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# [TBD: NAME OF TOOL]

*TBD: A tool to study microclimates in an orchard*

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By

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# **Executive summary**

## Dedication and acknowledgments

## **Author's declaration**

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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  $2.8^{\circ}\text{C}$  [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?**

LoRa stands for Long Range radio. Long range systems are a way of transmitting data over much longer distances than Wi-Fi allows. LoRa has a range 4000 times greater than Wi-Fi.

## **4.2 How LoRa works**

## **4.3 Benefits and limitations**

## **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.

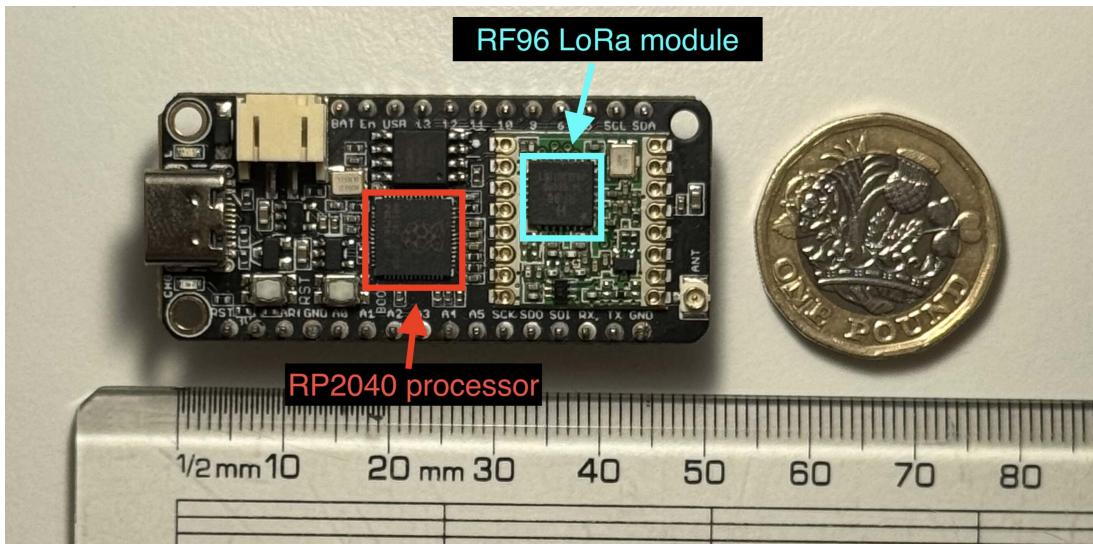


Figure 1: iLabs Challenger RP2040

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.

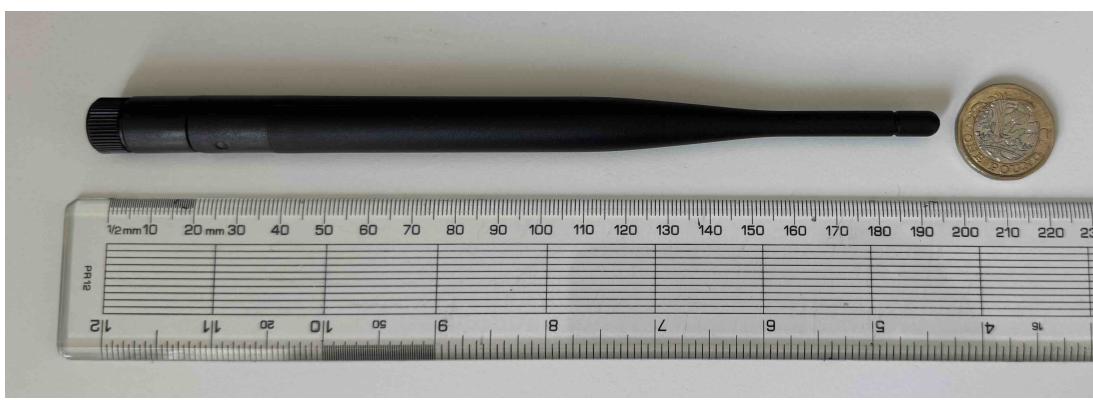
### **Antennae**

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 Chal-

lenger 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.

