[TBD: NAME OF TOOL]

TBD: A tool to study microclimates in an orchard

By

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1 Introduction

In this report, I give details of an online tool called [TBD: NAME OF TOOL] which was deployed alongside an IoT weather sensor network that I built myself. The tool aims to provide farmers with accessible, specific climate data to support real-time decision-making.

The IoT hardware deployed consisted of four separate custom built components: two field nodes capable of reading weather data and transmitting this using LoRa; a repeater that boosts received LoRa signals; and an internet-connected gateway that uploads weather data to an online database.

The nodes were placed at two different locations on the farm that the owner had identified as having distinct climate characteristics (see section on microclimates), meaning wider-area weather forecasts were unrepresentative.

Part I

Background

2 Microclimates

2.1 Microclimates in agriculture

A microclimate is generally understood as a set of distinct climatic conditions within a small, localised area [1]. The maximum size of a microclimate is debated, but the World Meteorological Organisation (WMO) regards it as occupying an area of anywhere from less than one metre across to several hundred metres [2]. In practice, microclimates can occur in spaces such as gardens, valleys, caves, or fields. Even human-made structures can generate their own microclimates; for example, tall buildings can create *street valleys* that reduce wind flow and lead to the formation of localised pockets of warmer air, which can also trap higher concentrations of pollution from vehicle emissions [3]. Vegetation plays a critical role in influencing microclimates. The addition of trees to an urban environment can reduce air temperature by as much as 2.8 °C [4].

This localised climatic variation, characteristic of microclimates, is therefore significant in agriculture. The climate that crops are exposed has an enormous impact on overall agricultural yields. Indeed, farmers have modified the microclimate of crop fields for millennia, a clear example of this being the use of fencing to reduce soil erosion and damage to edible plants [5]. Therefore, the relationship between microclimates and agriculture has been the subject of extensive research - particularly as climate change introduces new threats to food security.

2.2 Microclimates in apple orchards

3 *Internet of Things*

3.1 What is IoT?

The Internet of Things (IoT) refers to the concept of integrating networking capability in a range of devices, allowing for cooperation to reach common goals [6]. To this end, IoT is a very broad idea and there has been rapid ongoing growth of IoT in both domestic and business settings.

IoT therefore often involves the integration of wireless networking into objects which traditionally would not have had any such capability. As an example the use of smart lightbulbs, with the ability to control their status, brightness or even colour via a smartphone application, is a fairly standard demonstration of IoT. However

3.2 Examples of IoT in agriculture

3.3 IoT enabling technologies

4 LoRa

4.1 What is LoRa?

https://www.youtube.com/watch?v=jHWepP1ZWTk https://www.youtube.com/watch?v=T3dGLqZr
- see further reading on second one

LoRa stands for **Lo**ng **Ra**nge and it is a relatively modern radio modulation technique that allows for the transmission of data very long distances. Another comparable modulation technique is WiFi where LoRa has 4000 times the range (REFERENCE), with a theoretical maximum of 800km (although far less in realistic conditions).

This long distance can be achieved with remarkably little power, WiFi typically transmits data with 100mW-200mW of power for a range of 100-200m. LoRa meanwhile uses only 25mW of power.

4.2 How LoRa works

The preamble of a LoRa packet sends the same symbol multiple times in a row to allow the receiver to synchronise.

The most technically impressive aspect of LoRa is that it a receiver can demodulate signals below the noise floor. The noise floor is the sum of all unwanted signals in an environment. To use an example a stadium full of people talking will create a certain level of background noise, in order to speak to someone else in the stadium you would have to speak at a volume which can overcome this background noise. The fact that LoRa receivers can successfully demodulate below the noise floor is akin to being able to whisper in such a stadium and still be understood.

