University of Southern Queensland

Faculty of Engineering, Electrical & Electronic

Low Powered Remote Monitoring for Smart Beehives

A Dissertation submitted by

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in fulfilment of the requirements of

ENG4112 Research Project

towards the degree of

Bachelor of Electrical Electronic Engineering

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Abstract

Each year, we find ourselves reaching for a jar of honey to make warm lemon and honey concoctions to comfort our throat during flu season. We also spread the golden goodness on freshy baked bread and cereals; the delicate sweetness reminiscent of life's simple pleasures.

When we visit the supermarket, we enjoy the year round availability of our favourite fresh fruit and vegetables without the knowledge that behind these products is a sophisticated insect that silently works in the background and is central to our food production. That insect is the honey bee (Apis mellifera). It is a vital part of our food chain and critical to the pollination of a large majority of agriculture crops in Australia.

Over recent years however, the honey bee has been under threat. This threat is a small mite call the Varroa Mite, which humans have yet to find a solution to. Varroa Mite has just entered Australia and is trying to be contained. Varroa Mite is just one of the problems honey bees face. Other problems including Colony Collapse Disorder (CCD) have also seen a major decline in the bee population in the Untinted States of America. With the demand for food driving our agricultural farms to produce crops with the highest yield and in the shortest time frame, the failing health of bees has become a by-product of the demand.

This project has set out to research the possibility of early detection of pest and disease with the use of low powered remote monitoring for smart beehives. This type of technology would benefit commercial beekeepers with remote hive monitoring reducing overheads and the time beekeepers are required to travel to hive sites to conduct inspections.

As part of the project, remote monitoring technology was installed into the beehive so data could be remotely collected for a month before it had to be removed. The data collected was based on the parameters that best indicated hive health attributes found within the literature. These attributes were humidity, temperature, weight, pressure and bee counters, although not all the expected parameters listed had data collected in the experiment time frame.

Data was collected using an Arduino on the 4G Telstra Cat M1 network and stored in the Arduino cloud making it easy to access and interpret with timely updates. The data was then used with machine learning to predict internal hive temperature based on the rest of the parameters.

Modelling was also done with three models to pick out the most accurate results. Using linear regression, random forest and support vector machine models, a website application was built to give the beekeeper an indication of what the internal temperature should be based on the other parameters

The remote monitoring and hive temperature predictor will provide real time information on remote hives for the beekeeper, improving overall productivity reducing the risk and incidence of disease in hives.

University of Southern Queensland

Faculty of Health, Engineering & Sciences

ENG4111/2 Research Project

Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

I. Hutchings
[redacted]

Acknowledgments

This thesis was typeset using Word.

I would like to thank my wonderful partner and children for putting up with my study for the past six years and for allowing me to keep bees in our small backyard for this project. Without their support, I wouldn't be where I am now.

I would also like to thank my thesis supervisor, Catherine Hills, for her wonderful support and guidance. I'm very appreciative for her enthusiastic approach to my unusual and out-of-the-box idea.

Thank you,

I. Hutchings

Content Warning

This research contains material of a highly sensitive nature including pictures of livestock that have been euthanized. It may be distressing for some individuals.

Overview of dissertation

This dissertation is organised as follows:

Chapter 1: Introduction

This chapter provides detailed background information on what is affecting bees around the world at the current time and how other countries like New Zealand have dealt with problems like Varroa Mite. It explores examples of what Australia might do when faced with the Varroa Mite and the possible impact of pollination services. The chapter looks at the price of pollination with the arrival of the Varroa Mite and the overall revenue raised from honey bees and their associated products.

Chapter 2: Literature Review

The literature review investigates past projects, what parameters were monitored in those projects, whether the projects progressed past the developmental stage and or the prototype stage, and if data was obtained. The literature review also looks at the serious pests and diseases affecting honey bees and the important attributes that determine beehive health.

Chapter 3: Research design and methodology

The chapter details how the beehive monitoring system was designed and what sensors were required to setup the experiment. It also looks at the micro controller, how many inputs and outputs were required, and how long the battery life will last for during the experiment. This chapter also examines a major problem encountered throughout the experimental period and explains why the experiment had to stop early before it reached maturity.

Chapter 4: Results and analysis

This chapter addresses the successes and failures of the sensors. The limited timeframe available for the experiment, the remote location of the beehives and the unfavourable weather conditions, made it difficult to diagnose, analyse and rectify faults. The chapter details the testing that has been utilised for this project and the results obtained. This section also provides analysis of the data gathered from testing.

Chapter 5: Conclusion and further work

concludes the dissertation, discussing the success of the project in achieving the objectives. Further work in the field that can enhance this research is also discussed.

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Chapter 1 Introduction

1.1 Significance of honey bees

Honey bees have always been an important part of the Earth's ecosystem. Records show mankind keeping bees as early as 20000 BC (Palmer 2022). Many pottery designs from ancient Egypt depict honeybees and honeycomb (Palmer 2022). The fermented honey beverage, mead, appeared as an immortality-bestowing alcohol in the Rigveda from 1700 BC to 1100 BC (Palmer 2022). There was also an abundance of bees in medieval England, given the huge amount of wax required for candles (Hung et al. 2018).

European honey bees were introduced to Australia approximately 200 years ago for pollination and to make honey. Honey bees have become a critical part of Australia's ecosystem since then, particularly in their role as pollinators of managed habitats (Marshall 2022).

Today, honey bees are essential to Australia's agricultural industry as they carry pollen between plants of different sexes to fertilise them. However, the number of honey bees has declined over recent decades due to habitat loss, pesticides, changes in weather patterns and the excessive use of agrochemicals in intensive farming practices.

1.2 Australia's honey bee industry

Australia's honey industry produces between 20,000 and 30,000 tonnes per year. The industry has an estimated gross value of production of $147 million per year (2018-19). This includes a wide range of products from queen bees and packaged bee sales, to pollen, propolis, and beeswax production. While beekeeping products only represent a fraction of Australia's 1.397 trillion USD gross domestic product (2019), they are integral to many other industries in the production of everyday items including fresh food and vegetables, candles, medical balms, sealants and furniture polish.

Many agricultural crops rely on honey bees to provide valuable pollination services. Almonds crops, for example, are wholly reliant on honey bees for pollination. The pollination services honey bees provide is estimated to contribute up to $6 billion to the beekeeping industry annually (Crooks 2008).

Without honey bees, many common fresh fruit and vegetables would not be available. These include apples, apricots, avocado, blackberries, blueberries, canola oil, coffee, beans, cherries, cucumbers, dates (medjool), dragon fruit, goji berries, guava, kiwi, mangoes, muesli, nuts (almonds, walnuts, cashews, macadamia, peanuts, pecans), papaya, passionfruit, pear, pepitas, pineapple, pitted prunes, plums, pumpkin butternut, rockmelon, sesame seeds, spreads (peanut butter, almond butter and more), alfalfa sprouts, strawberries, sunflower seeds, watermelon and zucchini.

In 2021, a supermarket in Neutral Bay, Sydney, removed all products from it shelves that required pollination from honey bees. The experiment was part of Woolworths' Discovery Garden Collection, as part of a campaign to raise awareness of how important bees are to Australia's food supply (Sinclair, 2021). The sheer volume of products missing from Woolworths' shelves was a clear indication of the critical role honey bees play in the pollination of food crops.

1.3 Factors affecting Australia's honey industry

Australia's climate plays a big part of the production of honey. Weather events such as droughts, floods and bushfires can have a significant impact on the numbers of hives. Beekeepers must regularly monitor their hives to assess the impact of environmental factors, as well as for pests, diseases and nutritional deficiencies.

1.3.1 Pests and diseases

Australia's honey bee surveillance program plays an instrumental part in the management of pests and diseases which pose a threat to Australia's honey bee industry (Agriculture Victoria 2022). While the scourge of the Varroa Mite is the most significant biosecurity threat to the industry, honey bees can also be affected by a range of other common pests and diseases including American foulbrood, Chalkbrood, European foulbrood, Small hive beetle and Wax moth.

Asian honey bees, which are smaller than the European honey bee (Apis Mellifera), are also considered to be a pest. The Asian honey bee affects native animals that feed from nectar. They also displace native birds, as the bees commonly inhabit small cavities that birds use for nesting. The Asian honey bee has larger nests and often swarm more frequently than the European honey bee. This makes controlling and destroying the pest more difficult (Dollin 2021).

Asian Honey bees are considered to be a major competitor for European honey bee as they steal food stores from the European honey bee via a process known as 'robbing'. Robbing occurs when the Asian honey bee enters the European honey beehive and steals honey from inside the hive. Not only does this reduce the honey yield of the beekeeper, if done in Winter when the European honey bees are hibernating and enough stored food is taken, it could lead to loss of the beehive due to starvation. The Asian honey bee is also a potential host for the Varroa Mite (Dollin 2021).

A comprehensive list of pests and diseases known to Australian beekeepers is outlined in Table 1. Beehives are also susceptible to a number of brood diseases including:

- Varroatosis
- Small hive beetle
- Tropilaelapsosis
- American foulbrood
- European foulbrood
- Chalkbrood
- Stonebrood
- Black queen cell virus (BQCV)
- Sacbrood virus (SBV).

Other diseases, that are limited to affecting adult honey bees, include varroatosis and nosemosis.
It is important for a beekeeper to able to recognise a problematic disease and rectify it with the correct treatment even if that means destroying the hive by burning the hive and its contents. This is a keep part of responsible hive management, keeping livestock and protecting the greater population of bees.

Disease	Causative agent	Type
Acariasis	Acarapis woodi	Parasitic
Varroatosis	Varroa destructor	Parasitic
Aethinosis	Aethina Tumida (Small hive beetle)	Parasitic
Tropilaelapsosis	Tropilaelaps spp	Parasitic
American foulbrood	Paenibacillus larvae	Bacteria
European foulbrood	Melissococcus pluton	Bacteria
Chalkbrood	Ascosphera apis	Fungal
Stonebrood	Aspergillus flavus	Fungal
Nosemosis	Nosema apis – Nosema ceranae	Fungal
Amebiasis	Malpighamoeba mellificae	Protozoal
Sacbrood Virus (SBV)	Virus Picorna-like	Viral
Chronic Bee Paralysis Virus (CBPV)	Cripaviridae	Viral
Acute Bee Paralysis Virus (ABPV)	Dicistroviridae	Viral
Deformed Wing Virus (DWV)	Iflaviridae	Viral
Black Queen Cell Virus (BQCV)	Dicistroviridae	Viral
Israeli Acute Paralisysis Virus (IAPV)	Dicistroviridae	Viral
Kashmir Bee Virus (KBV)	Dicistroviridae	Viral
Kakugo Virus	Iflaviridae	Viral
Invertrebrate Iridescent Virus type 6	Iflaviridae	Viral
Tobacco ringspot virus	Secoviridae	Viral

Table 1: Main diseases of honeybees depending on the nature of the causative agent (Bailey, Ball 1982).

1.3.2 Brood chamber

The brood chamber says a lot about the health of a hive and whether it has been infected with pest or disease. The brood pattern will also indicate if a queen is failing and needs to be replaced. It should be noted that queens should be replaced every two or three years to maintain optimum hive performance. Queens can fail due to age, injury, poorly mated, poor genes or disease (PerfectBee n.d.).

Figure 1 illustrates the different brood patters that can be observed in a hive. A strong queen will move around the hive in a somewhat predictable fashion. She will start in the middle of the foundation and then follow ever-increasing circles, laying around 2,000 eggs (Agriculture Victoria 2022).

As well as indicating poor performance of the queen, a spotty pattern can be indicative of disease or poor nutrition. It can also signify an unusually high influx of nectar or pollen into the hive. In this circumstance, the bees will store the nectar or pollen in spare brood cells. This can make the brood pattern appear spotty, however a close inspection will confirm that’s not the case (Agriculture Victoria 2022).

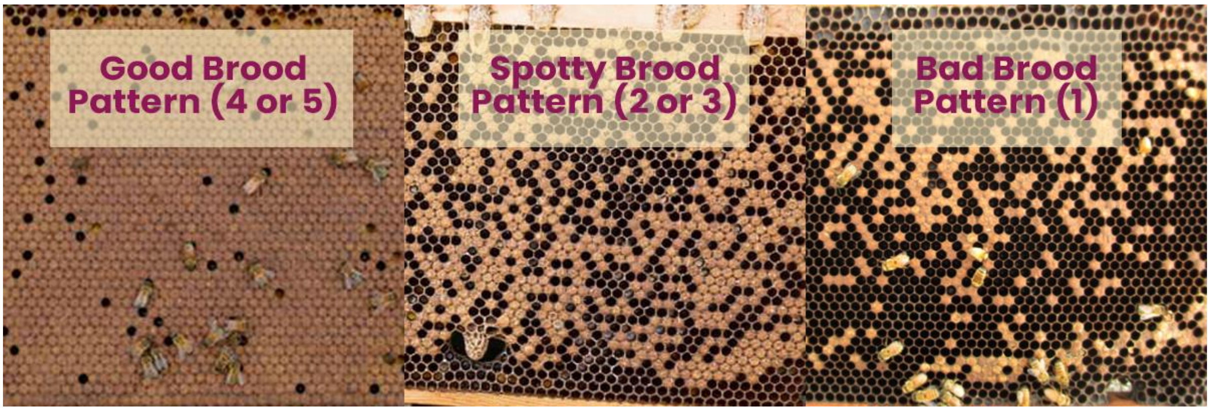


Figure 1: Brood frames patterns (Sullivan A 2023).

