lot of issues associated with this communication such as signal loss due to:

- Environmental conditions such as rain .lighting etc
- If the device's antenna is in line of sight with each other
- Even if the devices are in the line of sight we can still reflections from a multi-path environment
- Possibility of trees falling obstructing the path of the signal causing more attenuation in the signal strength

In this project I want to explore mesh networks and transmit data across them, a mesh network is a type of network where no node(a node is just a device which has a transceiver) in the network acts as a master. As we look at the environment in which this project aims to be, we expect different phenomena to occur such as Attenuation According to ITU ? "attenuation due to vegetation varies widely due to the irregular Nature of the medium and the wide range of species, densities and water content obtained in practice" when transmitting any radio wave it takes energy another factor to consider is whether wind which will cause a delay in the signal. this report aims to show my findings and try to count for Environmental conditions

1.1.1 Overview

This section provides a brief overview of my project on mesh networks in a forest the following question is:

1. What frequencies can transmit in a forest
 - What are the Disadvantages of transmitting at this range
 - What are the effects of the multi-path environment when there is a line of sight
 - What happens to Non-line of sight
2. What sensors /senor modules do we use
 - What sensors will give us a good range in an Irish forest

- What are the limitations on the board we use
 - Do we need to have any additional hardware to accommodate a specific board
3. What microprocessor/hardware do we use?
- What advantages/Disadvantages of Arduino vs Raspberry Pi
 - What is the major factor in the choice
 - How are the sensors wired to the processor
 - How to read the data
 - What is the effective Resolution needed for each application

1.1.2 Mesh network

A mesh network is a type of network that uses multiple devices to relay data between each other, making a decentralized network the mesh we looking to use is a wireless mesh network which is created through the connection of wireless access point(WAP) nodes. wireless mesh networks work through mesh nodes, mesh clients and gateways:

1. Mesh node nodes act as mesh routers and endpoints
2. Mesh clients these are end devices
3. Gateways data passes through the gateway as it enters or exits a network

The following is a block diagram of a mesh network each node will be attached to a tree each

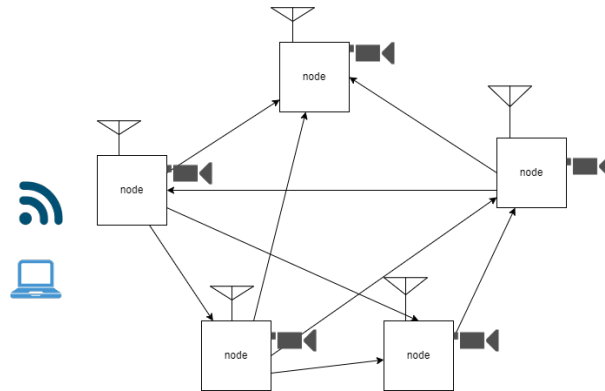


Figure 1.1: Basic block diagram of a mesh network

having a transceiver

1.2 Hardware Consideration

In this project we need to have data to transmit firstly let's describe what we want our network to have:

1. we want our mesh network to transmit data for example temperature, humidity and light and camera
2. I want there to be data read every hour and stored as a CSV file the image file will depend on the module I pick
3. I want to have a motion to detect any animal that passes the node

the following is a rough circuit diagram for the project: firstly let's establish the following:

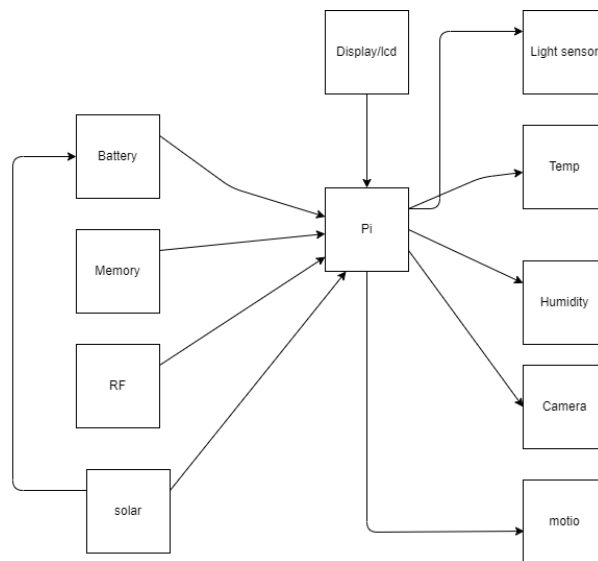


Figure 1.2: Rough circuit diagram for project

1. I can't use PCB due to the ordering process taking too long to come due to the time given to me
2. using any type of board like wire wrap would take too long and is outside of the goals of this project
3. This leaves with a choice of either the Arduino or pi

This section will Dicuss the following:

1. The sensors we will use in the project
2. the ADC we will have to will have to consider
3. the camera i picked considation for in this project
4. the memory module condestrations
5. the battery i picked
6. Considering the arduino vs PI

1.2.1 Sensor considerations

In this section, we will discuss the process of considering each commponet of the sensors these sensor will be the following:

1. Temperature
2. Humdity
3. Light
4. Motion

Temperature & Humidity sensor

In our consideration for this sensor we can establish that we want our sensor to work in the following conditions:

1. our mesh node will be outside
2. Our device is in Ireland
3. Our device is in a forest

From that knowledge, I researched the temperature range in Ireland,

According to Met eireann?, we get the following table which the highest temperature in a Shaded

| Highest Shaded Air (°C) | Station | Date |
|-------------------------|----------------------------------|-----------|
| 18.5°C | Dublin (Glasnevin) | 10th 1998 |
| 18.1°C | Dublin (Phoenix Park) | 23rd 1891 |
| 23.6°C | Dublin (Trinity College) | 28th 1965 |
| 25.8°C | Donegal (Glenties) | 26th 1984 |
| 28.4°C | Kerry (Ardfert Liscahane) | 31st 1997 |
| 33.3°C | Kilkenny (Kilkenny Castle) | 26th 1887 |
| 33.0°C | Dublin (Phoenix Park) | 18th 2022 |
| 31.7°C | Carlow (Oak Park) | 12th 2022 |
| 29.1°C | Kildare (Clongowes Wood College) | 1st 1906 |
| 25.2°C | Kildare (Clongowes Wood College) | 3rd 1908 |
| 20.1°C | Kerry (Dooks) | 1st 2015 |
| 18.1°C | Dublin (Peamount) | 2nd 1948 |

Table 1.1: Highest shader air Met Eireann(13th June 2023)

According to the table, the highest temperature is 33.3 now to look at the other extreme for the Lowest temperature:

| Lowest Shaded Air (°C) | Station | Date |
|------------------------|---------------------|-----------|
| -19.1°C | Sligo (Markree) | 16th 1881 |
| -17.8°C | Longford (Mostrim) | 7th 1895 |
| -17.2°C | Sligo (Markree) | 3rd 1947 |
| -7.7°C | Sligo (Markree) | 15th 1892 |
| -5.6°C | Donegal (Glenties) | 4th 1979 |
| -3.3°C | Offaly (Clonsast) | 1st 1962 |
| -0.3°C | Longford (Mostrim) | 8th 1889 |
| -2.7°C | Wicklow (Rathdrum) | 30th 1964 |
| -3.5°C | Offaly (Clonsast) | 8th 1972 |
| -8.3°C | Sligo (Markree) | 31st 1926 |
| -11.5°C | Wexford (Clonroche) | 29th 2010 |
| -17.5°C | Mayo (Straide) | 25th 2010 |

Table 1.2: Lowest shader air Met Eireann(13th June 2023)

According to the table above the lowest temp is -19.1 In consideration for where the project our condition was a range of -19.1°C to 33.3°C.