4.3 Benefits and limitations

Fresnell zone

4.4 Current applications of LoRa

Part II

Hardware development

5 Overview of hardware

6 Design

6.1 Nodes

6.1.1 Components

The first step in the design process was selecting hardware components that could operate autonomously without mains power. This required devices that were highly power-efficient, while also capable of transmitting small data packets via LoRa. An equally important consideration was ensuring the final devices could be fully weatherproofed to protect the sensitive electronics from water ingress and environmental damage.

Challenger RP2040 LoRa

The iLabs Challenger RP2040 LoRa is an embedded computer that uses the Raspberry Pi RP2040 chip that was released in 2021. The RP2040 itself is a low-cost and power-efficient processor with ample power to perform the data encoding and transmission in my use case. Additionally, the chip is extremely popular with over 10 million units being produced in the first two years of release [7]. This popularity means there is ample documentation for developing with this processor and it is compatible with circuit python which was my preferred language for development.

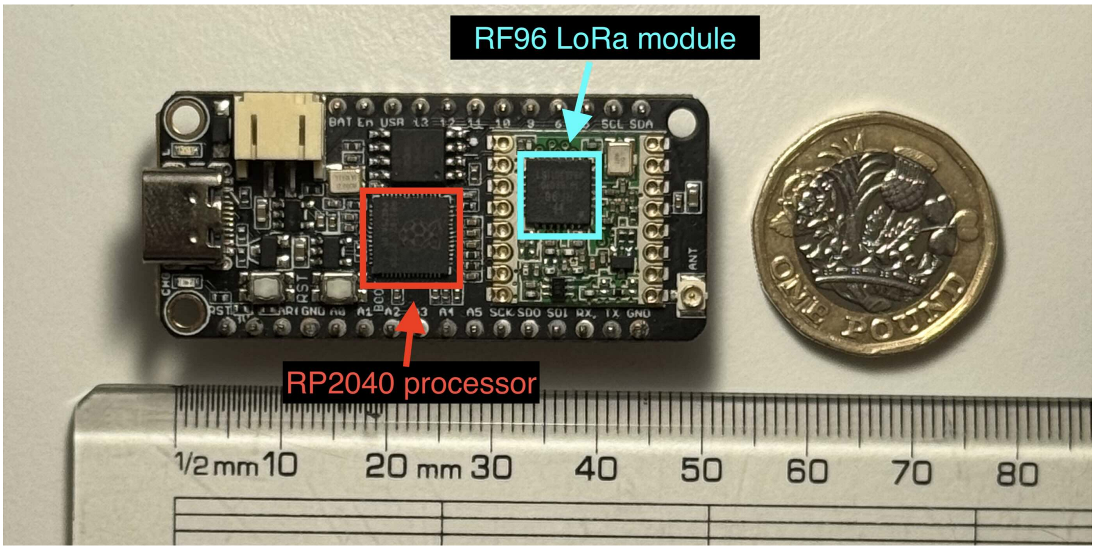

Figure 1: iLabs Challenger RP2040

The challenger board itself is well suited for this project for several reasons. It uses the compact Adafruit feather form factor, giving a board dimension of just 5cm by 2cm, making it easy to mount in a small enclosure. The onboard Hope RF96 LoRa modem is built directly into the board and the U.FL antenna connector allows for the swapping of antenna's to different varieties. This board's LoRa module is also set to transmit at a frequency of 868mhz which is a standard UK frequency for LoRa and gives a good balance between range and bandwidth.

Another useful aspect of the board is the abundance of GPIO pins (20 in total) allowing for a large number of sensors to be fitted to the board.

Antennae

The selection of antennae is one of the largest determinants of range and reliability in the context of wireless communication systems [8]. Initially I used a simple PCB antenna as shown in Figure 2, however as explained in the next chapter, the range of this was insufficient for my use.

Figure 2: Low range PCB antenna

To improve overall range I switched to a more capable omnidirectional whip antenna that was made specifically for the Challenger RP2040. The antenna is tuned to perform best at the 868mhz frequency range - which is the range I was using.