A bad brood pattern is an indication of improper egg-laying pattern by the queen and suggests the colony is diseased. A bad brood pattern is usually accompanied by capping that appears sunken in comparison to raised capping on a good brood pattern (Agriculture Victoria 2022). Diseased brood affects the overall temperature of the hive and in severe cases, can be fatal to the hive.

If the brood is diseased, caps may be perforated due to infected larvae and pupae that die after their cells have been capped. Diseased brood can also have concave, dark and at times, greasy caps. A matchstick inserted through the cap and into the cell, helps a beekeeper to determine if disease is present. A white, milky, non-stringy substance on the end of the matchstick indicates a healthy cell (Agriculture Victoria 2022).

During brood chamber inspections, a beekeeper should always sight the queen bee as she is the most important bee in the hive. Without a queen, the hive will become aggressive until such time that she is replaced, either by the hive itself or by the beekeeper.
According to (Sullivan 2023) when a hive swarms, the remaining nurse and worker bees will nurture a new queen by feeding royal jelly to selected eggs laid by the previous queen. This process can happen before the hive swarms. Once the larvae transitions from the egg stage to larvae, the cells are capped and a new queen will emerge from the cocoon state. The appearance of queen cells indicates whether a queen is being superseded or if the hive is about to swarm (Figure 2).

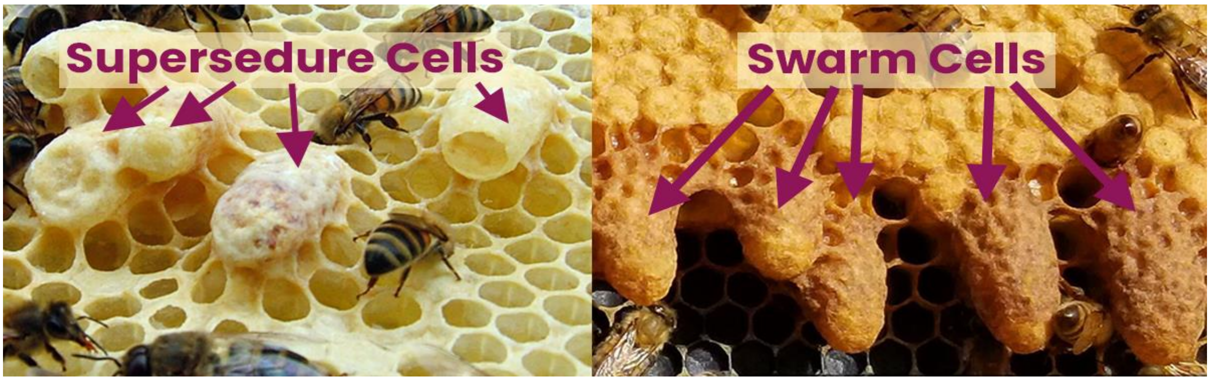


Figure 2: Two types of queen cells found in beehives. A new queen is raised by the hive once the old queen swarms (Sullivan A 2023).

1.3.3 Small hive beetle

Small hive beetle is one of the most common and easily identifiable pests (Figure 3). It thrives under the right conditions and when left uncontrolled. The Small hive beetle can have a devastating impact on a hive; the adult beetles lay eggs inside the cells of the wax frames and once the eggs hatch, the grubs eat through the comb structure and eventually destroy the hive (Figure 4) (BeeAware n.d.).

Figure 3: Small hive beetle (Lawrence 2020).

Figure 4: Small hive beetle grubs sliming a honey frame. (BeeAware n.d.).

Small hive beetle is generally controlled by placing beetle traps inside the hive. A nontoxic approach can be taken by using a beetle trap that is placed in between the tops of the frames. The traps hold vegetable oil and the bees will chase the beetle into the traps drown the beetle. Another method to kill the beetle is by a similar approach but the trap is filled with cockroach bait, the bees will chase the beetle inside the trap and the beetle comes into contact with the bait and dies over time (Annand 2008).

1.3.4 American foulbrood

A matchstick test returning a brown rope-like substance when removed from a cell of a brood chamber, is an indication of the American foulbrood (AFB) disease (Figure 5). A reduction in bee numbers and poor hive performance is an indication of AFB. In AFB-infected hives, nectar flow also decreases resulting in loss of weight as the bees use the honey stores.

AFB has a characteristic odour, however the odour alone is not a reliable diagnostic tool. Once AFB has been detected, the affected hive needs to be destroyed as AFB-infected spores can easily be spread in contaminated honey and honey products to other hives. Infected bees can also carry the spores. If AFB is not appropriately managed, the cycle of infection and hive destruction perpetuates, leading to serious outbreaks that can impact entire regions of bees (BeeAware n.d.).

Because AFB spores can live dormant for 50 years, it is a notifiable disease in all state jurisdictions (Agriculture Victoria 2022). Australia’s biosecurity agencies have a uniform response to AFB detections, which is either sterilisation or total hive destruction (Figure 6).

Figure 5: Brown rope on the end of a matchstick indicating AFB (Queensland – Department of Agriculture and Fisheries).

Figure 6: Eradication of hive infected with AFB (Agriculture Victoria 2020).

1.3.5 Chalk Brood

The appearance of a chalk-like substance in the brood pattern can be a sign that the hive has a fungus infection, known as Chalk brood. This type of infection occurs when the hive has poor nutrition, prolonged periods of cool and wet weather or is under stress (Snyder 2013).

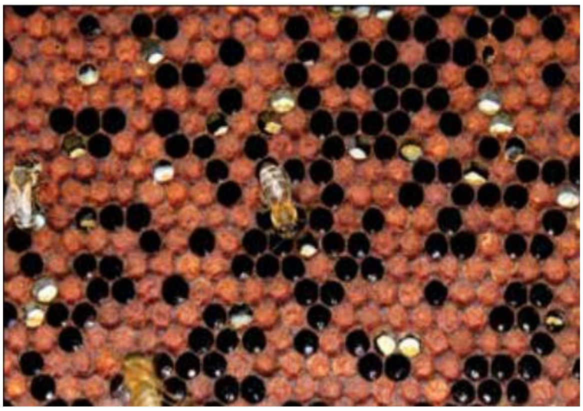


Figure 7: Chalk Brood can be identified by the mummy like bees inside the cells (Snyder 2013).

Chalk brood can be easily identified by doing a visual inspection. Other signs of Chalk brood include decreasing bee numbers and changes in overall hive weight (BeeAware n.d.).

Chalk brood can be remedied by cleaning away any chalk-mummified dead brood at the entrance of the hive, placing the hive in the sun and keeping it well ventilated. Figure 7 and 8 shows the different stages of Chalk brood including the damaged brood in the cells as it turns to a chalk-like state and the entrance of the hive where the bees are cleaning the dead bees out of the hive. The appearance of dead bees at the entrance of the hive is an indicator of Chalk brood inside the hive.

Figure 8: Chalk Brood – dead mummified brood being cleaned out of the hive by the bees (Snyder 2013).

1.3.6 European foulbrood

European foulbrood is spread through larvae and by beekeepers moving infected hives and equipment between different locations. While European foulbrood has a similar appearance to American foulbrood, they are different in that European foulbrood can be treated with a range of antibiotics (BeeAware n.d.).

European foulbrood affects all stages of larvae and is detected by the presence of a brown, slimy and liquid debris containing dead bee larvae in the cells of affected comb. These cells can have a sickly-sweet or rotten odour, or be odourless entirely. When a frame of brood infected with European foulbrood is examined under a microscope, the larvae will be seen to be discoloured and mummified and covered with bacterial spores (BeeAware n.d.).

Other indicators of European foulbrood include a decrease in the number of larvae and adult bees in the hive, an increase in the number of queen cells and reduced honey production. If left untreated, European foulbrood can decimate the affected beehive (BeeAware n.d.).

1.3.7 Varroa Mite

The parasitic Varroa Mite (*Varroa jacobsoni* and *V. destructor*) is considered to be the most serious and dangerous pest for honey bees and their brood. The Varroa Mite weakens and eventually kills honey bees (Figure 9). It is also a key transmitter of other honey bee viruses including deformed wing virus (Stokstad, 2019).

Figure 9: A Varroa Mite on a host bee (Wild 2019).

The male mite is smaller than its female counterpart. Females are generally approximately 1.1 millimetres long and 1.7 millimetres wide, with a visible reddish-brown scallop-shaped shell. The male is a yellow-white in colour. Both male and female Varroa Mites are visible to the naked eye (Stokstad, 2019).

Once the Varroa Mite enters a hive, the mated female crawls into a work or drone cell containing mature larvae, digs to the bottom of the cell and buries itself in the food of the larvae (Figure 10). Once the cell is capped, the female mite will begin feeding on the larvae and laying eggs. The female mite will lay up to six eggs, the first of which will be male and the remainder female (Stokstad, 2019).

It takes eight to 10 days for the mite to mature into its adult form. Once the mites reach maturity and mate, they emerge from the cell on the adult bee, which serves as the Varroa Mite's host (Agriculture Victoria 2022).

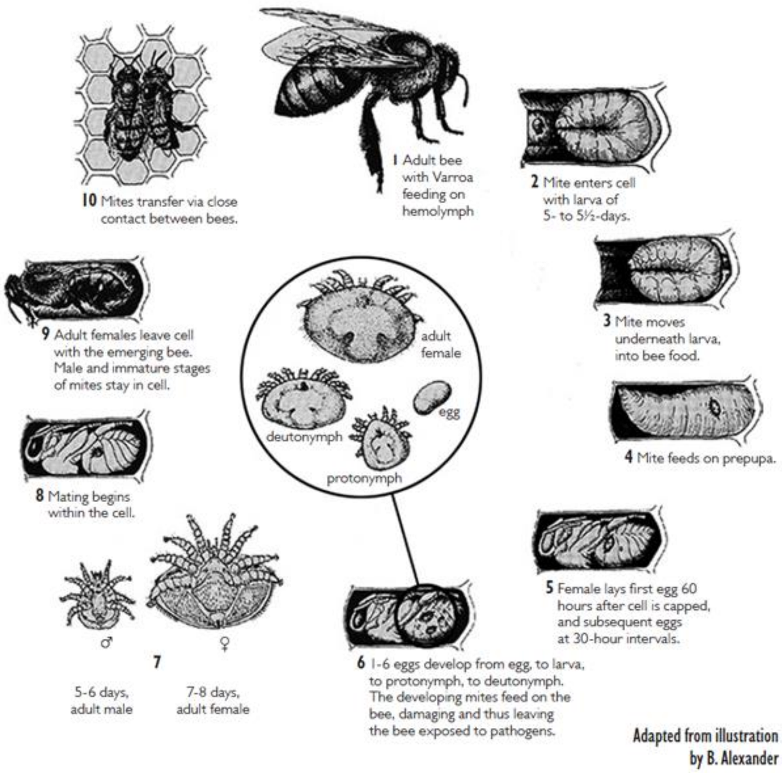


Figure 10: Varroa Mite lifecycle (Alexander 2019).

The impact of Varroa Mite

Countries that have already faced an incursion of Varroa Mite, saw feral hives progressively destroyed as a result. The loss of these hives directly impacted the horticulture industry, forcing farmers to pay for pollination services to yield a crop. This subsequently increased the price of food production, which the farmer then passed on to the consumer at the supermarket checkout.

According to Monck, Gordon and Hanslow (2008), once Varroa Mite arrived on the North Island of New Zealand in early April 2000, it quickly spread to the South Island and wiped out feral hives. The number of managed hives in the North Island decreased from approximately 135,000 in 2000 to 115,000 in 2004 with similar hive loss reported in the South Island. This resulted in a further cost to New Zealand beekeepers, of $40 to $50 per hive for pollination.

Monck, Gordon and Hanslow (2008) further suggest that similar price increases were seen in the United States of America (USA) where between 900,000 to one million hives were needed for the Californian almond pollination after the incursion of the Varroa Mite in the USA in 1987. Almond prices rose by $2.00 USD per pound as a direct result of the pollination services that were subsequently required. Farmers were charged as much as $200.00 USD per hive for pollination services during the season of 2006.