I also looked at humidity this refers to the amount of water vapor in the air. from met eirrean ? got this table: The ranges are 68.3% to 88 % So with these considerations here are

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Mean at 0900UTC | 87.0 | 86.4 | 84.0 | 79.5 | 76.9 | 76.7 | 78.5 | 81.0 | 83.4 | 85.5 | 88.5 | 88.0 | 83.0 |
| Mean at 1500UTC | 80.6 | 75.7 | 71.0 | 68.3 | 68.0 | 68.3 | 69.0 | 69.3 | 71.5 | 75.1 | 80.3 | 83.1 | 73.3 |

Table 1.3: Relative Humidity(%) according to met eirrean

the different components:

| Components | Voltage Range | temperature range | Accuracy | Analogue /Digital outputs | Current in | additional information |
|------------|------------------|-------------------|----------------------------------|---------------------------|------------|-------------------------|
| DHT22 | 3-6 volts | -40 to 80 °C | +/-0.5°C | Digital | 1.5mA | sample period 2 seconds |
| LM35D2 | 4 -30 Volts | -55 to 150 | +/-0.5°C (at 25°C) | Analogue | 10mA | None |
| TMP36 | 2.7 to 5.5 Volts | -40 to 125 | +/-1°C (at 25°C) | Analogue | 250 µA | NONE |
| LM75 | 3.0 to 5.5V | -55 to 125°C | +/-2.0°C (at -55 to 125°C range) | Analogue | 100 µA | NONE |
| DHT11 | 3-5.5V | 0-50 °C | ±2°C | Digital | 1mA | sample period 1 second |

Table 1.4: Comparing of temperature sensors

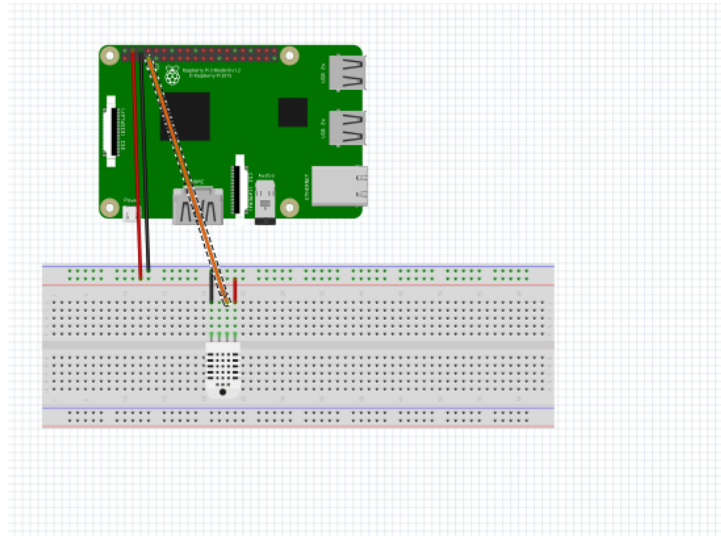
After this, I limited this down to two sensors DHT22 and DHT11. The following are the advantages and disadvantages of the DHT22 and DHT11: So in conclusion I choose DHT22

| Device | Advantages | Disadvantages |
|--------|--|---|
| DHT22 | good accuracy has temp and humidity, falls in our temp range | sample period 2 seconds |
| DHT11 | OK voltage,better sample period | draws a lot of current , and our of range |

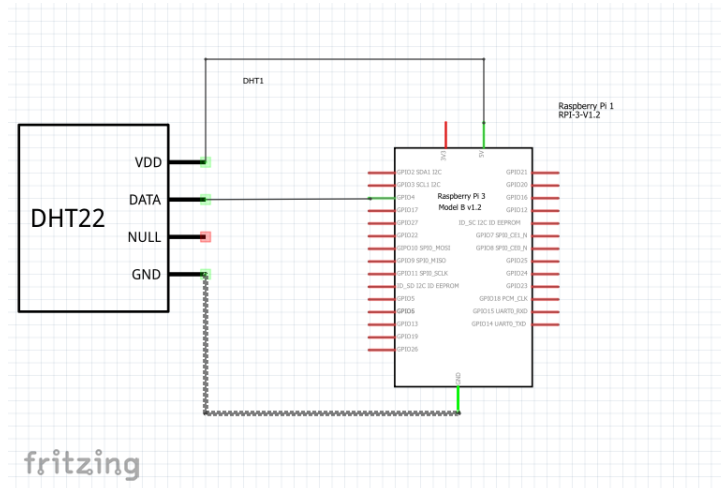
Table 1.5: Comparing DHT22 and DHT11

which is a Digital output. See a wiring diagram below

This will have an Interface of the following:



(a) Interface for DHT22



(b) Schematic for DHT22

From above we see our schematic, DHT22 connections are the following:

- VDD is connected to 5v of the pi
- the Data pin is connected to GPIO 3
- Gnd pin of the pi is connected to the ground of DHT22

? The following is the link to the datasheet of this module when reading from this component there is a delay of 2 second due to the sampling period.

Light sensor

In this section, we want to consider the following:

1. What region are we in
2. What light levels do we expect in this country
3. What sensor will accommodate this range

For this sensor we also must consider the outside aspect of the project i found this table on ? This table is the assoicated lux level incate when the vaules are . From above we want

| Imminence | Example |
|---------------------------|---|
| **0.002 lux** | Moonless clear night sky |
| **0.2 lux** | Design minimum for emergency lighting (AS2293). |
| **0.27 & 1 lux** | Full moon on a clear night |
| **3.4 lux** | Dark limit of civil twilight under a clear sky |
| **50 lux** | Family living room |
| **80 lux** | Hallway/toilet |
| **100 lux** | Very dark overcast day |
| **300 to 500 lux** | Sunrise or Sunset on a clear day. Well-lit office area. |
| **1,000 lux** | Overcast day; typical TV studio lighting |
| **10,000 to 25,000 lux** | Full daylight (not direct sun) |
| **32,000 to 130,000 lux** | Direct sunlight |