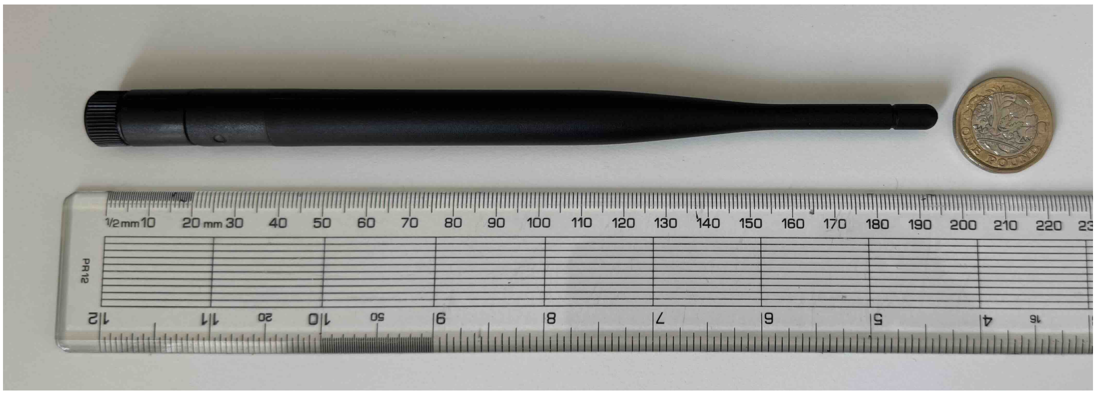

Figure 3: iLabs whip style LoRa antenna (868mhz)

Sensor selection

Temperature and humidity sensor

I used a DHT11 temperature/humidity sensor for each node to provide basic readings. It was chosen for it's low cost, availability and compatibility with both the RP2040 Challenger and CircuitPython (via libraries). The sensor can be connected to the microcontroller using a single GPIO pin as well as the usual power and ground pin.