In 2008, Monck, Gordon and Hanslow undertook data and scenario analysis to predict how the spread of Varroa Mite would impact Australia, specifically focusing on the implications on pollination. Several potential scenarios detailing the impacts of the Varroa Mite in Australia are outlined below.

Scenario 1

Scenario 1 is based on a nil impact of Varroa Mite and implies that demand for crop pollination in Australia will grow between 10 per cent and 20 per cent per year.

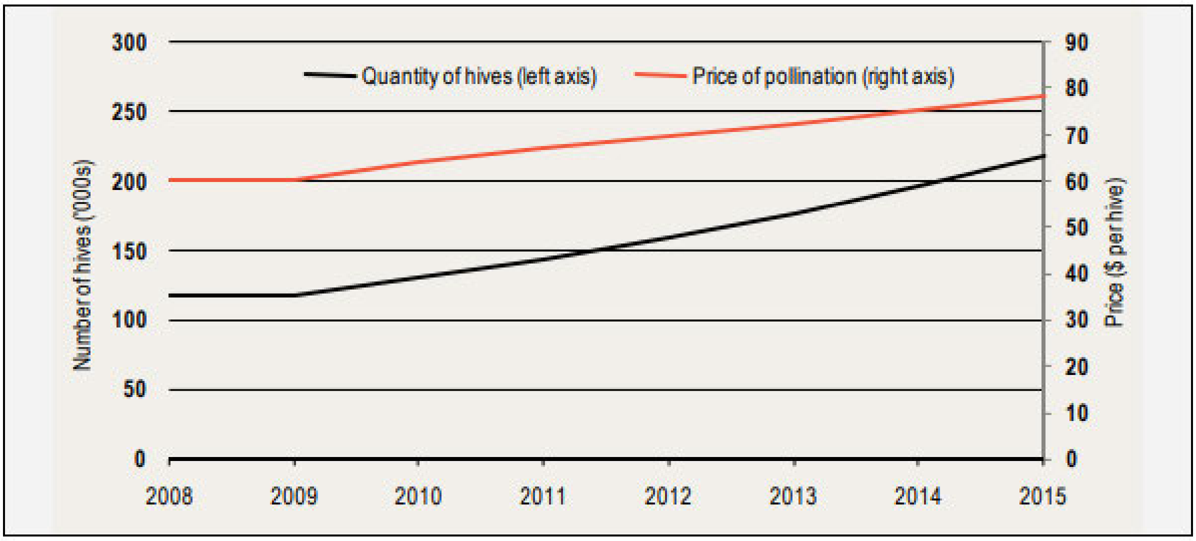


Figure 11: Business as usual price and quantity over time (Monck, M, Gordon, J, Hanslow, K 2008).

Figure 11 suggests that demand for beehives will increase year on year, along with the price of pollination. This highlights the demand on the commercial beekeepers without the effects of Varroa Mite. Jumps in demand for pollination services in the almond industry and conservative growth estimates from 93,000 in 2008 to 189,000 in 2015, indicates that the almond industry remains the largest user of pollination services. In 2015 alone, the almond used 50 per cent of the industry's pollination with the remainder of industries making up the rest (Monck, M, Gordon, J, Hanslow, K 2008).

Scenario 2

Scenario 2 is based on the invasion of Varroa Mite and feral wild hives being consequently infected and dying off. It should be noted that a feral will beehive is a beehive living on its own without human interaction an example of this is bees living in a hollow tree in the bush. These bees are critically important to our ecosystem as they naturally provide pollination to farms and the bush. The loss of feral wild beehives would have significant implications for the agricultural industry. An additional 530,000 beehives would be required across Australia to provide the pollination services that those feral wild beehives would have provided for free. The increased requirement of pollination is well above what the industry can deal with and its current capacity.

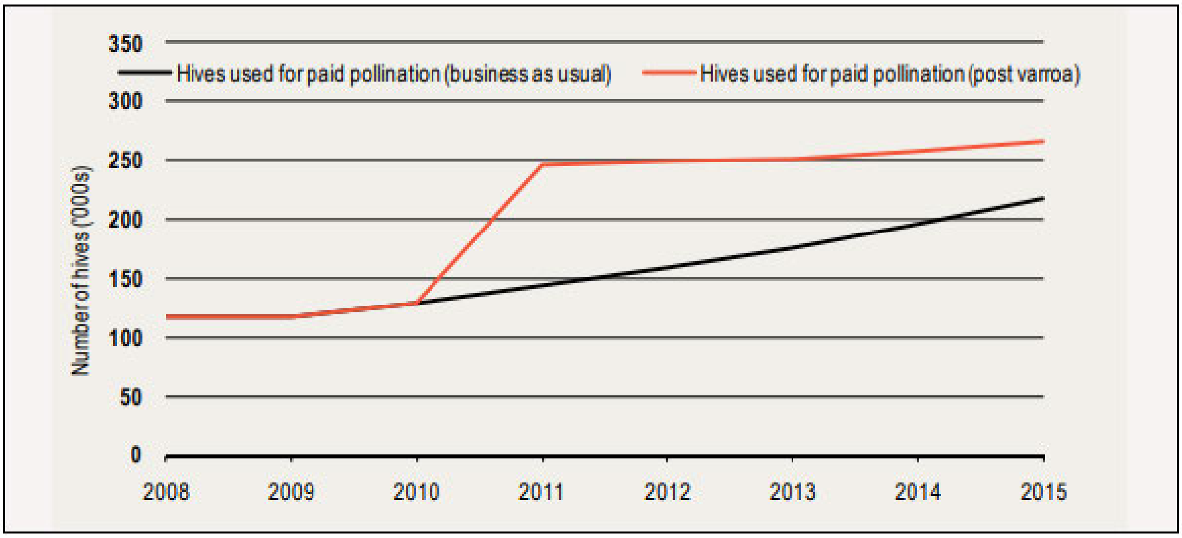


Figure 12: The impact of Varroa Mite on the quantity of beehives (Monck, M, Gordon, J, Hanslow, K 2008)

Figure 12 shows that an outbreak of the Varroa Mite in Australia would mean approximately 110,000 additional hives would be required to meet the demand on paid pollination services. Figure 12 further suggests that as the impact of Varroa Mite stabilised, the sharp increase seen at the onset of the outbreak would stabilise in line with the normal demand for paid pollination services.

Scenario 3

Scenario 3 is based on beekeepers responding to the threat of Varroa Mite early, and undertaking the necessary preparations. Like Scenario 2, there is a major spike in the price of pollination but after the spike, costs fall. This is a far better scenario for everyone involved including farmers, beekeepers and supermarket consumers.

In this scenario, food prices would stabilise faster. Conversely, as indicated by the other scenarios, the cost of paid pollination would stay higher for a longer period of time, and therefore impact the cost of products reliant of pollination services including fresh fruit and vegetables.

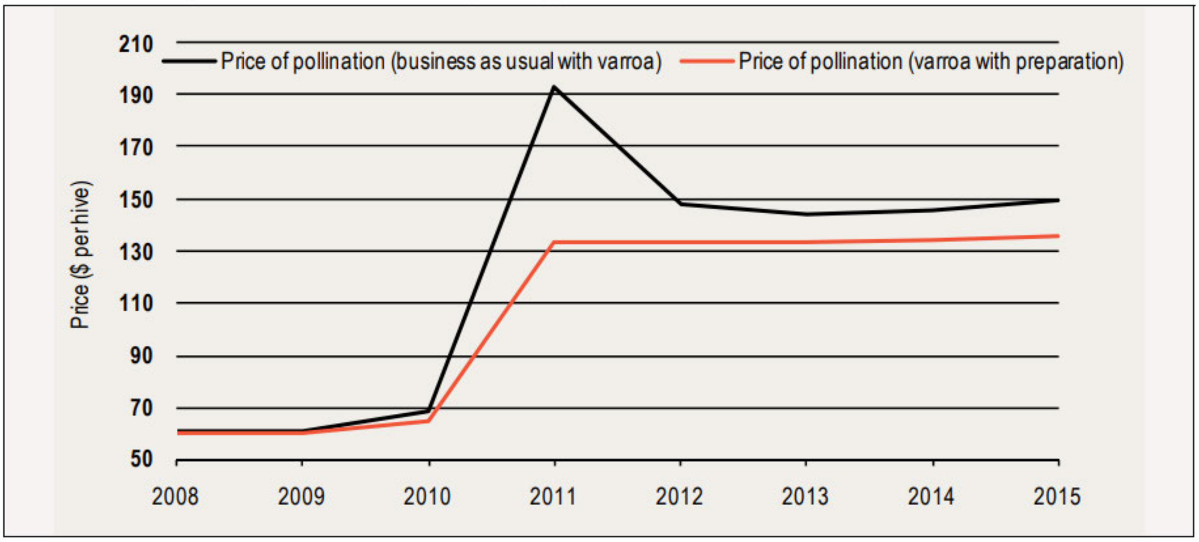


Figure 13: The impact of the Varroa Mite on the quantity of hives versus the price (Monck, M, Gordon, J, Hanslow, K 2008).

Varroa Mite in Australia

In June 2018, Australia narrowly avoided a major biosecurity threat posed by the Varroa Mite after an infected swarm of bees was found inside a shipping container docked at the Port of Melbourne (Agriculture Victoria 2022). After detection, all beehives within a two-kilometre radius of the Port, underwent a beehive surveillance program. This was conducted by Agriculture Victoria's Incident Management Team in conjunction with the local beekeeping community (Agriculture Victoria 2022).

In a separate incident in June 2022, Varroa Mite was detected at the Port of Newcastle as part of the NSW Department of Primary Industries' (DPI) biosecurity surveillance program. In an attempt to mitigate the spread of Varroa Mite, a biosecurity emergency order was introduced and an eradication plan was put in place to eradicate the Varroa Mite. This plan supported the establishment of biosecurity zones covering a 25-kilometre radius of each identified infection site (Department of Primary Industries 2022).

Since 16 May 2023, 156 Varroa Mite infection locations have been identified across Newcastle, the Central Coast and the Mid North Coast of New South Wales. Much like COVID-19 tracing, tracers have been identifying movement of hives in the biosecurity zone to try to determine how far Varroa Mite has spread (Department of Primary Industries 2022).

Once an infection site has been identified, the affected hive must be destroyed, as per the directive from the DPI. The subject sire then becomes part of the 'Eradication Zone', which is a 10 kilometres radius around the infected hives in which all other hives and bees need to be destroyed (Figure 13). The Eradication Zone expands with every new infection site identified (Department of Primary Industries 2022).

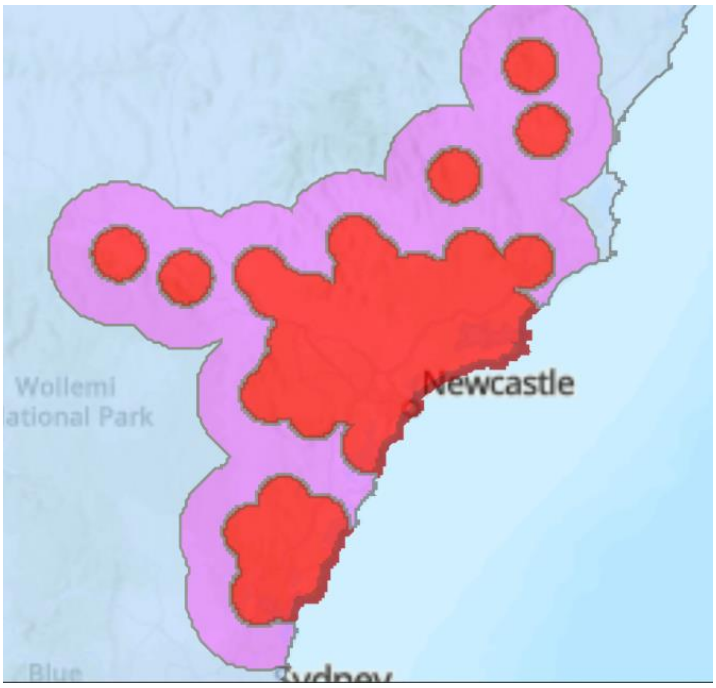


Figure 14: A map showing the Varroa Mite Eradication Zone (red) and Surveillance Zone (purple) in the Newcastle region as at March 2023 (DPI 2022).

A 'Surveillance Zone' starts at the edge of the Eradication Zone. The Surveillance Zone is 25-kilometre radius from the edge of the Eradication Zone in which beekeepers and the DPI conduct testing to determine the outer boundaries of the Eradication Zone (Figure 14). This DPI is aiming to eradicate all bees in and around the Eradication Zone. In doing so, they are working to remove the only possibly host and source of food for the Varroa Mite and consequently, completely eradicate the Varroa Mite (Department of Primary Industries 2022).