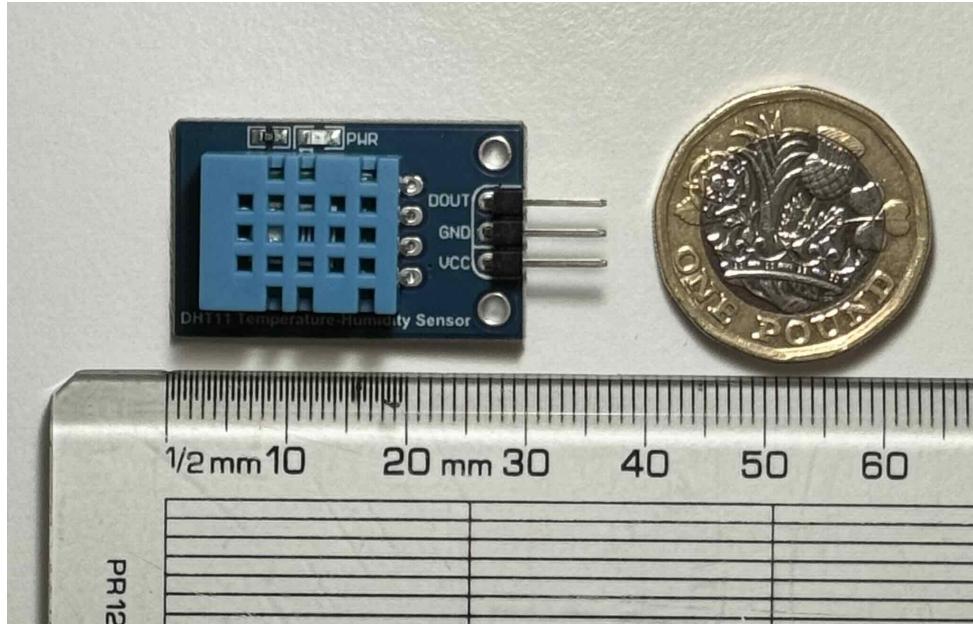


Figure 4: Waveshare DHT11 temperature/humidity sensor

### Soil moisture sensor

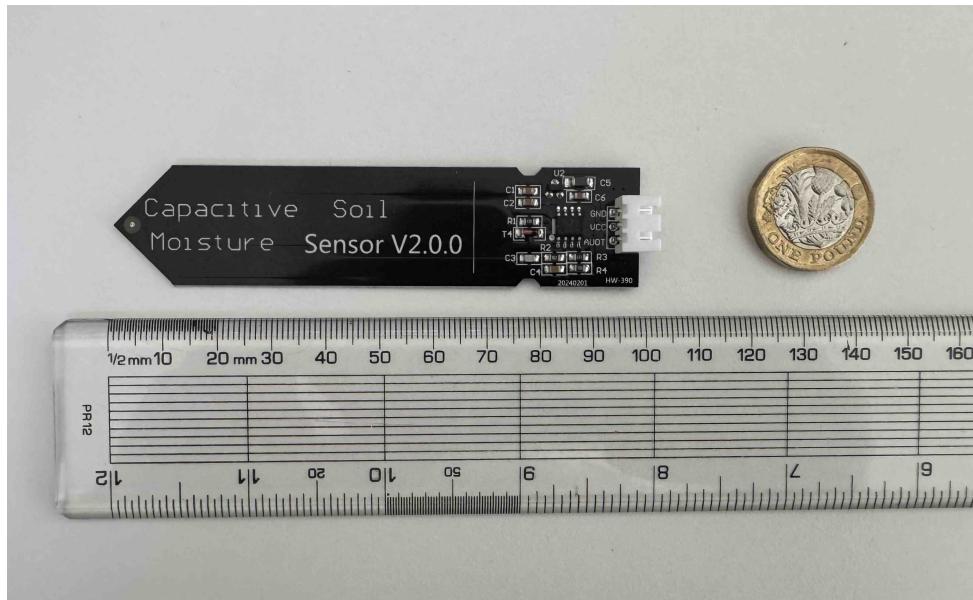


Figure 5: The Pi Hut capacitive soil moisture sensor

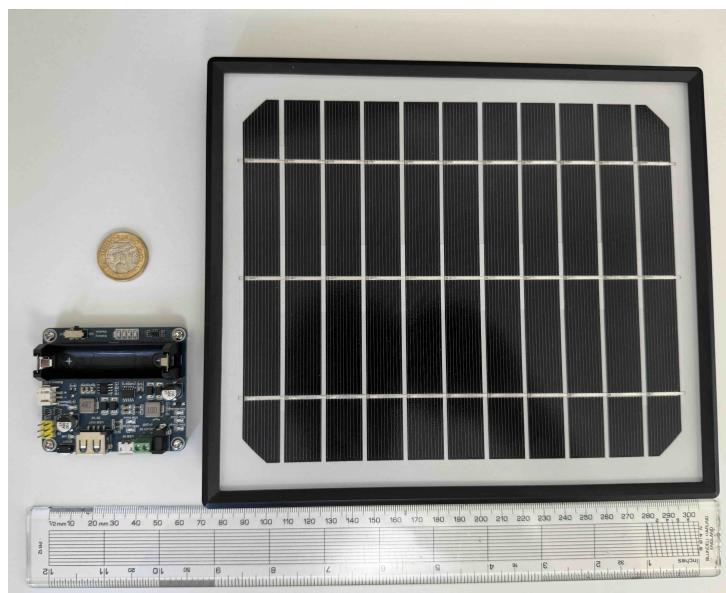
### Wind speed sensor



**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

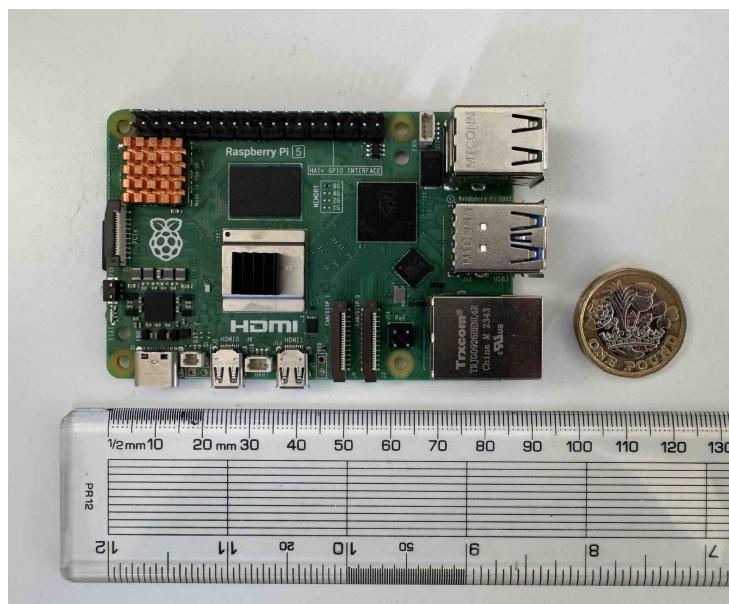
On each challenger I flashed the drives with CircuitPython, an open source interpreted language similar to Python but simplified for use in microcontrollers.

### 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 Hardware assembly

## 7.2 Programming the hardware

## 7.3 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) while quality of the signal was measured using the signal-to-noise ratio (SNR).