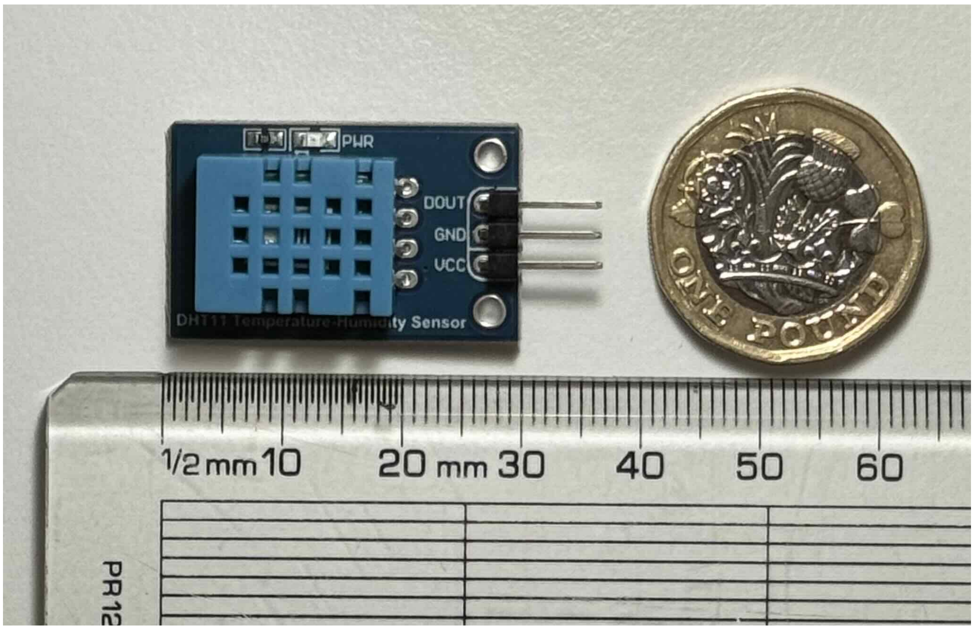

Figure 4: Waveshare DHT11 temperature/humidity sensor

Soil moisture sensor

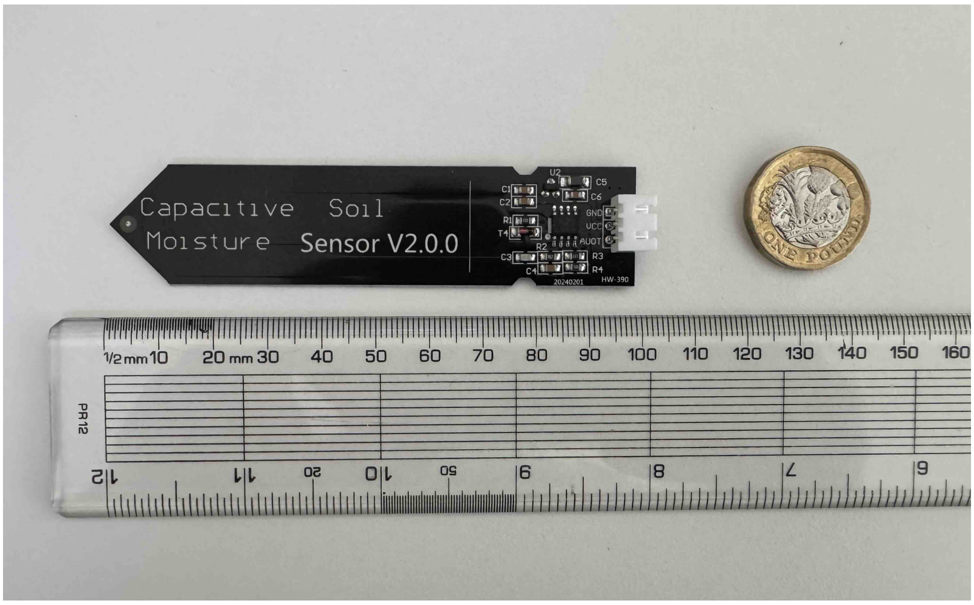

Figure 5: The Pi Hut capacitive soil moisture sensor

Wind speed sensor

Figure 6: DFROBOT wind speed sensor

Powering the node

To allow for continuous operation away from power sources, I set up a 5.5v Monocrystalline Silicon Solar Panel to each of the nodes. As the output from the solar panels was too high voltage to directly power the nodes I also installed a solar power management module onto the Challengers. This module powers a battery that is installed on it using a solar panel. It then is able to power the RP2040 using this battery, allowing for overnight or overcast usage of the challenger.

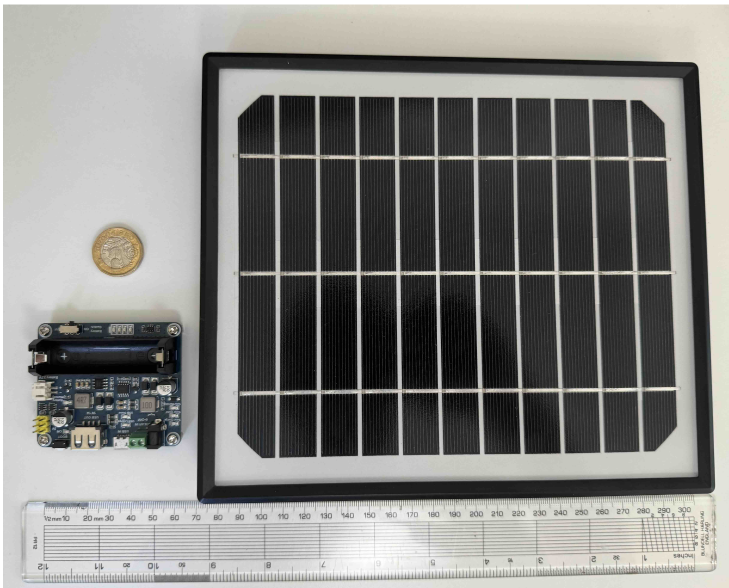

Figure 7: Waveshare solar power management module (left), solar panel (right)

Weather proofing

I 3D printed a water proof enclosure and a separate Stevenson weather shield for the temperature/humidity sensor to allow for accurate outdoor readings.