1.3.8 Signs of pests, disease or contamination

There are clear signs that indicate a hive has been infected by disease. One such sign is a pungent odor emanating from the hive. Another sign of disease or contamination is being unable to locate the queen, her eggs or larvae in the brood chamber (Agriculture Victoria 2022).

A healthy hive should smell of sweet honey when opened. If a hive has a sour, rotten or ammonia-like smell, it is generally an indication that the hive has been infected by a pest or disease like American foulbrood or Small hive beetle. Common household pests including mice, can also impact a hive (Department of Primary Industries 2022).

Hives can also be affected by the crops bees come into contact with, particularly if the crops have been sprayed with a pesticide shortly before contact occurs. This can lead to mass poisoning of bees within the hive, which will be evident by a significant number of dead bees found at the hive's entrance. In severe cases, dead adult bees will also be found inside the hives and brood will die from starvation. In less severe cases, the brood overheats or becomes too cold due to inability of the adult bees to feed the brood and regulate hive temperature according to (BeeAware n.d.).

Symptoms of poisoning can include:

- Significant number of dead bees at the hive entrance.
- Hives in nearby locations being similarly affected.
- Affected bees will have their proboscis fully extended and wings unhooked and at odd angles.
- Absence of foraging bees leaving the hive.
- Bees in the hive exhibiting aggressive behaviour.
- Bees moving slowly, showing signs of paralysis or involuntarily jerking their bodies.

A beekeeper is limited in what they can do for a poisoned hive other than move the hive to a safe location and try to add extra brood and young bees from another hive (BeeAware n.d.).

Multiple eggs being laid in one brood cell is also an indicator of a failing hive (Figure 15). This laying pattern only occurs in the absence of a queen bee, where a worker bee assumes the role of laying eggs. This results in an unproductive hive, as the worker bee isn't mated and therefore, her eggs are unable to hatch. When this type of laying pattern occurs, intervention is required by the beekeeper to ensure a new queen bee is introduced to the beehive (Burlew 2014).

Figure 15: Multiple eggs laid in one brood cell by a worker bee (Burlew 2014).

There are a number of simple checks beekeepers can conduct to assess the health of a beehive. A simple walk around a hive will give a beekeeper an indication about what is happening inside. According to Agriculture Victoria (2022), the types of observations a beekeeper may make inspecting the exterior of a hive include:

- Heavy bee traffic going in and out of the hive and field bees carrying pollen into the hive are signs of a healthy beehive.
- Small numbers of bees going in and out of the hive can indicate low hive numbers due to poor health or that the bees have swarmed.
- Aggressive bees from an angry hive and can be an indicator of weakness within a hive or poor hive health.
- Worker bees fanning their wings at the entrance of the hive opens the bee's Nasonov glands and releases a pheromone to help other bees doing their orientation flights. This action also signals their home.
- Bees formed in the shape of a man's beard on front of the hive indicates that the bees are hot and are trying to reduce heat inside the hive. It can also be an indication of new nectar within the hive.
- Bees fanning their wings outside the hive, which helps to increase the flow of air through the hive, suggests bees are working to cool the hive down. This is also a sign that space may be limited inside the hive and another box, known as a super, is required.

  A steady supply of pollen returning from the field usually indicates new brood in the hive and suggests they are feeding. With bee's back legs baskets full of pollen, it means they are feeding. The pollen gives bees lipids, vitamins, proteins, sterols and minerals. It also provides certain carbohydrates that are missing from flower nectar. Bees are the most reliant on pollen during the larval stage.

1.4 Research topic

Given the importance of honey bees to the agricultural industry and the Australian economy, the topic for this research dissertation is the use of IoT (Internet of Things) to aid in the early detection of pest and diseases in beehives. The focus of this research will be to enable commercial operators to monitor the health of their beehives remotely, and gain a better understanding of the precursors to common hive pests and diseases.

The remote monitoring technology used as part of this research project will obtain hive data to measure the hive weight and determine the honey flow and the number of bees. It will also provide data on temperature and humidity to measure the health of the hive during extreme temperatures.

Data will be gathered from the beehive remotely, with the use of IoT. Sensors placed inside the hive will measure heat and humidity. Weight sensors underneath the hive will measure the hive weight. A counter on the entrance will count bees moving in and out of the hive. GPS technology will monitor the location of the hive. Finally, tamper proof covers will detect any unwanted interference with the hive.

Information provided by the sensors will be relayed to a hand-held device, removing the need for a beekeeper to undertake a physical inspection of the hive. These capabilities are particularly appealing for commercial beekeepers, as it gives them the ability to gauge what was happening inside a hive without needing to undertake a physical inspection (Hollingworth and Hogan 2021).

Chapter 2 Literature review

2.1 The focus of existing research

Remote monitoring of beehives is not a new concept. The literature review conducted for this research project indicates that other researchers have already explored the possibility of using Internet of Things (IoT) and sensors to remotely monitor beehives to understand internal hive conditions.

It is also evident however, that previous research has been largely based on theory and or modelling. Few researchers appear to have carried out experimental testing, which may be due to:

- Not having practical beekeeping experience and confidence working with bees.
- The researchers not owning or being able to secure a hive to put their equipment into to undertake testing on a working beehive.

Much of the existing research has been conducted in other countries. In Australia, there is a scarce amount of existing literature on the remote monitoring of beehives, particularly on the east coast of Australia and in the context of the early detection of pests and diseases.

A summary of the existing research is provided below.

2.1.1 Smart Beehive Monitoring for Remote Regions

A research paper by Omar Anwar from the University of Western Australia identified the importance of using weight to measure hive health. Anwar's experiment used a total of eight different sensors to gather data and transmit it via the narrow band Internet of Things (IoT). Data was collected 144 times a day, allowing updates from the sensor every 10 minutes. As part of his research, Anwar also investigated the use of machine learning to eliminate the need for expensive scales and predict weight.

From his research, Anwar (2022) concluded that daily weight variations were crucial indicators of hive health and bee activity. He also suggested that using machine learning to eliminate expensive scales and predict weight would help assess bee health and activity.

A number of limitations have been identified in Anwar's research. These include:

- His research only considers the effect of CCD and not the broad range of pest and diseases that impact honey bees.
- The research was conducted on the west coast of Australia under vastly different climatic and geographic conditions than the rest of Australia.

2.1.2 Honey Bee Colonies Remote Monitoring System

Research conducted by Gil-Lebrero et al. (2016) obtained data non-intrusively from wild hives by monitoring environmental conditions surrounding the beehives using a three-level model (wireless node, a local data server, and a cloud data). Data obtained on each layer was saved individually in case of communication failures.

The research used LoRaWAN technology with the Atmega328P microcontroller using digital temperature and humidity sensors. A total of nine devices were deployed as part of their research.

While Gil-Lebrero et al. (2016) concluded that their data had to be excluded from further use in research due to mass failure, their findings indicated that the outer air temperature dropped to –36 degrees celsius and the internal temperature exceeded the outer air temperature. Their findings also suggested that the operating range of the temperature sensor was –40 to 85+ degrees celsius.

A number of limitations have been identified in the research of Gil-Lebrero et al. (2016). These include:

- The large data and storage requirements of the monitoring system used.
- As the experiment took place seven years ago, the technology and mode of transmission is outdated.
- Although the research experiment looked at real-time weight, temperature and relative humidity measurements, the sensors were situated outside the hive and thus, unable to gathering information about internal hive conditions.
- The use of wild hives for the experiment is risky as wild hives are more prone to swarming (Loftus, Smith and Seeley 2016).

2.1.3 Web Monitoring of Bee Health for Researchers and Beekeepers Based on the Internet of Things

Debauche et al. (2018) focused on the effects of CCD on bees and biodiversity in general using a number of lesser-known parameters: temperature, relative humidity, oxygen and carbon dioxide rates, contaminant gases, nitrogen dioxide, ethanol, ammonia, carbon monoxide, methane, video, vibration and the number of bees leaving and entering the hive.

Debauche et al. (2018) suggests that the introduction of new technology and placing sensors into a beehive, makes it possible to understand the causes of CCD. After monitoring bee activity manually by observing the hive for characteristic changes, Debauche et al. concluded that it was not possible to identify behaviour changes within a colony to eradicate CCD.

The study explored the use of Low Power Wide Area (LPWA) or 3GPP protocols to determine how devices can be connected to the internet to monitor the behaviour of bees. Weight scales were used to detect the start and the end of nectar flow when nearby plants were in flower by weighing hive stores. Vibration sensors were also installed on the external walls of the hive to predict swarming in advanced through changes in amplitude and frequency. External weather was monitored by its own weather station as Debauche et al. referred to in their internal and external temperature findings.

As part of their results, Debauche et al. found dioxygen and carbon dioxide sensors had higher readings when they think the bees metabolism started after hibernating over winter, the research also determined that the hive's microclimate and airflow could affect and influence the results of the sensor from air dilation. It is also evident that bee counting was undertaken throughout this research, however the means by which it was done is unclear. Debauche et al. refers to it as being done with 'mechanical or electronic devices'.

Some of the limitations identified in Debauche et al's research includes their discussion of Low Power Wide Area. They do not explain these results in detail as part of their research, suggesting that it was not properly tested. They also canvass data storage and IoT devices in their paper, however they also fail to progress these ideas to the testing stage. Additionally, their comments on future work relating to the use of NB-IoT protocol which is dependent on cellular network, suggest their model would not support remote monitoring.

2.1.4 Remote Data Monitoring to the Cloud for Apiary Measurement

A research project by Zeng (2017), aimed to design a data logging system that could record different parameters targeted at the industrial apiary process. The parameters included weight of the beehive, external temperature, water level and amount of rainfall. As part of the design, data was sent to the user via a text message or email using an electron board micro controller with a 3G sim.

In his remarks about further work, Zeng (2017) stated that the experiment needed to be tested in an outdoor environment which indicates that his design didn't progress to the prototype or experiment stage.

2.1.5 Osemn Process for Working Over Data Acquired by IoT Devices Mounted in Beehives

Dineva and Atanasova's (2018) research followed the Osemn workflow model that obtains, scrubs explores, models and interprets data. The study looked at placing sensors both inside and outside a hive to obtain correlation data. Their research was focused on data flow rather than real life application. It also the types of sensors that could be used in beekeeping environments.

The basis of Dineva and Atanasova's (2018) research was that beekeeping inspections were complex tasks, particularly for professional beekeepers with beehives situated outside of urban built-up areas. They argued that this further complicated by increased transport costs which has resulted in decreasing bottom-line profit and poorer weather conditions making it hard to get access to sites. According to Dineva and Atanasova (2018, following human intervention, it takes three to four days to stabilise a hive and restore it to optimum conditions.

2.1.6 Research gaps

It is evident from the literature review that the application of remote monitoring systems in the honey industry is not a new concept. However, the context of the previous research and the way in which the researchers have approached their designs, confirms there is still more work to be done to refine the design for industry application and address some of the biggest challenges facing bees in the current environment.

While the acknowledgement that beekeepers need to take decisive action to mitigate the spread of pests and diseases in beehives is a common feature of existing research, there has been little focus thus far on the breath of pests and disease that can affect bees and how technology can be used to improve early detection and diagnosis. That will be the primary focus of this dissertation.

The secondary focus of this research project will be to determine if machine learning can be used to gain an in-depth understanding of the precursors to common hive pests and diseases to further advice detection and diagnostics.

It should also be noted that as part of this experiment, field testing will be conducted on the east coast of Australia where the terrain and available technology are vastly different to other Australian and overseas jurisdictions, previous research in the same field has taken place.

2.2 Parameters for Beehive Monitoring

The research reviewed as part of this dissertation explored different approach to remote monitoring. A commonality of previous research was the use of temperature, humidity and weight as parameters of research to measure overall health and performance of a beehive.

This is evidenced by Table 2 below, which summarises the existing literature according to the parameters of research used and whether the surpassed the design and experiment phases and additionally, to ascertain the parameters of their research.