Table 1.6: Illuminates values

our sensor to be 0.002 to 25000 lux ideally, with that in mind here are the components I found through research:

| Modules | Voltage Range | Analogue /Digital Outputs | illumination range | Current rating |
|-----------------------|---------------|---------------------------|--------------------|----------------|
| LM393 with GL5528 | 3.3v to 5v | Analogue | 0 lux to 100lux | 250nA |
| DFR0026 | 3.3v to 5v | Analogue | 1 Lux to 6000 Lux | 120uA |
| LM393 with n5ac501085 | max 150V | Analogue | 10 lux to 100lux | 1mW |
| LM393 with NSL-06S53 | max 100v | analogue | 1 to 100 | 50mw |

Table 1.7: table of light sensors

After doing research DFR0026 ? is the option I propose to use as it is the best for our application which will have an analogue output to see the interface see below:

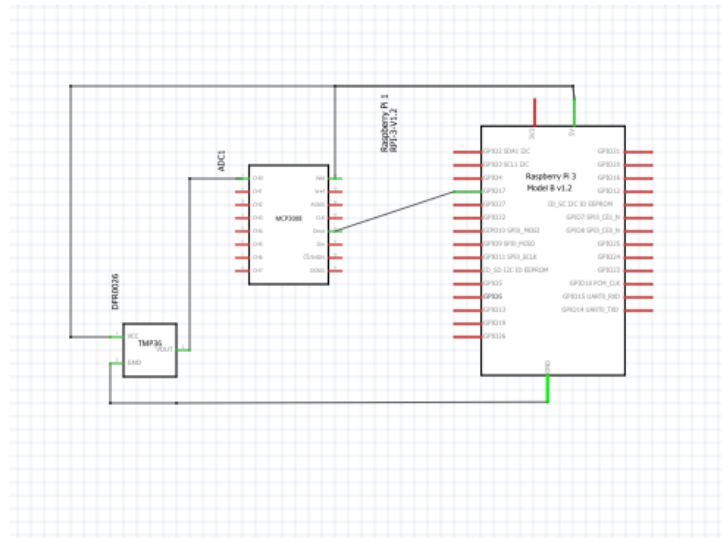


Figure 1.4: Interface for DFR0026

The following are the connections:

1. VCC pin is connected to 5v
2. Gnd of the sensor is connected to Gnd of the Pi
3. The output is connected to ch 0
4. the output ranges from 0 to 5 v

The commpoent relies on the ADC which is on page??

Motion sensor

For this section, we have to consider the following:

1. The range of the sensor
2. The degree of the sensor
3. How long of a delay is the sensor

The following are the components I considered:

| Modules | Voltage Range | Distance | Max angle | Analogue /Digital Outputs | Power |
|----------|---------------|----------|-----------|---------------------------|-------|
| HC-SR501 | 5-20V | 3 to 7m | 110 | Digital | 50uA |
| AM312 | 4.5-20v | 3m | 130 | Digital | 60uA |
| AS312 | -0.3 - 3.6V | 12m | 130 | Digital | 100mA |

Table 1.8: Motion sensor components

The sensor I'm choosing is AS312?(which has a delay time of 2 seconds) which is a Digital interface to see the wiring see below:

the following is the interface for our device

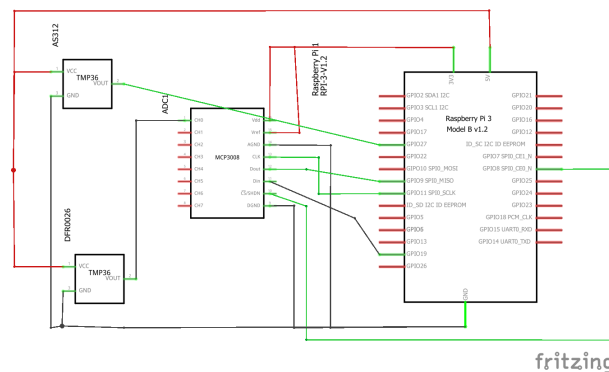


Figure 1.5: Interface for AS312

The connections are the following:

1. VCC is connected to 5v pin of the Pi
2. GND is connected to the GND of the Pi
3. Vout is connected to GPIO 27

This component has the following:

1. Range of 12 meters
2. An angle of 65° degree
3. A Delay of $15 \mu\text{Seconds}$

Radio Module

For this section, we have the following considerations:

- The devices are in a forest
- Meaning Gigahertz isn't a desirable frequency
- We want a module that low low-power
- a model that will have a high throughput

Through research, I found the following table:

| Modules | Tx/Rx Voltage | Frequency | Range | Tx/Rx power | Through put | Error detection | Rx sensitivity | Hopping channel |
|---------------------------------------|----------------|----------------|---------------|------------------------|-----------------|-------------------------------|--|-------------------------------------|
| Gravity 315MHz RF Receiver Module | 3.3v/5v | 315Mhz | 50 m | -10dbm -95dbm | 9.6kbps (max) | none | -108 dbi | no |
| MM2 Series 900 MHz OEM Radio | 3.5 5.0 | 902 928 Mhz | 32km | 1175 ma tx rx 125ma | 80 - 115.2 kbps | 32-bit CRC | -108dbm @ 115.2kbps for BER 10 ⁻⁴ -103 dbm @153.6 for BER 10 ⁻⁴ | 50 to 112, user-selectable |
| RF 433MHz Transmitter/Receiver Module | 5V 3-12v | 433.92 Mhz | 20-200 meters | 10 mW | 2kbps | ASK modulation no error check | -105 db | no |
| Digi XBee-PRO 900HP RF Module | 2.1 to 3.6v dc | 902 to 928 Mhz | 14km - 6.5km | 24dbm | 10kps ~200kps | NONE | -101dbm | FHSS (Software Selectable Channels) |

Table 1.9: Radio modules found in research

Out of these, I picked the MM2 Series 900 MHz. Note that the seller of this radio module has limited the documentation of this module makes it hard to draw an interface for this module which will be done next semester

1.2.2 ADC Considerations

for the ADC the following considerations:

1. low power
2. high bit resolution
3. low amount of channels
4. high sample rate

the two things we want for this is the high bit Resolution and a high sample rate

| Device | Resolution | Sample rate | Input range | Power consumption |
|-------------|------------|-------------|-------------|-------------------|
| ADC pi Zero | 17 bits | 100KHz | 0-5.06v | 10mA |
| MCP3008 | 10 bits | 200 ksp/s | 2.7v- 5.5v | 500uA |

Above are the components I had to choose from for this project, I picked MCP3008 due to its resolution and sample rate the following is the schematic for the MCP3008? the following