6.1.2 Programming the nodes

On each challenger I flashed the drives with CircuitPython, an open source interpretted language similar to Python but simplified for use in microcontrollers.

6.1.3 Repeater node

To improve range I made one of the four RP2040 challengers I used act as a repeater. This meant it did not require sensors like I used for the other two nodes and instead it just had a solar panel and battery connected up to it. The repeater would receive signals from the two nodes before relaying them to the final gateway. This had the effect of significantly boosting the range.

6.2 Gateway

The gateway consisted of a fourth Challenger RP2040 connected to a Raspberry Pi (TBD version). The challenger only received messages from the repeater and then would transfer these to the Raspberry Pi. After receiving data the Raspberry pi uploaded this to the internet.

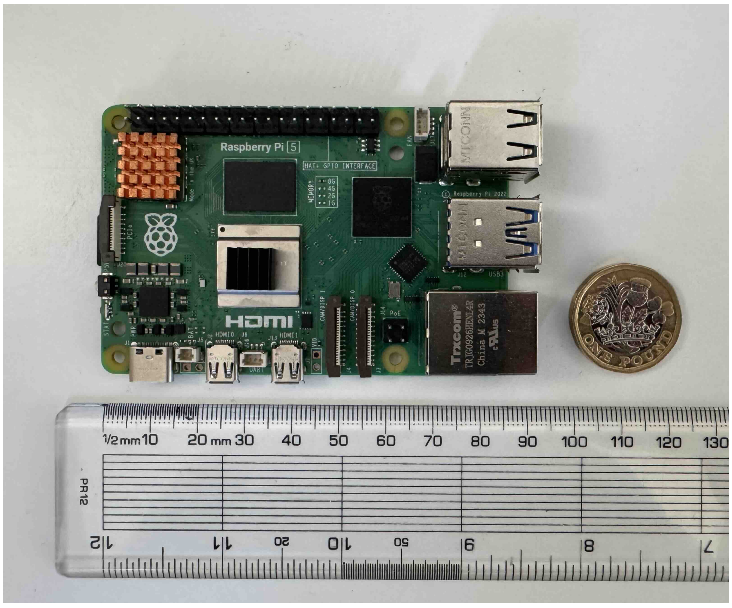

Figure 8: Raspberry Pi 5 (8GB)

6.3 LoRa settings

LoRa has many parameters that must be aligned for two devices to communicate successfully. These include:

1. **Spreading factor:**

2. **Frequency:** Must match across devices; this project uses 868 MHz, the UK LoRa ISM band.
3. **Bandwidth:** Determines how wide the signal is, I am using 125 kHz.
4. **Coding rate:**
5. **Transmit power:** Affects the power and therefore range. This must be set within legal limits (e.g., 14 dBm in the UK).

6.3.1 Compliance with regulatory limits on radio power

The UK has strict regulations on the usage of radio transmitters under the Ofcom ISM band rules. For the 868mhz band, the maximum effective radiated power that can be used is 25mW. This corresponds to a transmit power of roughly 14dB.

Additionally, the UK has rules on duty cycle rates. This is essentially how long radio signals are permitted to be on air. For example at a spreading factor of 12 a message may take approximately 1 second to send. The duty cycle limit in the UK is 1%, meaning you may only transmit for 1% of the time on a given day. 1% of a day is 864 seconds. This means to stay in line with UK regulations only 864 messages could be sent on a given day - or roughly 1 message every 2 minutes.

7 Development and testing

7.1 Programming the hardware

7.2 Range tests

One of the most important tests to carry out prior to deployment in the field was testing the range of the devices.

In this experiment I took four challenger RP2040s to The Downs, a large public park in Bristol. Here I tested four different antenna configurations to compare how well the signal travelled across an increasing distance. Signal strength can be measured using the received signal strength index (RSSI), a measure of the difference in signal from the transmitter to the receiver and measured in decibels (CHECK THIS).