Parameters of research	**Stage of study**	**Method of data transfer**	**Author/s**	**Name of paper**
None	Scientific study	None	Dineva, Atanasova 2018	*Osemn process for working over data acquired by iot devices mounted in beehives*
Temperature Weight Humidity Vibration	Experimental	Low Power Wide Area (LPWA) or 3GPP protocols	Debauche, O, Moulat, ME, Mahmoudi, S, Boukraa, S, Manneback, P & Lebeau, F 2018	*Web monitoring of bee health for researchers and beekeepers based on the Internet of Things*
Weight	Full prototype build with data collected	Low power Zigbee radio	Fitzgerald, D., Murphy, F., Wright, W., Whelan, P. and Popovici, E. (n.d.).	*Design and development of a smart weighing scale for beehive monitoring*
Video Temperature Weight Humidity	Full experiment	GSM/GPRS	Zabasta, A, Zhiravetska, A, Kunicina, N, Kondratjevs, K	*Technical implementation of IoT concept for bee colony monitoring*
Temperature Weight Humidity Vibration Acoustic	None	Idea and manual study	Zogović, N., Mladenović, M. and Rašić, S.	*From primitive to cyber-physical beekeeping*
Weight Sound Gas sensor Temperature Humidity	Wi-Fi	Prototype	Sadad, M, Al Rakib, A, Faruqi, M, Haque, M, Rukaia, S, Nazmi, S 2019	*An IoT based smart beekeeping system using MQTT*

Table 2: summery of existing literature according to the parameters

2.2.1 Weight

The weight of a beehive, which provides information about the overall health of the hive, is made up of three components:

1. Bees at both stages of the life cycle (adult or brood)
2. Hive structure (wooden boxes, lid, base and frames)
3. Honey stores within the hive.

Hive weight monitoring can be used to detect the start and the end of nectar flow. The hive weight allows a beekeeper to measure the consumption of food during non-foraging periods, estimate the number of foragers and indirectly, the fertility of the queen. The occurrence of swarming events also correlates with a decrease in hive weight. It should be noted that while pollen stores are a critical component of a hive, they are difficult to quantify as their weight is incorporated into the combined weight of the frame and wax when full (Robustillo, Pérez and Parra, 2022).

According to Nerum and Buelens (1997), in the peak of summer, a beehive has a population of 70,000 bees, weighs approximately seven kilograms and has a short life span of around 30 days. A hibernating winter hive of bees has a population of between 10,000 and 20,000 bees and is expected to survive for several months.

When honeybees hibernate during winter, they ball into a cluster to preserve heat to raise the brood and keep the queen alive. The honeybees' ability to maintain the core temperature of the hive at 35 degrees celsius is a key factor in keeping the hive alive. Honey food stores are used for heat production by the worker bee causing heat friction from high-speed rubbing of their wings (Döke, M. A., Frazier, M., & Grozinger, C. M. 2015).

The weight of the hive is a key indicator to the health of the hive. An increasing hive weight indicates the forger bees are collecting nectar and pollen. This process usually starts in September or October in Sydney. The influx of extra nectar is stored in the frames of the brood box. When coupled with an increase in the number of eggs laid by the queen in cells, space in the brood box can become limited. Honey bees naturally store honey in cells at the top of the frame. They instinctively load the cells top down, pushing the egg laying cells further down the frame as they become free from hatching brood (Somerville 2010).

As the weight of the hive increases and it reaches capacity, it becomes necessary for the beekeeper to intervene and either spit the hive or add a new super and queen excluder. The super is a box that is placed on top of the brood box for the bees to fill with honey. A queen excluder, which is installed between two supers, restricts the queen's access and stops her laying eggs in the new super. This usually happens during spring once the hive's winter hibernation period has ended. Then, bee numbers start to grow and nectar from spring flowers starts being brought into the hive and stored (Somerville 2010).

Hives are normally one box high during the winter period. In autumn, excess honey supers are removed from the top of the brood box to reduce the hive to a single box. This is known as 'packing down for winter'. The extra honey super added when the hive is building numbers is used to store the influx of nectar, which the bees later turn into honey.

A full frame of honey can weigh up to three kilograms when wax capped. When using a Langstroth hive box, which usually holds eight or 10 frames, this would equate to a weight of between 24 and 30 kilograms when full. Alternatively, nucleus hives are small version of the Langstroth design and can hold up to five frames, which equates to 15 kilograms when full.

Adding weight scales to a beehive will enable a beekeeper to detect foraging bees as they move in and out of the hive to collect nectar. The nectar carried back to the hive from a foraging bee is between 0.02 grams and 0.05 grams. The foraging bee itself weighs 0.11 grams. With each trip of a field bee and if conditions are suitable, the weight of a healthy hive should increase daily. The best conditions to facilitate honey production include warm weather with trees and plants in flower (Waikato Domestic Beekeepers Association, 2022).

The main aim of the beekeeper is to obtain a good yield of honey (Connor, 2015). A sudden decrease in the weight of a hive can be a sign that the hive has swarmed. Alternatively, a small decrease in weight may indicate that a hive's honey stores have been robbed by another hive.

2.2.2 Temperature

Temperature is an important factor in beekeeping. It affects both hive survival and honey yield. Kontogiannis (2019) states that honey yields can be affected by the temperature of a beehive; the movement of bees within the hive slows down as the temperature decreases. Kontogiannis further suggests that bees actively regulate their hives and are sensitive to temperature fluctuations. The differences can lead to brood death within the hive, causing a cascading effect and lowering the overall number of bees.

A brood box where the queen is laying eggs is maintained at a constant temperature between 32 and 36 degrees celsius (Strob, M, Kašparů, M, 2016). The brood is extremely important, as it facilitates the reproduction of future worker bees. Honey bees can transfer body heat to the brood (up to 43 degrees celsuis for 30 minutes) by pressing their chest against the brood cell. The heat comes from the exercising their flight wings, which creates endothermic heat production. Similarly, if the temperature is too high, the bees will bring water into the hive and spread it around the around the edge of the cell in a thin layer. Then the bees fan the hive with their wings to allow air to travel around the hive for cooling and ventilation.

The brood has a low metabolic rate and does not have the ability to create enough heat to survive, without the correct microclimate the nest nurse bees to keep the brood warm the brood sensitivity is extremely high. A prolonged hive temperatures under 32 degrees celsuis can cause shrivelled wings and legs, and abdomen defects. The trigger for the adult bees to heat the hive comes from the brood releasing chemical stimuli.

The outside ambient temperature affects the bee's ability to fly. The outside temperature must be at least 17 degrees celsuis and a maximum of 35.7 degrees celsuis in order for honey bees to fly. It has been found that there is an increase of 1.5 to 3.4 degree celsius within a hive's core temperature before a swarm (Micu, 2021).

Swarming occurs when the queen leaves the hive with about half the total hives population and ventures off to find a new home this could be a tree hollow or a roof space or wall cavity of a house. During a swarm, the field worker bees and nurse bees are left behind to make a new queen from the eggs and lava that the original queen left behind. The process of swarming is one that beekeepers try to avoid as it significantly reduces honey production and therefore affects the total honey yield (Zacepins et al. 2016).

A study entitled, 'Remote detection of the swarming of honey bee colonies by single-point temperature monitoring' (Zacepins et al. 2016) monitored nine hives over a period of three months, looking at changes in temperature before a swarming. The results were collected using a data logger setup on a Raspberry pi and suggested that the normal temperature conditions of the healthy hive fluctuated nominally between 34 and 35 degrees celsius.

The results also showed that 10 minutes before the bees swarmed, temperature rose by 1.5 to 3.4 degrees celsius, taking the overall hive temperature to between 37 and 38 degrees celsius. This was observed for a small duration of time. Namely, between eight and 20 minutes before the queen bee took flight and the rest of the swarming workers left the hive.

2.2.3 Humidity

According to Kontogiannis (2019), when atmospheric humidity levels exceed 70 per cent, bees begin manually ventilating the hive and producing a higher-than-normal lever of propolis and wax. In fact, any change in humidity below or above the optimum level of 60 per cent, poses a risk to honey bees.

If the relative humidity is too high, honey bees will instinctively cluster at the entrance of the hive to facilitate temperature and humidity control. This hinders the bees' productivity and can result in starvation as instead of foraging for food, the bees are spending the majority of their time regulating the humidity inside the hive (Ntawuzumunsi et al. 2021).

According to Ellis et al. (2008), a minimum of 55 per cent humidity is required for honeybee eggs to hatch with a maximum survival rate between 90 and 95 per cent. The bees will bring water to the hive to add humidity on hot days to help maintain an optimum humidity level for the brood eggs.

A study undertaken by Oluwaseyi et al. (2022), indicates that bees thrive in relatively high temperatures and with relatively low humidity; these conditions will sustainable a high yield of honey.

2.3 The importance of hive design

Evidence suggests that the concept of collecting honey originated in Spain 15,000 years ago. A painting of a person climbing a tree with a basket robbing unhappy looking bees suggests the earliest form of honey collecting was akin to honey stealing. It wasn't until the eighteenth century that these techniques changed. Bees in medieval Europe started to be kept in woven baskets called skeps see Figure 16. Similarly, in Egypt, early beekeepers began keeping bees in terracotta jars. The big difference during this time, was the bees were killed to harvest the honey (Thompsom 2019).

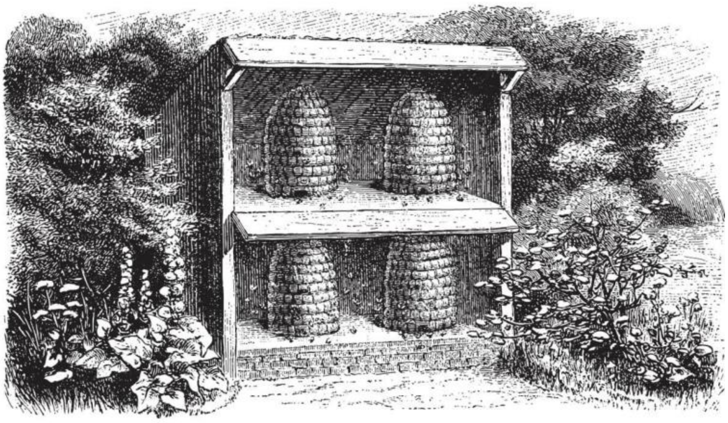


Figure 16: Hive from medieval Europe (Bove 2013).

Figure 17: Langstroth Hive (Lovely Greens)

In 1851, Lorenzo Lorraine Langstroth developed a new type of hive, known as the Langstroth Hive (Figure 17). The Langstroth Hive is the same hive design used by beekeepers around the world today. Its success is grounded in the concept of hanging frames which bees can build wax comb into. It also provides for a brood chamber, where the single queen bee lays eggs, and honey stores.

Langstroth's design enables hive inspections to be done to examine queen laying patterns and or check for disease, without taking the hive apart. The other benefit of the Langstroth Hive is the removable frames. At harvest time, the frames can be easily removed from the hive and placed in a centrifugal spinner, which allows the honey to run out of the de-capped frame. Once the honey has been harvested, the frame can then be placed back into the Langstroth Hive for the bees to replenish without any part of the beehive being damaged (Figure 18) (Urban Bee Project Australia, 2020).

In a review of the different approaches to beekeeping, Hargus (2018) highlighted the benefits and challenges associated with the Langstroth Hive. According to Hargus, some of the benefits include:

- The hive boxes are designed to take eight or 10 frames. The weight of a full frame of honey can be up to and above two kilograms.
- Full frames of honey can be removed for harvesting by using an extractor. Honey is easy spin out of the frames and collect in a tank. The frames can be installed straight back into the hive for the bees to refill.
- Individual frames can be removed to reduce the overall weight during harvesting.

Figure 18: Once de-capped, the Langstroth hive honey frame is placed into a honey extractor which spins the honey out without damaging the frame (Hargus, 2018).

Some of the challenges associated with the Langstroth Hive, as cited by Hargus (2018), include:

- At capacity, a hive box can weigh between 8.1 and 36.2 kilograms. This is a significant weight, particularly for commercial operation, which the beekeeper would be required to move when harvesting.
- A beekeeper must own an extractor to extract honey without damaging the frames so they can be reinstalled into the beehive after extraction.
- The design has poorer ventilation in comparison to other designs.

2.4 Machine Learning

The use of machine learning in beekeeping is a relatively new concept. With the introduction of new and advanced technological designs, and with the use of Internet of Things, beehives can have sensor systems embedded into them to gather data in real time. The data can then be used to generate data sets that will help a computer predict conditions inside a beehive.

Collected data must be divided into two parts to be effective; one for training and the other to validate the constructed model. This approach is used widely used in the field of modern machine learning (Heath 2018).

Appropriate machine-learning models need to be determined as there the wide variety available. These models depend on the type of data as some of the models are better suited to images, some to text, and some purely to numerical data. The data in this experiment will be numerical data, this means many of the available machine learning models can be filtered out as they more designed to preform classification tasks (Dineva and Atanasova, 2018). According to (Dineva and Atanasova, 2018) two models most suited to this experiment are support vector machines and random forests. According to (Gandhi 2018), every machine learning enthusiast starts with is a linear regression algorithm. Regression is a method of modelling a target value based on independent predictors. In basic terms, it is a way of predicting the value of something by using a function. Using the following example of a linear regression algorithm:

$$Y = g(X)$$

(Y) could be the outside temperature of the hive and (X) could be the inside temperature. These are the independent variables being predicted. By setting up a table of (Y) and (X) in training data, the value of (g) could be determined.