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 the 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 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 were 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 10 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

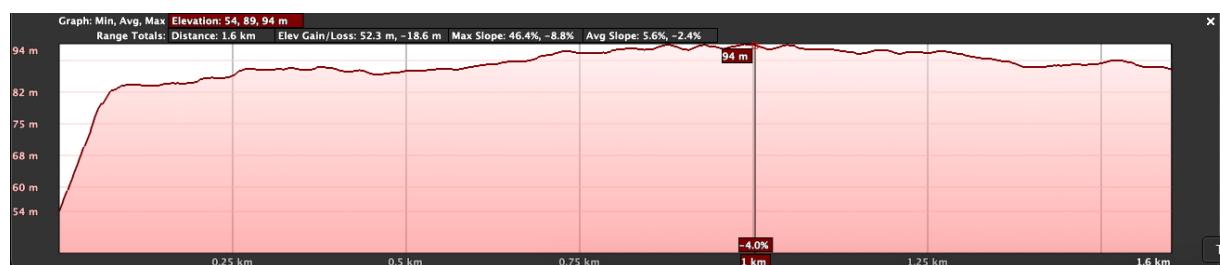


Figure 10: Elevation profile of test area (ignore large dip at start)

## **8 Deployment in the field**

### **8.1 Placement of nodes**

# Part III

# Software development

## 9 Software design

## **Part IV**

# **Evaluation**

## References

- [1] Met Office, “Factsheet 14: Microclimates,” Met Office, Tech. Rep., 2023, Accessed: 16 June 2025. [Online]. Available: [https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/library-and-archive/library-publications/factsheets/factsheet\\_14-microclimates\\_2023.pdf](https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/library-and-archive/library-publications/factsheets/factsheet_14-microclimates_2023.pdf).
- [2] World Meteorological Organization (WMO), *Guide to Instruments and Methods of Observation: Volume III – Observing Systems*, 2024 edition. Geneva: World Meteorological Organization (WMO), 2025, ISBN: 978-92-63-10008-5. DOI: 10.59327/WMO/CIMO/3. [Online]. Available: <https://library.wmo.int/idurl/4/68661>.
- [3] S. Yang, L. L. Wang, T. Stathopoulos, and A. M. Marey, “Urban microclimate and its impact on built environment—a review,” *Building and Environment*, vol. 238, p. 110334, 2023.
- [4] D. Lai, W. Liu, T. Gan, K. Liu, and Q. Chen, “A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces,” *Science of The Total Environment*, vol. 661, pp. 337–353, 2019, ISSN: 0048-9697. DOI: <https://doi.org/10.1016/j.scitotenv.2019.01.062>. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0048969719300683>.
- [5] H. A. Cleugh, “Effects of windbreaks on airflow, microclimates and crop yields,” *Agroforestry Systems*, vol. 41, no. 1, pp. 55–84, 1998, ISSN: 1572-9680. DOI: 10.1023/A:1006019805109. [Online]. Available: <https://doi.org/10.1023/A:1006019805109>.
- [6] L. Atzori, A. Iera, and G. Morabito, “The internet of things: A survey,” *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010, ISSN: 1389-1286. DOI: <https://doi.org/10.1016/j.comnet.2010.05.010>. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1389128610001568>.
- [7] L. Pounder. “Raspberry pi produced 10 million rp2040s in 2021, more pi stores likely.” Accessed: 02/07/25. [Online]. Available: <https://www.tomshardware.com/news/raspberry-pi-10-million-rp2040s>.
- [8] A. Q. Khan, M. Riaz, and A. Bilal, “Various types of antenna with respect to their applications: A review,” *International Journal of Multidisciplinary Sciences and Engineering*, vol. 7, no. 3, pp. 1–8, Mar. 2016, ISSN: 2045-7057. [Online]. Available: <https://www.ijmse.org/Volume7/Issue3/paper1.pdf>.

# Part V

## Appendices

## A Example