For the test, two challengers were programmed as transmitters, sending an example data packet similar to the data that would eventually be used at the farm. One of the transmitters used a simple PCB antenna (Figure 2) while the other used a higher range whip style antenna (Figure 3). Then I programmed two challengers as receivers, again one had a low range antenna and the other a long range one.

This meant that four different antenna configurations could be tested concurrently, as the receivers could pick up the signal from each transmitter. An estimate of their estimated relative performance before testing is shown below:

1. Whip antenna to whip antenna (Likely best result)
2. PCB antenna to whip antenna
3. Whip antenna to PCB antenna
4. PCB antenna to PCB antenna (Likely poorest result)

The reason PCB transmitter to whip receiver will likely outperform the whip to PCB configuration is that generally it is more important that the receiver has better "hearing" capabilities than the transmitter can "shout".

Nine different distances from transmitter to receiver were tested, in 200m increments starting from 0m as a baseline to a distance of 1600m (Figure 9). An important aspect in getting a successful LoRa connection is whether there is line of sight between the transmitter and receiver. Figure 11 shows the elevation profile of the test area, with the initial large dip being an inaccuracy from google earth's topology data as the 0m point is near a cliff edge. The lowest elevation point is at the starting point at around 83m above sea level, while the highest point was at the 1km mark at around 94m making an elevation range of 11m. My hypothesis was that signal would likely drop off or stop entirely beyond this point as points beyond 1000m would be below the hill line. This would effectively mean that the receivers would be in a signal shadow point where the transmission waves would not be able to reach them. The only possibility for signal to reach this area would be from reflections either from nearby buildings or topology. However the effects of reflections are virtually impossible to account for in the real world and therefore no accurate predictions could be made.

Figure 9: Google earth image of data collection points

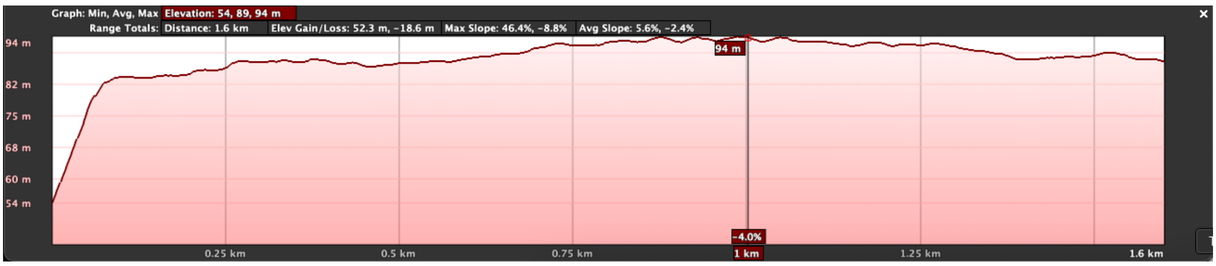

Figure 10: Elevation profile of test area (ignore large dip at start)

At the time of the actual test however a festival was being run between the 1200m and 1400m mark. The festival had a number of large tents and temporary buildings constructed which almost certainly blocked the signal. Therefore tests past this point should be heavily caveated. It is likely this contributed to the lack of signal past this point. Final data below:

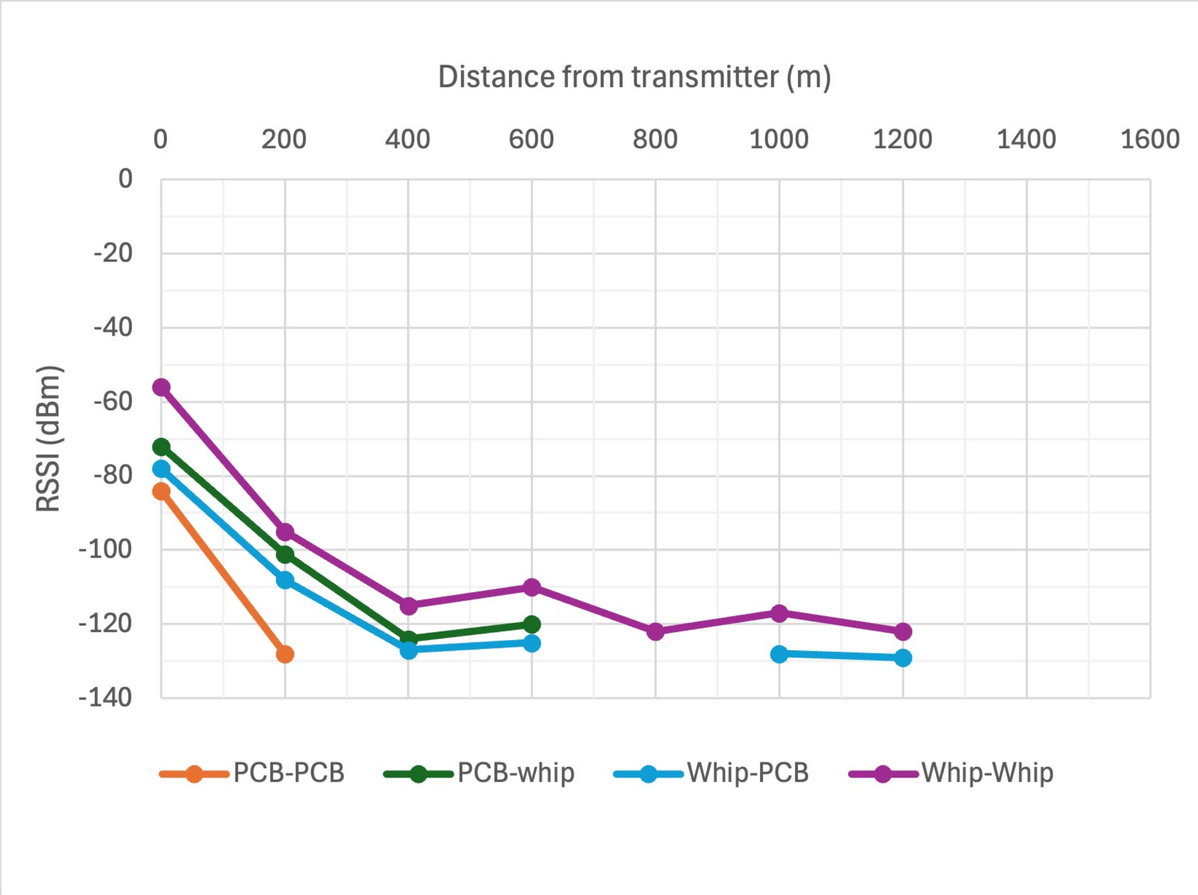

Figure 11: Graph to show signal loss from different receiver and transmitter configurations (higher is better)

7.3 Battery tests

There is no mains electricity available in the apple field so the nodes must be able to operate without external power source. Even with the use of a solar panel the node must be able to work through the night and during periods of dense cloud coverage where the solar panel will not have sufficient power to keep the node running. This is where the use of a battery is particularly useful as the solar panel can charge the battery with excess energy during periods of excess solar radiation, such as during midday hours, and then store this energy for periods of low or no solar radiation.

However, while daylight will be of little concern during the summer months when this dissertation is being written, there will be far fewer days of usable sunlight over the winter period. As the UK has very high latitude, there is large seasonal variation in the length of a day. For the town of crediton (nearest town to Small Brook Farm), in the summer there are 16.5 hours of daylight while in winter it receives only 7.6 hours; meaning a night that is 16.4 hours long. Therefore the node must have a battery sufficiently large to power it for a minimum of 16.4 hours with some additional charge to account for high cloud cover during the early evening and morning period.

To see if the battery solution was sufficient for this environment a test was run on a fully charged 18650 battery that was then connected to the solar power manager to allow the voltage to be regulated up to the challenger's 5v input voltage.