Using the following regression function as an example:

$$g(x) = ax + b$$

(g) stands for regression and is a linear function, which is why it is known as linear regression; (a) is the slope of the slide and (b) is the intercept. The aim is to find a line as close as possible to the training data, so when values are predicted that are not in the training data, the regression values have close values to model (Heath 2018).

By using the equation:

$$\sum_i (\mathrm{ax_i}) + \mathrm{b} - \mathrm{y_i})\text{^}2$$

Then by taking the gradient and setting it to zero:

$$\begin{pmatrix} \sum 2x_i(ax_i + b - y_i) \\ 2\sum_i ax_i + b - y_i \end{pmatrix} = 0$$

A solution can be found for (a) and (b)3:

$$a = \frac{\sum_i x_i y_i - \sum_i x_i \sum_i y_i}{\sum_i x_i^2 \sum_i {y_i}^2}$$

$$b = \frac{1}{n}\sum_i y_i - a\frac{1}{n}\sum_i x_i$$

Machine learning code and programs like SKLearn can automatically create linear regression models with short Python code (Figure 19). Functions like linearRegession(), fit(x,y) can set up a graph model. The function 'predict' can also predict the valve on the slope required. The benefit of linear regression models is that more variables can be added as needed (Scikit-learn 2019).

```
>>> import numpy as np
>>> from sklearn.linear_model import LinearRegression
>>> X = np.array([[1, 1], [1, 2], [2, 2], [2, 3]])
>>> # y = 1 * x_0 + 2 * x_1 + 3
>>> y = np.dot(X, np.array([1, 2])) + 3
>>> reg = LinearRegression().fit(X, y)
>>> reg.score(X, y)
1.0
>>> reg.coef_
array([1., 2.])
>>> reg.intercept_
3.0...
>>> reg.predict(np.array([[3, 5]]))
array([16.])
```

Figure 19: SKLearn Linear Regression code (Scikit-learn 2019)

2.4.1 Support vector machine

Support vector machines can be used for both regression and classification tasks, but generally, they are better suited to classification problems. In the case of a supervised machine learning problem, the support vector machine tries to find a hyperplane that best separates the two classes. The main objective of the support vector machine algorithm is to identify a hyper plane in N-dimensional space that distinctly classifies data points. The best hyper plane to use is one that provides the maximum distance between classes, as this separates the classes better (Heath 2018).

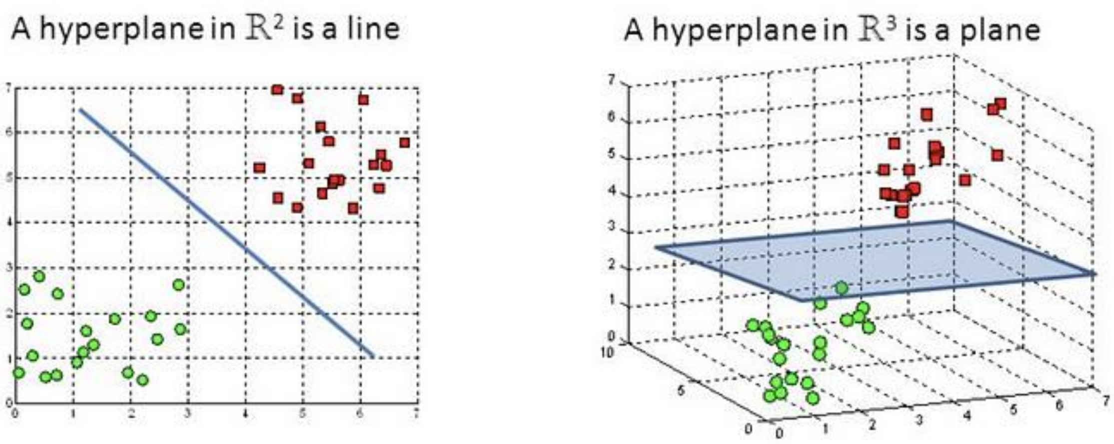


Figure 20: Hyperplanes in 2D and 3D feature space, support vector machines (Gandhi 2018).

Support vector machines can project the data into a higher dimensional space where the classes can be separated if the data is not linearly separable, as shown in Figure 20 (Gandhi 2018).

2.5 Remote Site Communication

The single most important part of this project is to provide the beekeeper with information from field sensors installed in a hive. There are many different communication options available to aid this objective. Some of the most commonly used types of communication are Bluetooth, Wi-Fi and cellular.

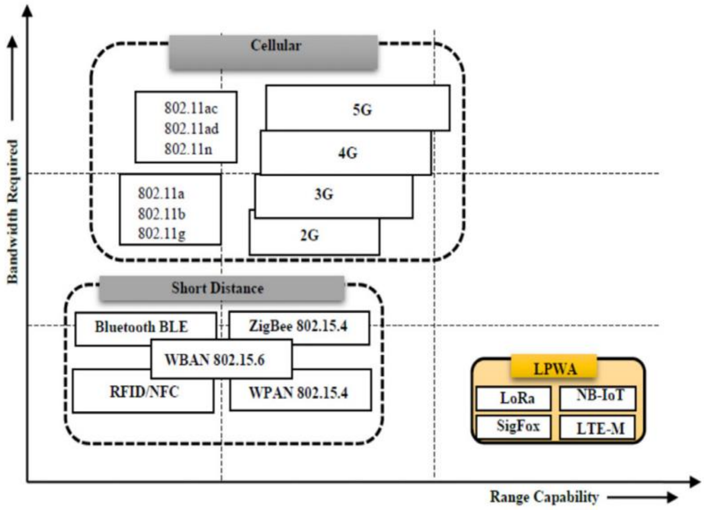


Figure 21: Required bandwidth versus range capacity of short distance, cellular, and LPWA

Different communication types have different purposes; some are better suited for short range communications including Bluetooth, and others are specifically designed for long range communications including satellites. Short range communication types would not usually be suitable for transmitting data from a beehive site, unless the network was setup in such a way that multiple hives sent information to a hub hive, which then exported the data via long range communication to the user.

The most cost-effective way to transfer information from the beehive to the user is via LoRaWAN (LoRa refers to a wireless modulation that enables communication with very low power consumption). LoRaWAN refers to a network protocol with LoRa chips for communication or the cellular network (yosensi 2021). The Starlink satellite is also an available option, however it has high power demands as well as high costs associated with equipment and the ongoing transmission of data via a monthly plan (Starlink, n.d.).

2.5.1 LoRaWAN

A LoRaWAN (low-power wide area networking protocol) wirelessly connects devices to the internet via managing communications between end node gateways. LoRaWAN is made up of two components: the 'Lora' being the physical layer or the chipset, and the LoRaWAN being the MAC layer or the software that allows the chip to communicate to the network (yosensi 2021).

LoRa's star-shaped network architecture uses different regional frequency ranges in the ISM band (industrial, scientific, and medical) and SRD band (short-range device). In Australia, Bands 915 to 928 which cover 915 megahertz (MHz) to 928 MHz is used for the LoRaWAN system. Europe uses the frequency bands from 433.05 MHz to 434.79 MHz and 863 MHz to 870 MHz. In North America, the frequency band from 902 MHz to 928 MHz are used (yosensi 2021)

LoRa allows users to transmit at no cost. It also supports the energy efficiency of IoT devices. LoRa's network architecture is normally built in a star topology, wherein gateways act as a transparent bridge that forwards messages between a central network server terminal at the backend. Using LoRa, IoT devices have transmitted over a nine-kilometre range. The highest transmission range on record is 832 kilometres (LoRa n.d.).

Several factors affect the efficiency of LoRa including indoor and outdoor gateways, payload of the message and antenna type and use. The 400 to 900 MHz radio wave range will pass through some obstructions, depending on the material. While radio waves can sometimes be absorbed or reflected, best practice indicates that radio line of sight should be achieved where possible by placing Lora devices on rooftops and atop of rugged terrain.

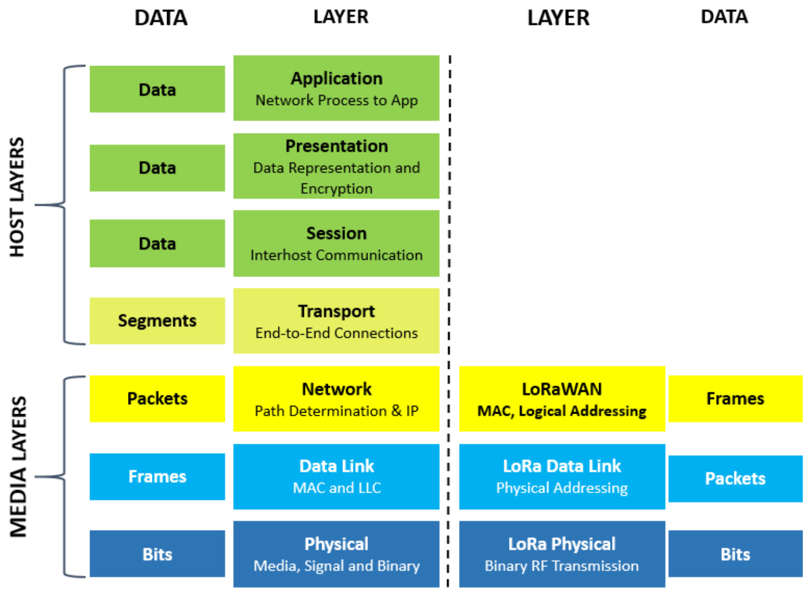


Figure 22: OSI seven-layer network model (Developer Portal n.d.).

Normal range of LoRa is 15 kilometres, however longer range can be achieved in rural settings where there are fewer obstructions (LoRa n.d.)

According to (LoRa n.d.) benefits of the LoRaWAN network include long range and broad coverage, low power and data rates, low-cost hardware and prolonged battery life.

2.5.2 Coverage

The coverage of LoRaWAN in Australia is limited compared to other countries. There are only 450 gateways connected around Australia compared to a country like Germany that has 6,000 gateways connected (LoRa n.d.). LoRaWAN networks are publicly available in 137 countries as shown in Figure 23 (LoRa n.d.). The coverage of the LoRaWAN network is very small across the eastern seaboard of Australia. This is not suitable for the project as it needs to have a coverage that is able to cover the remote bush. the other problem with LoRaWAN network is the hardware required to support the commutation transmission a base station at one node and a transmitting node at the other end. This make LoRaWAN network impractical for the experiment.

Figure 23: Map of LoRaWAN coverage across the world ((Lora-alliance.org 2019).

2.5.3 Australia LoRa network locations

In Australia, LoRa gateways are very limited. The majority of the existing LoRa gateways are located on Australia's east coast (Lora-alliance 2019) where LoRa base stations are located (Figure 24). This is a limiting factor in the suitability of many beehives sites when using LoRa for the purposes of remote monitoring. It also limits the ability of a beekeeper to move beehives between sites to obtain an optimum nectar source.

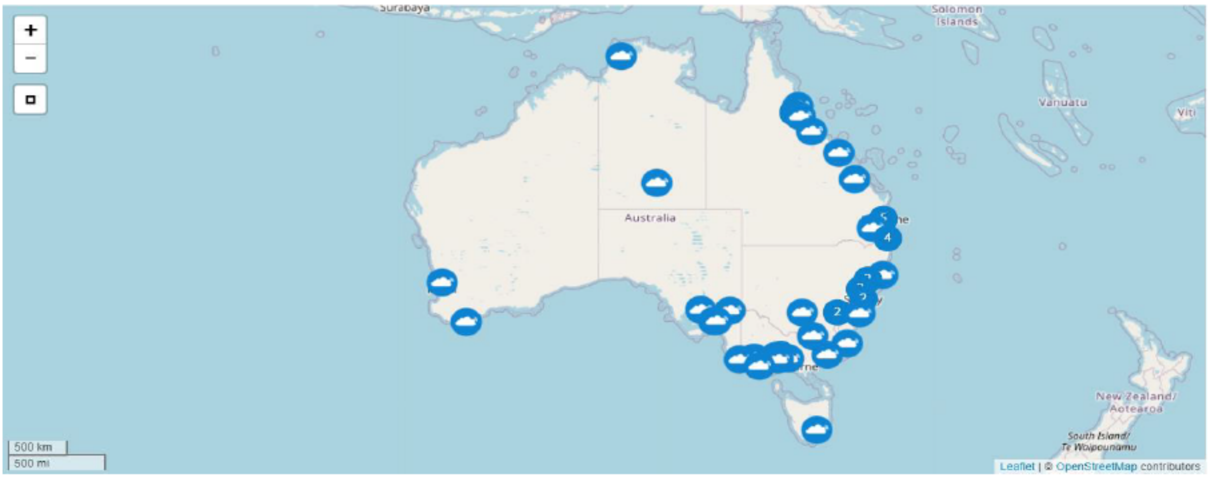


Figure 24: There are 415 gateways connected around Australia (Network n.d.).