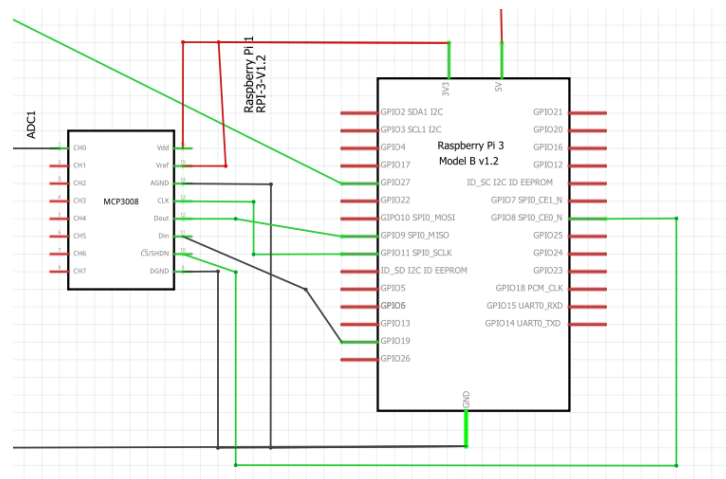


Figure 1.6: Schematic for MCP3008

are connections:

1. VDD is connected to 3v3 pin of the Pi
2. VRef is also connected to 3v3 pin of the Pi
3. AGND is connected to the gnd pin
4. CLK pin is connected to GPIO port 11
5. Dout pin is connected to GPIO port 9
6. Din pin is connected to GPIO port 19
7. CS pin is connected to GPIO port 8
8. DGND ping is connected to the gnd pin

this commponet has the following:

1. A 10 bit resolution
2. seen as the reference will be 3.3v
3. 200ksps meaning the delay to read is 5μ seconds

1.2.3 Camera

For the camera, we have to keep in mind the following:

1. Focal length
2. Resolution
3. Power
4. what lux values it works at

| Modules | Voltage range | lens size | Image Resolution | Video Resolution | Frame Rate | Type of Output | Preferred condition | Power |
|----------------------------|-----------------|-------------------------|------------------|------------------|------------|------------------|---------------------|-------|
| Raspberry Pi VR 220 Camera | 3.3V ac | can change with lens | 3280 X 2462 | 1920 x 1080 | 30 FPS | Need to research | Daytime | 38mA |
| DIGILENT 410-358 | 3.6v | optical size 1/4 inches | 2592 x 1944 | ? | ? | Digital | ? | 200mA |
| The Raspberry Pi NoIR | 3.3v | 1/4 inches | 3280 x 2464 | 1080 or 720 | 30 60 fps | need to research | house | 38mA |
| OV7670 VGA | 2.45 to 3.0v ac | 1/6 inches | 2.36mm x 3.6um | ? | 30 fps | analogue | need to research | 60mW |

Table 1.10: Camera module

The camera I pick is a Raspberry Pi VR 220? Camera to see how to connect look at the following link

1.2.4 Memory module

For this section, we consider the following:

1. The file formatting of the sensor data
2. The file formatting of the camera data
3. What are the possible sizes of data
4. what is the size of the raspberry pi OS

in my project, I plan on using the following:

1. For the sensor I plan on use storing the data in a CSV file with the following heading: (timestamp, heat, humidity, light level, anything detected) which can be around 25KB
2. For the camera in the plan using 10 MB is the largest file size
3. For the raspberry pi i downloaded the raspberry imager this has loads of options such as the following on ??

after has been we must consider a mircoSD ,here is the following considerations: the best here is the silicon power 32GB due to its tempearure rnage and read and write times now for a testing the data and tranfering code i want an flash drive so i can extract python file and mix and manage sensor data and a back up for the data incase. for this we have the following to consider:

1. DHTT22 has a sample period of 2 seconds
2. AS312 which has a delay time of 15μ seconds
3. MCP3008 5μ seconds

here is what I found through research: The Raspberry Pi 4 supports USB 2 and USB 3. For this, I'll pick the Turbo 1GB USB 2 Flash Drive

| product name | Capacity | Speed class | Read speed | v |
|--|----------|-------------------|---------------|----|
| SAMSUNG EVO Plus Class 10 microSDXC | 256 GB | U3 | up to 130MB/s | up |
| SANDISK Ultra Performance Class 10 microSDXC | 128 GB | class 10 u1 | up to 80 MB/s | up |
| Silicon Power 32GB 3D | 32GB | class 10 | Up to 100MB/s | Up |
| SanDisk 64GB Extreme PRO | 64GB | UHS Speed Class 3 | Up to 100MB/s | up |

Table 1.11: mirco SDs in considration

| Brand | Product Name | Storage Capacity | USB Version | Data Transfer Sp | Read/Write Spee | Durability | Encryption | Form Factor | Compatibility | Price |
|----------|--------------------------------------|------------------|-------------|------------------|-----------------|---------------------------|------------|-------------|---------------------|--------|
| SanDisk | Cruzer Glide 1GB USB 3.0 Flash Drive | 1 GB | USB 3.0 | 100 MB/s | 80 MB/s | Water and shock resistant | No | Standard | Windows, Mac, Linux | \$5.99 |
| PNY | Turbo 1GB USB 2.0 Flash Drive | 1 GB | USB 2.0 | 480 Mbps | 300 Mbps | Water and shock resistant | No | Standard | Windows, Mac, Linux | \$3.99 |
| Verbatim | Store 'n' Go 1GB USB 2.0 Flash Drive | 1 GB | USB 2.0 | 480 Mbps | 300 Mbps | Not specified | No | Standard | Windows, Mac, Linux | \$2.99 |

Table 1.12: Memory usb to consider

1.2.5 Battery

In this section, we want to consider the following:

1. Have enough power for all sensors and radio module
2. Have storage of the battery
3. Discharge rate of the battery (how many operating hours can I get out of the battery)

Here are the following Devices I found :

| Modules | Voltage | Interface | Power | Chemistry | Supply time |
|------------------------|---------|-----------|-------|-----------------|-------------|
| Li-polymer Battery HAT | 5v | Micro USB | 1.8A | lithium battery | 5 hours |

Table 1.13: battery considerations

The battery I'm going for is the li-polymer which has a micro USB how to charge:

- Step 1: Insert the Li-polymer battery into a 2.0mm battery socket
- Step 2: Connect the power adapter to a micro USB or Type-C interface by USB cable.

Aside: this commpoent has the following:

1. A battery that is 3.7v 3000mAh
2. Output voltage of 5 volts
3. an estimated Power supply time of 5 hours

1.2.6 Arduino vs PI Consideration

In this project, we will have to choose between what microprocessor we will use. we can have 3 options

1. PCB (printed circuit board) where we design the circuit in a program like Fusion 360. The major issue is due to the current state of silicon chips which will slow down the progress of the implementation stage
2. Arduino
3. Raspberry Pi

| Arduino | pi |
|---|--|
| Advantages | Advantages |
| 1. Arduino has a 10-bit ADC | 1. Pi can compile Python (easier to write) |
| Disadvantages | Disadvantages |
| 1. Arduino has a supper set of C++ 2. Arduino only has 6 Analogue pins | 1. Pi is a technically a small CPU 2. The pi needs an ADC circuit to deal with inputs that are analog |

Table 1.14: Advantages /Disadvantages of Arduino vs pi

for these will consider the Arduino and the Raspberry Pi the Advantages and disadvantages of these are the following:

Although the Arduino would be more efficient than the Raspberry Pi due to Raspberry Pi has an Operating System I am picking the Pi as I'm more familiar with Python and Linux. Linux can be used to handle the networking side of the project I am willing to lose some efficiency in power for an easier time making the code for this project

Picking a Raspberry Pi

Now that we have picked out a device to use we need to define what we need in terms of the following:

1. The amount of GIPO PORTS we need
2. Nature of the output of the sensor
3. Speed of the clock

GPIO(General purpose input/output) is used to select the input/output the pi can only take in digital signals only Seen as we have our components chosen that require A GPIO port (temperature/ humidity, on page ??, Light on page ??, motion on page ??) we need at least 3 GPIO ports to be available to us as the light sensor and the motion will need an adc as looking through the documentation .firstly let's look at the different models

| Raspberry Pi Model | Internal Clock Speed | Power (Watts) | GPIO Features | Type of Connectors | SRAM |
|-------------------------|----------------------|---------------|---------------|--|---------|
| Raspberry Pi 1 Model B+ | 700 MHz | 5.5 | 26 GPIO pins | 1 HDMI, 1 micro USB, 1 USB 2.0, 1 audio jack | 512 MB |
| Raspberry Pi 2 Model B | 900 MHz | 7.5 | 40 GPIO pins | 1 HDMI, 1 micro USB, 4 USB 2.0, 1 audio jack | 1 GB |
| Raspberry Pi 3 Model B+ | 1.4 GHz | 8 | 40 GPIO pins | 1 HDMI, 1 micro USB, 4 USB 2.0, 1 audio jack, 1 Gigabit Ethernet, 1 PoE header | 1 GB |
| Raspberry Pi 3 Model A+ | 1.4 GHz | 5 | 26 GPIO pins | 1 HDMI, 1 micro USB, 2 USB 2.0, 1 audio jack | 512 MB |
| Raspberry Pi Zero | 1 GHz | 1.2 | 40 GPIO pins | 1 mini HDMI, 1 micro USB, 1 micro-USB OTG | 512 MB |
| Raspberry Pi Zero W | 1 GHz | 1.3 | 40 GPIO pins | 1 mini HDMI, 1 micro USB, 1 micro-USB OTG, 1 Wi-Fi/Bluetooth module | 512 MB |
| Raspberry Pi Zero 2 W | 1 GHz | 0.8 | 40 GPIO pins | 1 mini HDMI, 1 micro USB, 1 micro-USB OTG, 1 Wi-Fi/Bluetooth module | 512 MB |
| Raspberry Pi 4 Model B | 1.5 GHz | 7 | 40 GPIO pins | 2 HDMI, 2 USB 3.0, 2 USB 2.0, 1 Gigabit Ethernet, 1 audio jack | 1 GB, 2 |

Table 1.15: Table of Raspberry Pi's

The above table displays the modules seen as our radio modules is 900Mhz we want 1.5GHZ which is the Raspberry Pi 4 which needs USB c charger and an HDMI.

Picking an PI OS

Seen as

1.2.7 Conclusion

In this project the hardware needed is the following commonponets:

1. 1 x Raspberry Pi 4 Model B

2. 1 x HDMI cable
3. 1 x USBC cable
4. 1 x USB C charging head
5. 1 x DHT22
6. 1 x DFR0026
7. 1 x AS312
8. 1 x MM2 Series 900 MHz
9. 1 x MCP3008
10. 1 x Raspberry Pi VR 220 Camera
11. 1 x Li-polymer Battery HAT
12. 1 x Turbo 1GB
13. 1 x silicon power 32GB microsd

1.3 Software considerations

now that we have established the essential Hardware needed for our project we must consider the following for the software of the project:

1. How to structure code
2. Linux set up of sever and nodes
3. How will data be sent
4. Is this gonna be an OOP or functional approach
5. How to program each device?

1.3.1 Raspberry pi OS

In this Section we want to keep in mind that each os is heavy weght we need to consider the following:

1. When we format the os is the data on the sd lost does it croupt the card?
2. We want an os that is low in capacity ?
3. Is desktop needed or can we use the terminal?
4. How does the os respond to usb drives

According to the ? the imager will erase all the data while installing the os, from reaserch the suggestion of backing up the data is a good sugestion. for now i will use the recommended os and stripdown from there which will be dicussed in the methodolgy section of this report.

1.3.2 Sensor code

in this section, I will discuss the following :

1. DHT22
2. AS312
3. MCP3008
4. DFR0026
5. Kuman for Raspberry Pi 3B+ TFT LCD Display
6. Raspberry Pi VR 220 Camera

this project code will mainly be object-oriented. so the goal is to first test it with my laptop and Create A bash file full of commands to install the Libraries making the code to be split up into different parts so that all that is needed is the Libraries I make and code that won't all have to compiled in one file

DHT22

in this section we have to consider the following:

1. the GPIO port as on page ?? this is connected to port 3
2. the type of output is digital so no extra hardware/code is needed

the following is a rough guide on how to read from the DHT22 I got this from the following link (**Note: I haven't tested this due to the constraints of this year so I can only go off what others have done.**)Firstly open the terminal in the pi and type the following commands

```
git clone https://github.com/adafruit/Adafruit_Python_DHT.git
cd Adafruit_Python_DHT
sudo apt-get update
sudo apt-get install build-essential python-dev
sudo python setup.py install
```

the code does the follwoing:

1. firstly git clone will clone the repository on to device
2. Then change dirertorys a
3. update linux
4. install dev kit for python
5. and install the setup

this will then lead to the following code:

Listing 1.1: Example code for DHT2

```
1      #Libraries
2      import Adafruit_DHT as dht
3      from time import sleep
4      def setup_DHT22(Gpioport:int):
5          humidityy,temp=dht.read_retry(dht.DHT22, Gpioport
6              )
7              sleep(5)
8              return humundity,temp
9      h,t=setup_DHT22(3)
      print('Temp={0:0.1f}*C_ _Humidity={1:0.1f}%'.
          format(t,h))
```

this code will do the following:

1. Import DHT from the adafruit libaray
2. in the functipon which takes the gpioport as an integer this will read the data on the pin and print it out

AS312

for this section i followed this link we also want to keep in mind the following:

1. This has a digital interface and is connected to GPIO 27

Here are the rough steps firstly type the following into the terminal

```
sudo apt-get install python-rpi.gpio
```

which will intall a gpio python module

Then type this into an IDE of your choosing

Listing 1.2: Example code for AS312

```
1      import RPi.GPIO as GPIO
2      import time
3
4      pir_sensor = 27
5      GPIO.setmode(GPIO.BOARD)
6
7      GPIO.setup(pir_sensor, GPIO.IN)
8      current_state = 0
9
10     time.sleep(0.1)
11     current_state = GPIO.input(pir_sensor)
12     if current_state == 1:
13         print("GPIO pin %s is %s" % (pir_sensor,
14                                     current_state))
15         # trigger camera
16         # must look up this
17     GPIO.cleanup()
```

this code does the following:

1. it will look at the pin for a pulse
2. once it senses a pulse it will trigger the camera

DFR0026

from the last example, nothing has changed from the last component an example code for this can be found on page ??

