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

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

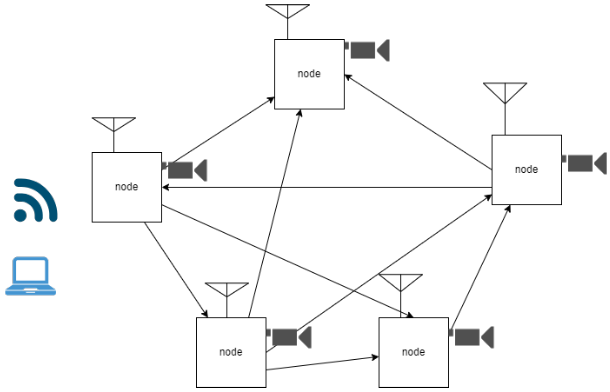


Figure 1.1: Basic block diagram of a mesh network

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:

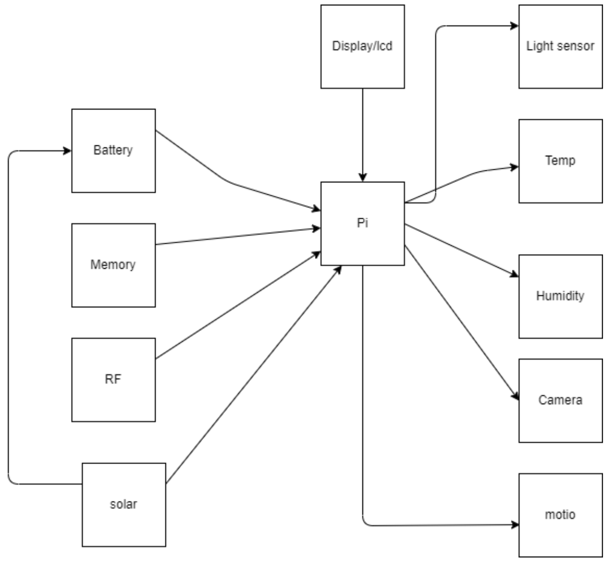


Figure 1.2: Rough circuit diagram for project

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 ardunio 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 humdity this referes to the amount of water vaper in the air. from met eirrean **?** got this table: The ranges are 68.3% to 88 % So with these conserdations 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: Realtive Humidity(%) according to met eirrean

the diffrent components:

Components	Voltage Range	temperature range	Accuracy	Analogue /Digtial outputs	Current in	additional information
DHT22	3-6 volts	-40 to 80^o C	+/-0.5ºC	Digital	1.5mA	sample period 2 seconds
LM35D2	4 -30 Volts	-55 to 150	+/-0.5ºC (at 25ºC)	Analogue	10mA	None
TMP36	2.7 to 5.5 Volts	-40 to 125	+/-1ºC (at 25ºC)	Analogue	250 µA	NONE
LM75	3.0 to 5.5V	-55 to 125ºC	+/-2.0ºC (at -55 to 125ºC range))	Analogue	100 µA	NONE
DHT111	3-5.5V	0-50 °C	±2°C	Digital	1mA	sample period 1 second

Table 1.4: Comparing of temperature sensors

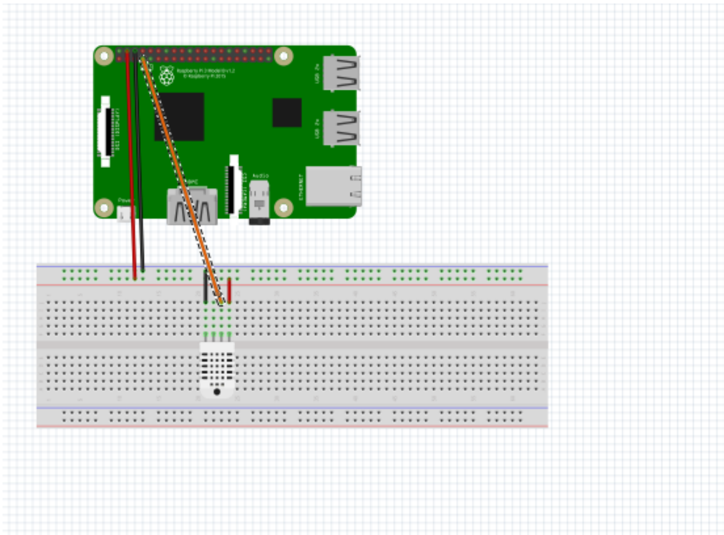
After this, I limited this down to two sensors DHT22 and DHT11. The following are the advantages and disadvantages of the DHT22 and DHT11: So in conclusion I choose DHT22

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

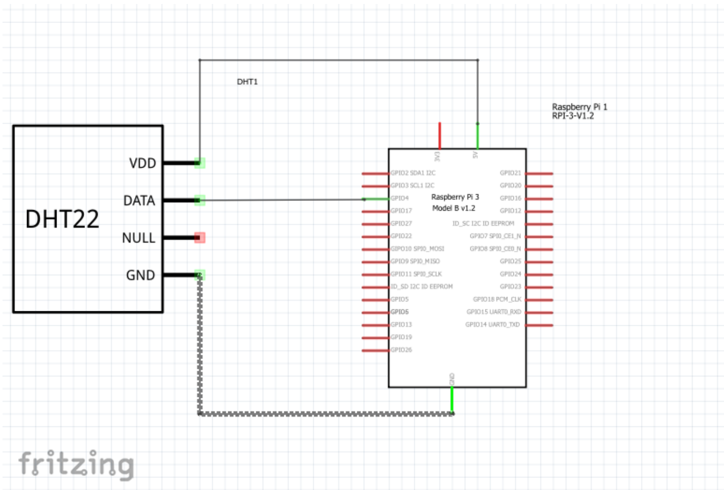
Table 1.5: Comparing DHT22 and DHT11

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 componet 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:

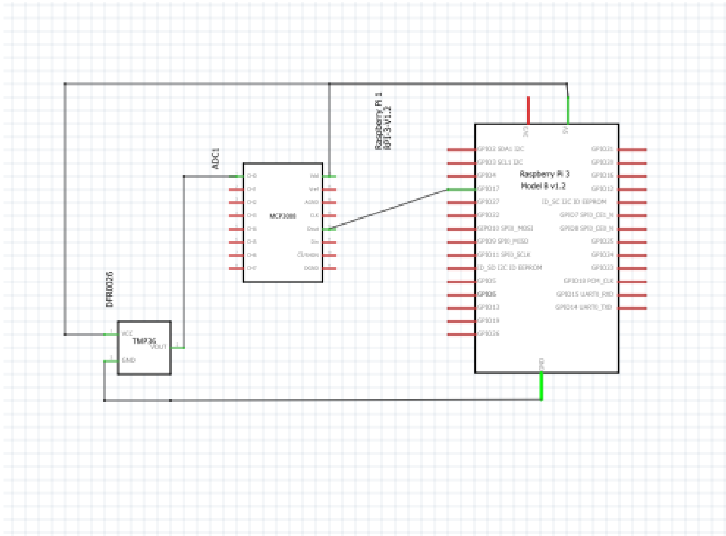


Figure 1.4: Interface for DFR0026

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 page17

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

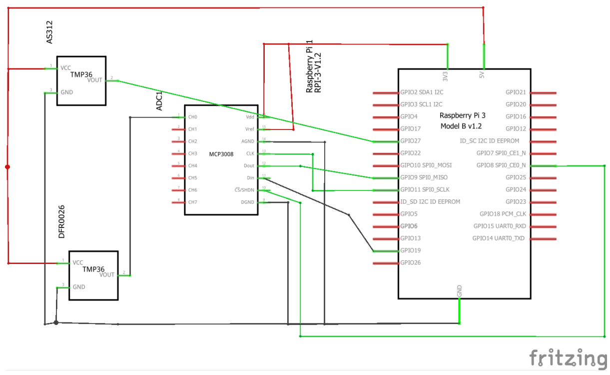
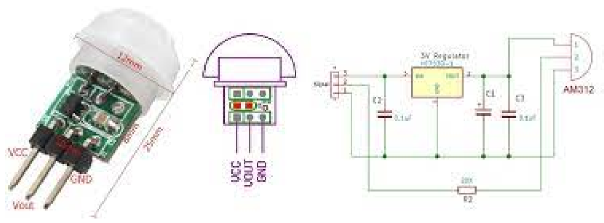


Figure 1.5: Interface for AS312

with The connections are the following:



Pinout of AS312

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 17

This component has the following:

1. Range of 12 meters
2. An angle of 65^o degree

3. A Delay of 15 $\mu Seconds$

1.2.2 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 -95dm	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 dm @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	24dm	10kps -200kps	NONE	-101dm	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

1.2.3 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 ksps	2.7v- 5.5v	500uA
DFR0553	16 bits	1.7Mhz	0 5.0V	10mA

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 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

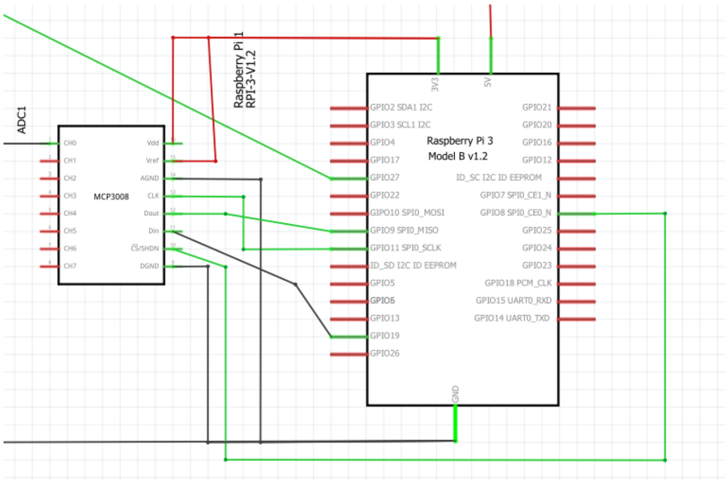


Figure 1.6: Schematic for MCP3008

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 resultion
2. seen as the reference will be 3.3v
3. 200ksps meaning the delay to read is 5μ seconds

1.2.4 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

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 consirdation

1.2.5 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 raspbery pi i downloaded the raspberry imager this has loads of options such as the following on 22

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 15 μ seconds
3. MCP3008 5 μ seconds

here is what I found through research: The Raspberry Pi 4 supports USB 2 and USB 3. For

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

this, I'll pick the Turbo 1GB USB 2 Flash Drive

1.2.6 Battery

In this section, we want to consider the following:

1. Have enough power for all sensors and radio module

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

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 :

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

1.2.7 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

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

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 analogu

Table 1.14: Advantages /Disadvantages of Arduino vs pi

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