While a gateway could be setup at a hive site, the amount of power required to operate it could not be sustained using battery-powered equipment.

As LoRa transmits over long-distance, it would have a high-power consumption. Even when coupled with a solar battery backup, the connection could still be expected to be lost intermittently (Fourfaith 2022).

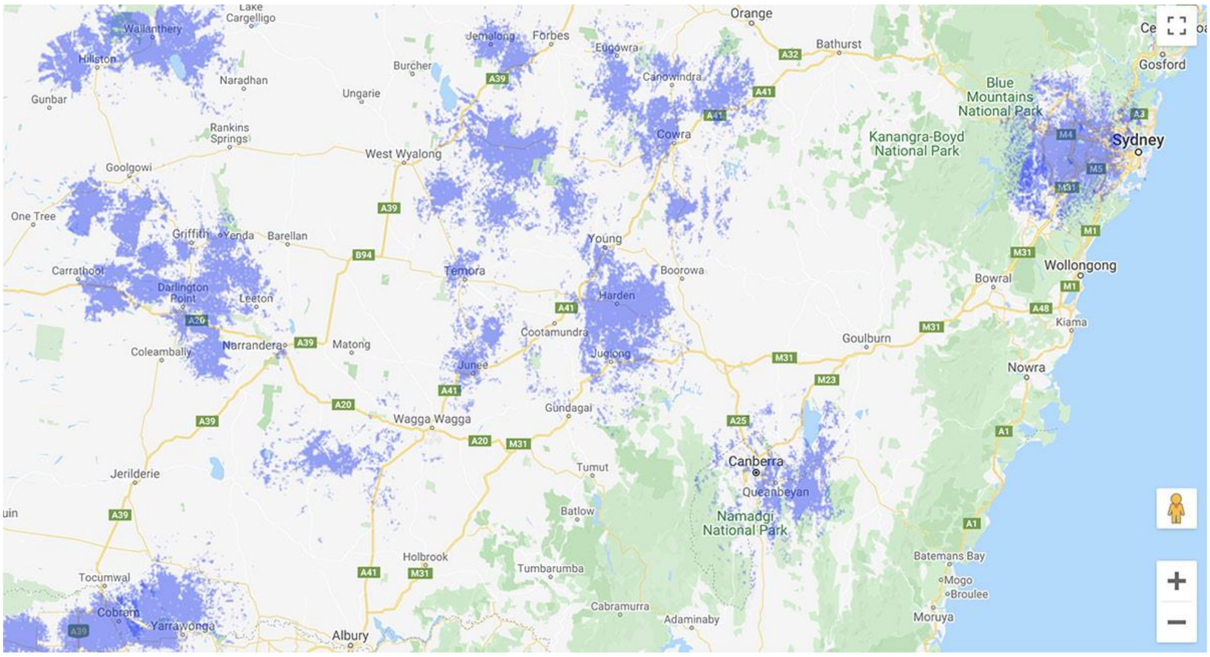


Figure 25: Coverage of LoRa Network in lower NSW. This map illustrates that the existing coverage is poor and focused on the major town centres (NNNCo. n.d.). For this reason, the technology has been deemed incompatible with this experiment.

2.5.4 LTE Cat M1 and NB-IoT

The category M1 low-power wide area network was built specifically for IoT projects. Cat M1 functions at its best when transferring low to medium amounts of data at a long range (Heredia 2023).

Major telecommunication providers host a range of plans that allow users to connect to the network. Telstra offers band 1 at 2100 MHz, band 3 at 1800 MHz, band 5 at 850 MHz, band 7 at 2600 MHz, band 8 at 900 MHz and band 28 at 700 MHz for the Cat M1 service. Cat M1 bands are not available through Optus and Vodafone. Instead, they offer NB-IoT on selected frequencies (Whirlpool n.d.). So too does Telstra.

The frequencies are in the service that is offered by Cat-M1 range. LTE Cat M1 operates using existing LTE networks. Cellular applications that use the LTE band operate on the same band as the LTE Cat M1. NB-IoT on the other hand, operates using unused spectrum or the guard bands (Heredia 2023).

LTE Cat M1 is a complementary technology to NB-IoT, with faster upload and download speeds of one Megabits per second (Mbps) and lower latency of 10 to 15 milliseconds (ms) and operates on half duplex or full duplex modes. LTE Cat M1 modems require less power, making them compatible with power-constrained devices. They can function for several months to several years on a small battery (Heredia 2023).

Plans from the Telstra IoT service allow users to connect to both NB-IoT and Cat M1. The benefit of this is that the Cat M1 will transfer more data at higher speeds with less latency, making it ideal for IoT projects covering a wide geographic region, particularly in the agricultural sector as seen in fig 19 the coverage for reginal towns (Shrestha 2021).

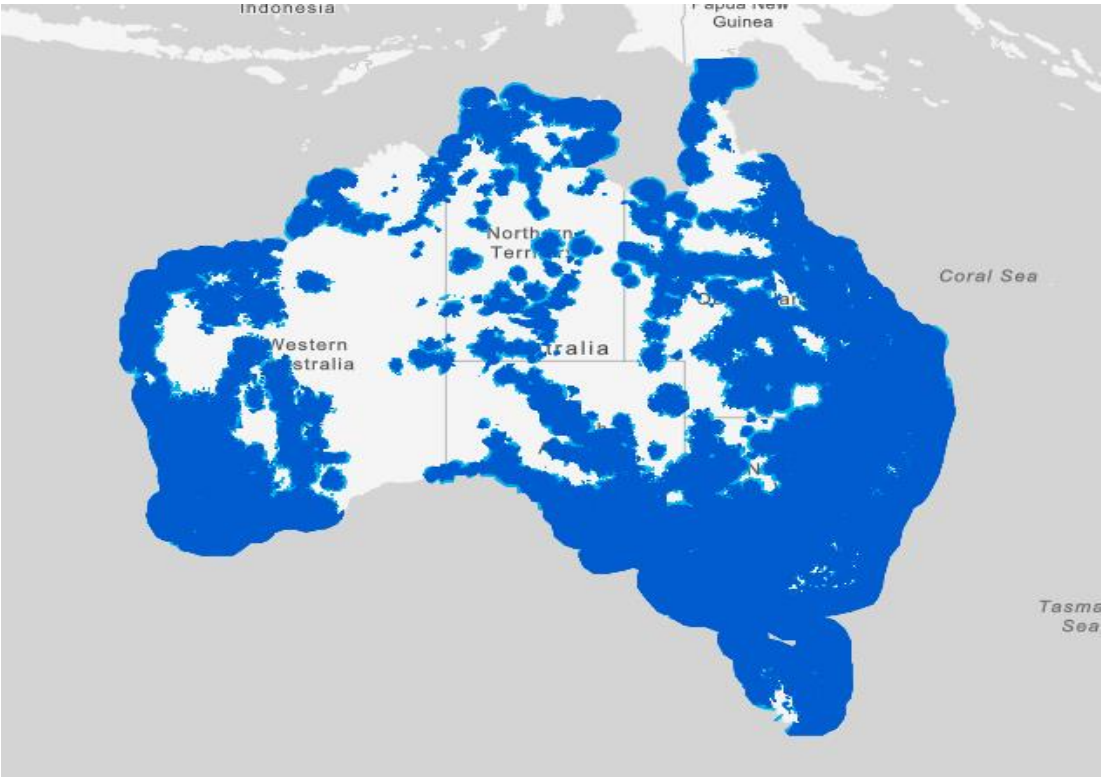


Figure 26: LTE Cat M1 coverage across Australia (Telstra Enterprise n.d.).

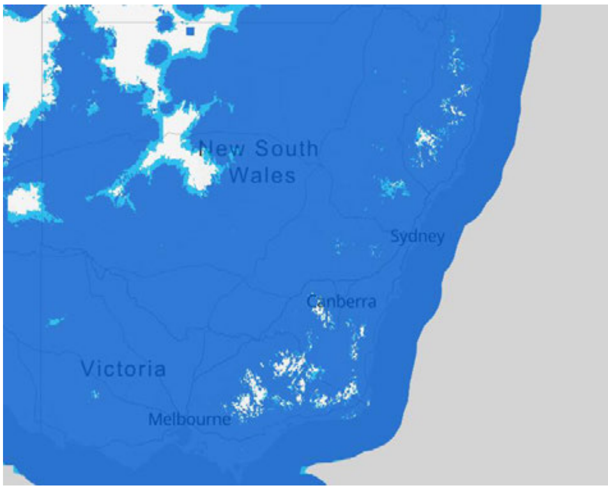


Figure 28: Telstra LTE Cat M1 coverage in NSW (Telstra Enterprise n.d.).

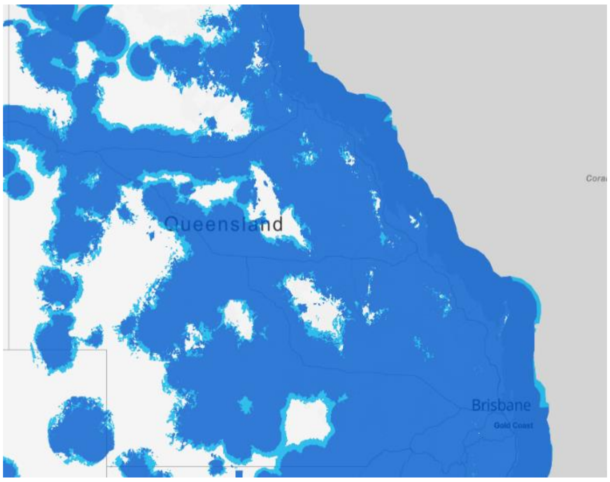


Figure 27: Telstra LTE Cat M1 coverage in Queensland (Telstra Enterprise n.d.).

2.6 Micro controller

There are a number of different micro controllers which can be used in for this type of design required to support this research. These include Giant Board, Arduino MKR GSM, Raspberry Pi 4 Model, Arduino Uno REV3, BeagleBone Green Gateway, ESP32-Gateway, Jetson Nano and Udoo Bolt V8.

The Arduino Nano 33 IoT is the simplest and cheapest point of entry into IoT. The device works on Wi-Fi and transfers data to the Internet of Things cloud (Arduino Official Store n.d.).

2.6.1 WM2000

The WM2000 is an IoT modular setup that can be programmed using Tibbo basic or C-Programming language and is compatible with WIFI, low energy Bluetooth and 4G/LTE connectivity (Tibbo n.d.).

The WM2000 has an on-board flash memory and EEPRON, allowing for data saving and file startup. The cost of the board is $29.10 USD. The board itself plugs into a mainframe which helps map the pin outs to devices (Tibbo n.d.).

Figure 29: 2925:WM2000 (Tibbo n.d.).

The board is not ideal for the use in the remote field, as it is only has Wi-Fi capability. However, the device has low power consumption and will run off a single cell lipo battery at 3.3 volts. With 12 analogue and digital channels, there is also enough input output channels to run the required sensor for the project. The 4G /LTE is also an added benefit (Tibbo n.d.).

2.6.2 MKR 1400

Arduino's GSM 1400 has the ability to transfer data over the GSM network (Global System for Mobile). This is a particularly important consideration due to the remoteness of many beehive sites and the scarcity of Wi-Fi at such sites. It is important to note that the MKR 1400 GSM has been superseded by the MKR 1500 model (Arduino 2018).

2.6.3 MKR 1500

The MKR 1500 model has been used extensively in previous research. The existing literature provides guidance on how best to setup the device to the Arduino IoT cloud and other cloud servers like Blynk-cloud.

The MRK 1500 can run off a LiPo (lithium polymer battery) battery. Other researchers have used a mix of different power supplies to power their devices including lead acid and lithium ion. The existing literature suggests that lead acid technology and solar are the most common power sources for the batteries required. It may be possible for newer, low-powered devices like the Arduino to last longer on newer battery technology. The types of batteries compatible with these devices are LiPo (lithium polymer battery) or Life (lithium iron phosphate battery) (Arduino 2018).

Although beehives have been monitored with sensors before, it is important to determine the correct sensors to use before the microprocessor is chosen. This will ensure the correct inputs and outputs are available for the correct sensors.