1.3.3 MCP3008

for this section, we want to consider the following:

1. The MCP3008 data out is GPIO 9

this section follows this link firstly try the following in command in the terminal

```
sudo raspi-config nonint do_spi 0
```

Listing 1.3: ADC code

```
1      from gpiozero import MCP3008
2      from time import sleep
3      DFR0026 = MCP3008(channel=0, device=0, port=9)
4
5      print('raw: {}'.format(DFR0026.value))
6      sleep(0.1)
```

this code will select a channel and device , port and print the values of the adc's

1.3.4 Raspberry Pi VR 220 Camera

to get started with this simply look at the following link here is an example of the code of this module :

Listing 1.4: example code for camera

```
1      from picamera import PiCamera
2      from time import sleep
3
4      camera = PiCamera()
5
6      camera.start_preview()
7      sleep(5)
8      camera.stop_preview()
```

this will take a photo of what is in front of the camera

1.3.5 MM2 Series 900 MHz

for this section, the seller of this module has no public documentation so it is hard to come with an make a interface for this section

1.3.6 code structure

The code structure for this will be an object-oriented program all the individual sensors and hardware for the pi will be as displayed above the code in this section will be formatted into objects for example I will have an object called proj_sensor and a method of this would be DHT22 while an attribute of this would be the sample rate the following is a rough breakdown of the structure of the code

- Sensor object
 - Temperature and humidity method
 - light method
 - Motion method which triggers the camera
 - Battery method which is a constructor method
 - Memory method which links with the radio
- radio object which reads from Memory and transmits the data

1.3.7 File structure

For the File structure, we want our sensor data to be stored every hour in a CSV file with the following column headings:

1. timestamp
2. Heat
3. Humidity
4. light level
5. motion detected (True/False)

for the writing to Date, we will use Pandas to write to the CSV file for file sorting, I will use the Python Library glob which I can use to look for files the following is an example of how to make a CSV file: firstly let's make a data frame:

Listing 1.5: sample code for turning sensor data into a data

```

1      import pandas as pd
2      import numpy as np
3      from datetime import datetime
4      cols_name=["Timestamp","Tempeature","Hummidty","
               Light_level","Motion_dected"]
5
6      #assume that being recorded now
7      data=[]
8      timestamp=datetime.now()
9      timestamp=timestamp.strftime("%d/%m/%Y_%H:%M:%S")
10     Current_state=1
11     Heat=0.40
12     Hummidty=1.0
13     Light_level=0.23
14     data=np.array([[timestamp],[Heat],[Hummidty],[
               Light_level],[Current_state]])
15     data=data.T
16     df= pd.DataFrame(data,columns=cols_name)

```

Next, use the.To_csv method from pandas another Libraries that could be useful is the Tkinter here is a sample of how to store where the file is gonna be:

Listing 1.6: example code for storing directory

```

1      import tkinter as tk
2      from tkinter import filedialog
3      import json
4      import os
5
6      root = tk.Tk()
7      root.withdraw()
8      selected_dir = filedialog.askdirectory()
9
10     if not os.path.exists('selected_dir.json'):
11         # Write the selected directory to a JSON
12         # file
13         with open('selected_dir.json', 'w') as f:
14             json.dump(selected_dir, f)
15             print("Successfully saved
               selected_directory to JSON
               file.")
16     else:
17         print("File 'selected_dir.json' already
               exists. Not saving the directory.")
18
19     root.quit()

```

Other useful Libraries allow you to select all .csv, png called glob for our TDD Section we will have use the following command:

```
# !/bin/bash

dir_name=$1

size=$(du -sh "$dir_name" | cut -f1)

echo "Directory size: $size"
```

This is a script that will look at a director this can be home dirctory this will cal the space if 13K the "— cut -f1" will only focuss on the size string messeage and then print out the size. this is just a sample script

1.3.8 Test Driven devolmponet

In this project ill will be using Test Driven Development (TDD) is a software development approach where tests are written before the actual code the following is the advantages and dissadvantges of TDD:

1. Advantages
 - (a)
2. Dissadvantages
 - (a)

1.4 Attenuation

Attenuation refers to a reduction in the strength of a signal. Attenuation occurs with any signal, whether digital or analogue. Seen the aim of making a network the first step is to look into what frequencies can be transmitted and received.

In the environment in which we want our project to take place, we want the following:

1. An antenna that a high so we can affect the data rate of the signal
2. A frequency range at which Attenuation is not present

Through research, I found the following plots:

1. First Plot The first plot I got for Savage e.t al pg. 7 ?

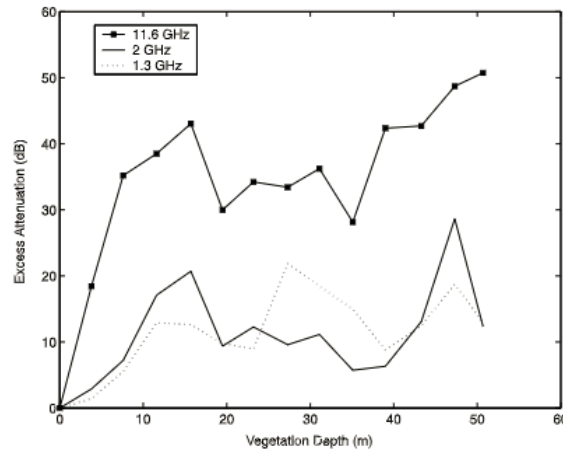


Figure 1.7: Silver Maple in-leaf excess attenuation for the line of trees geometry (receiver antenna height: 3.5 m, SAVAGE ET AL.pg.7

This graph displays as vegetation depth increases Attenuation rises. The problem with this graph is that it doesn't give an in-depth view of which attenuation occurs. This then led me to look up the International Telecommunication Union ? recommendations for Attenuation in wooded areas

2. Second Plot V is the vertical polarization H is the horizontal polarization

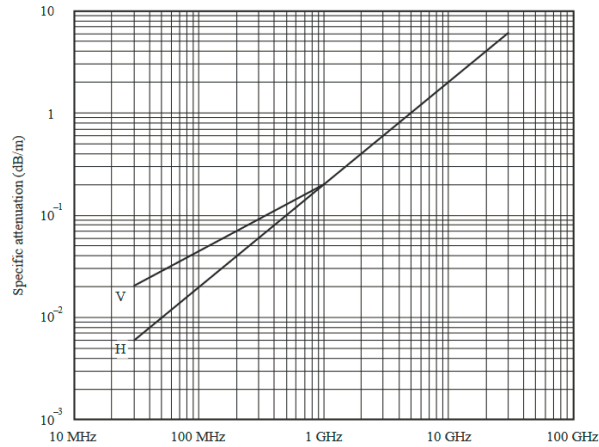


Figure 1.8: Specific attenuation due to woodland (Recommendation ITU-R P.833-7 (02/2012) Attenuation in vegetation pg.5

From this graph we can assume the following:

- (a) From a frequency $\geq 15\text{GHz}$ we can assume Attenuation is more components
- (b) Around the 1 GHz range we get low values of Attenuation
- (c) in the MHz range we get the best response

from this, I selected the range which is 10^6hz

so now that we established our range let us consider what happens when it rains ?

| Frequency MHz | Attenuation dB/m |
|---------------|------------------|
| 106 | 0.04 |
| 466 | 0.12 |
| 949 | 0.17 |
| 1852 | 0.3 |
| 2118 | 0.34 |

Figure 1.9: Predicted attenuation due to rain for the region, which is measured by using the ITU standards,(Source: Hindawi(2014))

Ideally, we want a low MHz but we want speed and this is dictated by what we choose let's further see how radio waves are affected by water/rain

1.4.1 Absorption of water

for this, I found this graph from Lunken Heimer ?