A digital multimeter was installed between the solar power manager and the challenger's usb c input to view the voltage and current in real time as well as running a timer for the test and a calculation of the number of watt-hours consumed by the node. The node was then run with a full suite of sensors attached. During the test the node used 80ma at 5V for a wattage of 0.4W.

The node ran until the battery would no longer discharge, with the final battery life of the node being 19 hours and 17 minutes. The meter showed that the node consumed 7.96Wh of power. Considering the battery capacity is 9 Wh it may seem that the battery ran out too quickly. However, the solar power manager documentation tells us that the battery boost efficiency - being the conversion of battery voltage from native 3.7V to 5V output - is only 86%. With that in mind effective battery capacity is roughly 7.74Wh, which is very similar to the actual result.

The achieved result of 19 hours should be sufficient for running the node continuously for much of the year as this compares to the longest night period of 16.4 hours. However, during periods of heavy cloud cover in winter there is a chance the node would not be able to charge the battery sufficiently in the day to allow the node to run over night.

7.4 Solar panel testing

The solar panel is rated for 6W maximum power. This however would only realistically be achieved under optimal conditions with a clear sky and full sun around midday. This power rating was first verified using a multimeter on such a day where a voltage of (INSERT VOLTAGE) and amperage of (INSERT AMPERAGE) was measured for a wattage of (INSERT WATTAGE).

As explained in the battery section above, the node consumed about 7.96wH over a 19 hour and 17 minute period. We can therefore determine that the node requires roughly 10wH of energy per day to able to run continuously. It would be tempting to then say that the node would need less 2 hours of ideal sunlight to operate for an entire day (being 6W * 2h = 12Wh), however we must also account for the energy loss when converting from raw solar output to regulated 5V input that challenger accepts.

The solar panel manager rates it's conversion efficiency for solar at 78% meaning for each watt of solar energy received 22% of this will be wasted as heat when converted to the correct voltage. If we adjust for this loss we would need effectively 12.8Wh of energy just to power the node for a day, being 2 hours and 8 minutes of ideal conditions.

An additional 9Wh is needed to charge the battery which if we adjust again for solar efficiency factor we get 11.5Wh. This is an additional 1h:55m of ideal sun, leaving a total sunlight requirement each day of 4h:03m.

7.5 Hardware assembly and weatherproofing

Since most of the hardware in this project contains exposed electronics, the final assembled devices needed to be made water and wind resistant to prevent failure. However many of the components also would need to be exposed to perform their function effectively - e.g. a solar panel must have a clear view of the sun throughout the day. The final design therefore needed to balance multiple conflicting purposes:

- The core electronics (challenger, solar manager, battery etc) must be kept dry, cool and away from wind which may damage electronics.
- The wind sensor must be exposed to the elements and securely fastened to withstand intense wind, it must also be kept high off the ground for accurate readings. It has no exposed electronics and is water resistant.
- The solar panel must be exposed to the elements and be south facing at at an angle of 30 degrees to optimise solar efficiency. It is water resistant.
- The soil moisture sensor must be inserted into the ground and as it has exposed electronics must be made waterproof.
- The antenna of the challenger must be placed as high as possible (at least 1.5m from the ground). IT is water resistant.
- The temperature/humidity sensor must be exposed to the elements to ensure accurate readings but cannot be exposed to rain due to the exposed electronics on it.

Due to the conflicting nature of some of these needs - particularly with respect to altitude. The final device would need to allow for positioning of different components at different heights.

Therefore the electronics would be mounted inside a water proof box (rated IP68 water resistant) with a small cut out for wires at the bottom - which reduces the risk of water ingress from rain fall. Then the box was fitted to a wooden fence post that could be secured in earth. Components needing to be higher up could be secured higher up the pole while soil moisture sensor could be placed lower.

8 Deployment in the field

8.1 Placement of nodes

Part III

Software development

9 Software design

Part IV

Evaluation

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Part V

Appendices

A Example