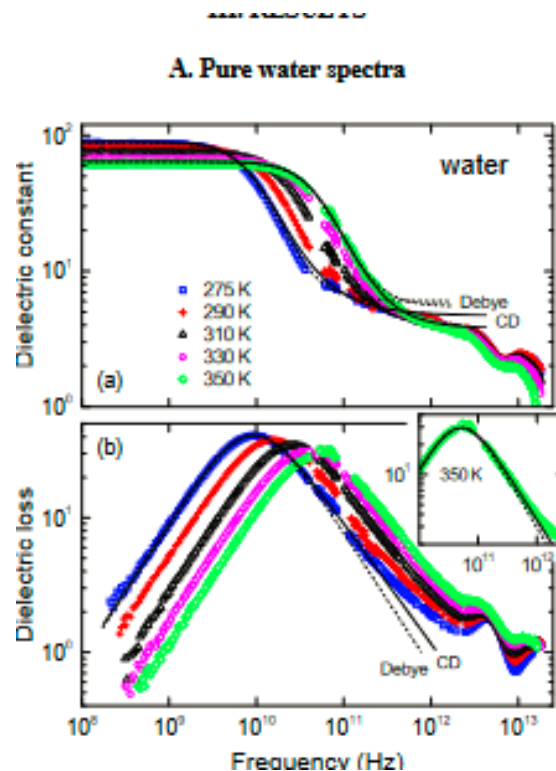


Figure 1.10: absorption of water

According to the graph, Water absorbs MHz frequencies which will affect the transmission in the transmission and in some cases, we might have to consider non-line-of-sight communication when it rains or we might also consider another node to route to receive the node.

1.5 mesh network considerations

For this section, we have to consider the following:

1. How are we setting up the network
2. What framework are we using to set this Up
3. What are the advantages/disadvantages

In my research I found two main frameworks that this project could use to achieve the mesh network these are the following:

1. LORA
2. Zigbee

According to Chen (2023)? "LoRa, as one of Low Power Wide Area Networks (LP-WANs) technologies, aims to enable IoT devices to perform long-range communications with lower power consumption [18]. LoRa makes use of the chirp spread spectrum (CSS) modulation to improve the transmission distance up to kilometres and also be resistant to multi-path effects."

According to Vlad?, "ZigBee is an LP-WPAN (Low-Power-Wireless Personal Area Network) with short range and low power consumption, as mentioned before. The range for ZigBee devices is up to fifty meters and it is characterized by a low data rate, having a maximum value of 250 kbps. The protocol is suitable for sensors and IoT applications because of the low data rate and low power consumption"

the following are the differences between the two: from research, these are very similar but

| LoRa | | ZigBee | |
|--------------------------------------|-------------------------|-----------------------|---------------------|
| Advantages | Disadvantages | Advantages | Disadvantages |
| Long transmission distance | Low transmission rate | Low power consumption | Low data rate |
| Low power consumption | Slow data transfer rate | Long range | Limited range |
| Multi-channel information procession | Small payload | Scalability | Signal interference |
| Strong anti-interference ability | Low bandwidth | — | High-sensitivity |
| High-sensitivity levels | Spectrum interference | | |

Table 1.16: Advantages and Disadvantages of LoRa and ZigBee

it seems if I plan on adding lots of Zigbee is the best for this challenge

1.6 Review key of research Papers

The following are the research papers I used

1. zhao

In my research, I found multiple projects that are similar to mine In Zhao(2023)(?, zhao) used LORA to track light sensitivity, air pressure one of the challenges Zhao came across was Attenuation as stated above and also the author came across the problem of not having sufficient solar panels

2. Daniel

Another paper I found in my research is by Daniel ? In this, Daniel discusses modeling radio wave propagation in a forest environment which isn't in the scope of the project Daniel's work shows that a better approximation for transmission loss was a key read to under what happens on a more in-depth scale in my project

3. Anna

? in Anna's paper she mainly used LORA where she compared line of sight and the non-line line of sight environments in urban and forested areas this paper aims to study the effects of signal propagation in different environments.

4. ITU

? in ITU in most research papers I found it referred back to this document this document was very helpful in terms of understanding Attenuation and challenges that face

1.7 Summary

This report highlights the challenges at come from transmitting data in a wooded area these challenges are the following:

1. Attenuation
2. Absorption

In a wooded area, we established that Attenuation occurs due to the reflection, and penetration of radio through any type of medium. We established that our antenna will have to be in the Mhz range but will still have signal loss /errors due to Absorption of the signal received due to rain or water being in the signal path we have yet to consider the non-line of sight environment but this is to be discussed when prototyping, this report mainly focuses on the hardware where the focus is on sensors such as:

- Temperature
- Light
- Motion
- Humidity

The report focuses on how to read this data from a Software perspective the code will be an object-oriented program where the code will be separated into different blocks of code so the file size is minimized and leads to a faster compile time.

]

Chapter 2

Methodology

2.1 Introduction

In this Section i will discuss the proposed methodology of this project this will cover the following:

1. The setup of the raspberry pi
2. The Data Collection Methods
3. The Model Development
4. The Data Analysis Methods
5. The Ethical Considerations
6. The validity and reliability
7. The Limitations and Delimitation
8. The timeline

2.2 Setup of raspberry pi

Firstly once you have your pi heres a quick guide to setup the pi are the following:

1. once you unpack the pi be sure to connect keyboard mouse and hdmi cable
2. next on a computer you must download the raspberry pi imager and selet the 64 bit recommned os
3. once u have os set simply put the mircosd card into the pi once the pi is setup you can make sub dirrys for this project type the following:

```
git clone https://github.com/mistaherd/meshnetwork_in_forest.git
```

this will downlaod the nessary eniroment for setinng up the pi intiall this will have to built out through the process of the project look at the timeline Section

4. next simply follow the ReadME.md file to understand how to setup the py

2.3 Data Collection Methods

In this section i dicuss the following:

1. the intall unit test this is for what we expect our sensor to output this will be updated
2. How the data from sensor will be stored
3. the code assoicated with the above points

2.4 Unit testing

Fristly i want to made some unit tests the aim of this is the following:

- To make test that will be there for the codeing section of the project

this section will discuss the following for testing:

1. 1 x DHT22
2. 1 x DFR0026
3. 1 x AS312
4. 1 x MM2 Series 900 MHz
5. 1 x MCP3008
6. 1 x Raspberry Pi VR 220 Camera
7. 1 x Li-polymer Battery HAT
8. 1 x Turbo 1GB

DHT22

According to the data sheet ? seen as the data is 8 bits and the range at which this operates at -40 to 80°C for tempeature meaning we have at least 7 bit in the exponent to represent the measured value. to represent the high end of this sensor i used the following calculation:

$$2^6 + 2^4 = 80$$

which mean we have a 2 bits dedicated to decimal place so the high temperature to be 80.3°C for the lowest temp we have 6 bits to represent - 40 due to 2s complement so lowest will be -40.3°C so with that that stablish we must make a unit that will do the following:

1. Test if the output is a float
2. Test the high end of the temp sensor so it reads 80.3 as the highest
3. Test for the lowest temp around

be sure to follow steps for folder setup follow instructions on page ?? we get the following sample code:

Listing 2.1: sample test intial code

```

1 import unittest
2 from protest import Read_DHT22
3 class test_project_code(unittest.TestCase):
4     def test_DHT_22_temp_output_type(self):
5         self.assertIsInstance(Read_DHT22, float)
6     def test_DHT22_temp_range(self):
7         self.assertGreaterEqual(Read_DHT22, -30.3)
8         self.assertLessEqual(Read_DHT22, 80.3)

```

This code import unittest . the from protest is a python files we can install functions from other python files this can be usefull for testing purposes then we initalized a test class call Unittest.testcase our firstion fucntion of the class we check if the number of the output is a float or not this is for testing tempearture the next function we test for is the range i look at the datasheet online this code is simply testing the limits of the DHT22 for humidity the Datasheet which ranges from 0 to 100 % we want to test for the following:

1. Test if the output is a float
2. Test if the output ranges 0 to 100

this lead to the following code

Listing 2.2: sample test for DHT22

```

1 import unittest
2 from protest import Read_DHT22
3 class test_project_code(unittest.TestCase):
4     hum,temp=Read_DHT22(2)
5     def test_DHT22_output_type(self):
6         self.assertIsInstance(Read_DHT22, tuple)
7     #....
8
9     def test_DHT22_hum_output_type(self):
10         self.assertIsInstance(hum, float)
11
12     def test_DHT22_hum_range(self):
13         self.assertGreaterEqual(hum, 0.0)
14         self.assertLessEqual(hum, 100.0)

```

seen as we expect our sensor to print out a humdity and temp values we set the output to a tuple to test for this we use isInstacne which will test if its a tuple next we test for the limits of the humidity

DFR0026 & MCP3008

According to the datasheet ? we must keep in mind that this componet is connected to an ADC this will give me the following test conditions:

1. Test if the output is a float
2. Test the range of this with the upper limit being 5v
3. test the lover limit being 0

Listing 2.3: unit test for DFR0026 and MCP3008

```

1  import unittest
2  from protest import Read_DHT22, Read_MCP3008
3  class test_project_code(unittest.TestCase):
4  def test_DFR0026_MCP3008_out_type(self):
5      self.assertIsInstance(Read_MCP3008, float)
6  def test_DFR0026_MCP3008_out_range(self):
7      self.assertLessEqual(5.0000000)
8      self.assertGreaterEqual(0.0000000)

```

this code is in the same in theres of limits

AS312

for this section we want our tests to be the following:

1. test for type is boolean

we can now add to the snipppet :

Listing 2.4: unit test for AS312

```

1  def test_AS312_out_type(self):
2      self.assertIsInstance(Read_AS312, bool)

```

Note : Don't forget to import `read_as12` function from test file seen as this is a motion sensor our output will be

Raspberry Pi VR 220 Camera

according to the data sheet ? we the resoulution to it uses is 1080p50 which is 1920x1080p so our tests will have to in copoarte the followoing:

1. Test the output shape if open cv is gonna be used
 - (a) test the amout of elelecelm in the 3 dimesional array
2. test the file type is png

this would lead me to the following code snippet.

Listing 2.5: camera unit test

```

1  def test_Raspberry_Pi_VR220_out_shape(self):
2      self.assertEqual(Read_Raspberry_PiVR220.shape, (1920, 1080, 3))

```

this function check the pixeal count or resoulkation

Li-polymer Battery HAT

memory moduldes

in this setion will dicuss the following:

1. silicon power 32GB
2. Turbo 1GB

for this i will use using a bash script(see this on page ??) and what we are doing is testing the size in a certain range for the silicon SD card

1. Turbo 1GB as from above we are import the file at which where our functions live in code frist we import the function

Listing 2.6: si powerd SD snippnet

```
1      import unittest
2      from protest import Read_DHT22,Read_MCP3008,
        Read_AS312,Read_Raspberry_PiVR220,
        Read_Memory_module
3
4      def Test_memory_module_turbo_1GB_size(self):
5          #testing turbo 1GB
6          self.assertEqual(Read_Memory_module,1e9)
7          self.assertGreaterEqual(Read_Memory_module,0)
```

then simply we call assert and greater than which sets the bounds of the modes the 1e9 is a way to put 10^9 whcih output that will between 1GB and 0

2. silicon power 32GB

MM2 Series 900 MHz

conculsion

The intiall draft code for the test developemnt si the following

Listing 2.7: Final draft test template

```
1      # waiting for other sections
```

2.5 Model Development

High-performance computing (HPC) resources are utilized to develop and train computational models. The models are designed to capture the essential features of the research problem and generate meaningful outputs.

2.6 Data Analysis Methods

Statistical and machine learning techniques are employed to analyze the data collected from both computational models and real-world sources. These techniques are used to identify patterns, trends, and relationships within the data.

2.7 Ethical Considerations

The use of computational methods raises ethical concerns regarding data privacy and security. To address these concerns, data anonymization and encryption techniques are employed to protect sensitive information. Additionally, informed consent is obtained from participants when applicable.

2.8 Validity and Reliability

Validation of computational models is achieved through rigorous testing and evaluation. This involves comparing model predictions with real-world data and examining the sensitivity of the models to different parameters. Reliability is ensured through the use of standardized methods and procedures for data collection, analysis, and interpretation.

2.9 Limitations and Delimitations

The computational nature of the research introduces limitations due to the complexity of the systems being modeled and the potential for errors in modeling and data analysis. Moreover, the generalizability of the findings may be limited to the specific contexts and conditions considered in the research.

2.10 Timeline

The model development phase of the research is scheduled to take place from [start date] to [end date]. The data collection and analysis phases are scheduled to take place from [start date] to [end date]. The final write-up of the research is scheduled to be completed by [deadline date].

Chapter 3

Results