The MKR 1500 has plenty of examples and is advertised by Telstra to connect to its Cat M1 network and would work for a period of time but then would loss signal. The Ubloz SARA-R4 onboard modem will runs and then shut down after hours or days of running. There is plenty of support via the Arduino forum of how to fix the fault modem via firmware. The firmware upgrade for the lower end of upgrades from 2-6 can be floated in via the serial connection using Putty via the serial link on the USB but to get the latest firmware version 19 it requires a bit more technical process to update. The process again is well documented in the Telstra developer and Arduino forums at https://forum.arduino.cc/t/firmware-upgrade-for-ublox-sara-r410m-02b-on-the-mkr-nb-1500-2/699292/14?page=3.

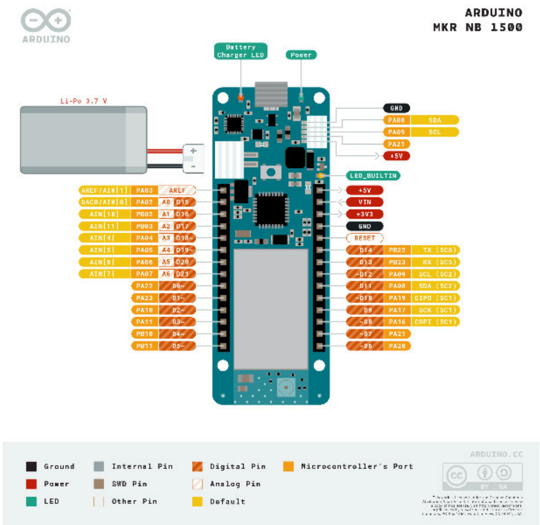


Figure 31: MKR 1500 Arduino MKR NB 1500 pin out (Arduino Official Store n.d.).

Figure 30: MKR 1500 Arduino MKR NB 1500 pin out (Arduino Official Store .n.d.).

2.6.4 MKR WAN 1300/1310

The MKR WAN boards are Arduino's cost effective, low-powered board that uses LoRa to connect sensors to internet. The MKR WAN 1300 and 1310 boards use a SAND21 microchip and incorporates a Murata CMCMWX1ZZABZ module. It also has 2MB SPI Flash memory for onboard storage (Arduino Official Store n.d.).

The advantage to using a MKR WAN 1300 – 1310, is when in range of a base station, a telecommunications service provider isn't required, so it is more cost-effective than the MKR1500. This may also be considered a limitation of the device as the board has to be within range of a base station, or a base station would need to be installed at the site of the beehive.

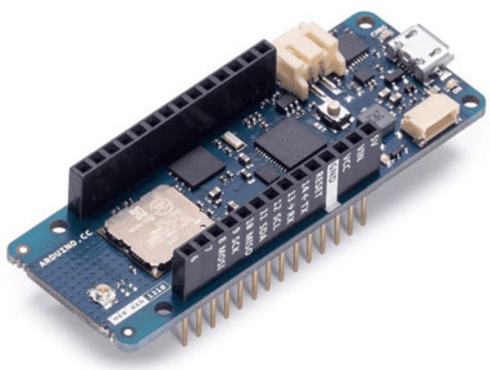


Figure 32: Photo of MKR WAN 1300 (docs.arduino.cc, n.d.)

On a beehive in a remote bush location without standard 240-volt power, the MKRWAN and the Arduino LoRa libraries would be able to provide the APIs (Application Programming Interface) to communicate with LoRa and LoRaWAN networks, making it easy for the user to program and setup sensor data transmission to the chosen IoT Web dashboard (Arduino 2018).

2.6.5 SparkFun LoRa Gateway - 1-Channel (ESP32)

Another possibility is the SparkFun LoRa Gateway - 1-Channel (ESP32) board (Figure 35), which has been proven to operate on LoRa. The ESP32 board is very similar to the Arduino range. The ESP32 works from the Arduino IDE (Integrated Development Environment) and allows easy programming and support (core-electronics n.d.).

Figure 33: SparkFun LoRa Gateway - 1-Channel (ESP32) (core-electronics.com.au n.d.).

The ESP32 RF95W works on the 915MHz band, while the ESP32 has the ability to connect by Bluetooth and WiFi capabilities are inbuilt into the total package of the finished board. The ESP32 has 14 pin – breakouts and requires a five-volt input making it ideal to run off a small battery (core-electronics n.d.).

The board is priced at $65.40 (core-electronics n.d.).

2.6.6 4G EM06-E LTE CAT-6 HAT FOR Raspberry Pi, MULTI BAND, GPS GNSS

This board is a hat for a Raspberry Pi. It sits on top of the board male pins slot into the Raspberry Pi board acting like a hat feature. This gives the original Raspberry Pi the ability to transmit data between the hat and itself.

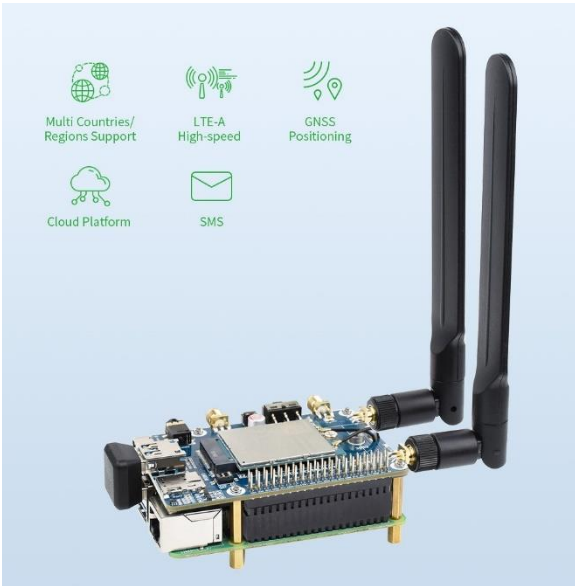


Figure 34: 4G EM06-E LTE CAT-6 HAT

The hat can facilitate communication with GNSS (Global Navigation Satellite System) up to 300Mbps (downlink) / 50Mbps (uplink) data rate. With high-speed networking, it can perform cloud platform communication, SMS, and global GNSS positioning functions with ease. The board can operate in temperature in a range of -30°C ~ +70°C, making it able to operate in the extreme Australian summer heat (IOT Store n.d.).

4G and GPS HAT For Raspberry Pi - Waveshare SIM7600X is the same concept as the 4G EM06-E LTE CAT-6 HAT FOR Raspberry Pi, MULTI BAND, GPS GNSS. The main limitation of these devices is they use more power than the Arduino, as they have a running a hat component, as well as the main board. The prices is also significantly more; $252.80 for both devices, with the hat at a cost of $179 and the Raspberry Pi 4 Model B 2GB at a cost of $73.80 (IOT Store n.d.).

Chapter 3 Research Design and Methodology

3.1 Research questions

The primary objective of this experiment is to determine whether a remote monitored smart beehive can aid in the early detection of pests and diseases in beehives and, what further knowledge can be gained through machine learning about the precursors of hive pests and diseases.

In the pursuit of that objective, this research will seek to answer the following questions:

1. Can critical hive attributes be measured remotely?
1. Does the data obtained accurately reflect conditions inside the beehive?
2. Can inferences be made from the data to accurately detect pest and diseases?
3. Can machine learning predict patterns in hive conditions to reduce the incidence of pest and disease?

3.2 Research objective and design

The primary objective of this project is to design, develop and build a low powered remote motoring system for beehives to aid in the early detection of pest and diseases. It is intended that the data obtained through the remote monitoring system will be presented on a smart device so the user can make informed decisions about the treatment of pests and diseases and other aspects of hive management.

In order to fulfill the research objectives, the research will be undertaken according to the following plan:

1. Conduct initial background research on:
    a. hive health and what keeps a beehive alive
    b. pests and disease that affect bees
    c. the signs or effects of contaminated hives and heathy hives
    d. algorithms used in artificial intelligence (AI).
2. Establish important parameters to monitor such as temperature, humidity and hive weight.
3. Research and establish technical requirements for remote hive monitoring.
4. Design a hive monitoring system and building functional code to match the chosen hardware.
5. Acquire hardware, build and bench testing a prototype.
6. Install prototype hardware into a working hive.
7. Monitor data and inspect field hardware to verify correct data samples.
8. Collate data and conduct initial background research into algorithms for use of AI.
9. Develop a scale to measure how critical data sets are compared with bee health.

If time and resource permit:

10. Evaluating experimental data.
11. Investigating counting the bees leaving the hive and then re-entering the hive as a measure of the pollination rate.

As part of the research phase of this project, the indicators of hive pests and diseases will be critically assessed to guide the specification and design of the micro controller component. Cloud-based data storage options to support the micro controller will be investigated, in addition to the development of a scale to measure beehive health. Data will also aim to be collected beyond the testing stage to provide an in-depth understanding of conditions inside a beehive and how these conditions are influenced by external factors.

3.3 Hypothesis

There are several hypotheses that this research project will seek to test. The first is that the internal hive temperature will fluctuate between 32 and 35 degrees celsius during the winter period when the testing phase of this experiment will take place. During the same period, humidity inside the hive will range between 50 and 60 per cent.

Secondly, the weight of the hive will slowly decrease over the winter period. This is to be expected as when hibernating, bees will consume some honey food stores and use others to keep the brood chamber warm.

Thirdly, daily bee counts, which will be measured by bees entering and exiting the hive, will increase as the external temperature increases.

Finally, data collected as part of this experiment will be stored in the cloud. Data will become available once the experiment has been running in the field for a pre-determined period.

3.4 Timeline

The timing of this research project is anchored by the spring season. This marks the end of the hibernation period for bees. It is also when trees and plants come into flower. During spring, the queen bee lays more eggs and the flow of nectar and pollen into the hive increases. In optimum conditions, a productive queen, who has the capacity to lay an average of 3,000 eggs per day, will ramp a hive from a sleeping state to full production within a few weeks (Penn State Extension n.d.).

To answer the research questions for this project, critical hive attributes need to be measured and recorded while the hive is performing at its peak. This begins during spring and continues into summer, where the number of bees in a healthy hive reaches around 60,000 and honey production is at its highest (Mid-Atlantic Apiculture Research and Extension Consortium, n.d.).

Table 4 sets out the timeline for this research. Further detail is provided at Appendix D

Timeframe	**Activity to be undertaken**
March - June 2023	• Research and design electronic parts of the hive. • Obtain the correct temperature sensors or load cells to measure the weight of the hive. • Confirm Arduino IoT range is compatible with all the sensors and can transmit the required data.
End of June 2023	• Install equipment into the beehives.
July 2023	• Commence data recording and monitoring (data will be recorded through the spring and summer peak production period and through the autumn and winter to determine how much of the food stores the bees are consuming during the 2023 hibernation period).
September 2023	• Results analysis and conclusions.

Table 3: Project timeframe.

3.5 Selection of parameters

Selecting parameters is one of the most important design elements of this research project, as they determine the overall effectiveness of the monitoring system and aid in the objective of the project to answer the research questions.

The parameters selected for the purposes of this project are:

1. Weight
2. Temperature
3. Humidity
4. External hive temperature
5. Pressure
6. Bee counters (time permitting)
7. Lid tamper activity
8. GPS location.

As indicated by Table 3, temperature, humidity and weight have consistently been used as parameters of research in other similar studies on beehives. The contribution to those studies made by data obtained about the temperature and humidity inside a hive, and the overall weight of the hive, reinforce their importance in determining hive health, and the decision to include them in this research project.

Including outside temperature and pressure as research parameters will enable the correlation between internal and external temperatures to be identified and further investigated under changing conditions. The additional inclusion of bee counters will enable the proficiency of pollination to be measured via the movement of bees in and out of the hive.

The final parameters included in this research, lid tamper activity and GPS location, were inspired by the commonness of hive theft in the honey industry. Adding GPS and lid tampering as parameters of the research and subsequent design, mitigate the risks of such activities. These additional parameters have the potential to give large commercial beekeepers peace of mind that their beehives are safe and secure.

3.6 Functional design specification

Outlined below is a functional requirements specification for the design and construction of the operational monitoring system that will be used as part of this experiment. The specification details how the control system will operate, by:

1. Setting out how the system will operate:
    - The call-in rate for data
    - The reset time on the counters
    - Alerts for out of scoop parameters

1. Providing an overview of the hardware and software:
    - Explain how the remote system will work
    - Software and code

2. Detailing the system equipment:
    - Equipment makes and models

3. Providing examples of collected data.

Throughout the design process for this research project, a number of considerations had to be made to ensure the overall design had practical application in the field, including:

- the accessibility of parts and replacements as required.
- the remote location of the experiment site, where mains power would not be available and telecommunications connectivity would be limited.
- the installation of electronic equipment into the beehive where temperatures and humidity levels often exceed the optimum operating temperature of the equipment.

A conscious decision was also made to design the system with the welfare of bees in mind, ensuring that neither it, nor the experiment, would cause any harm to the bees, their hives or the local environment.

3.6.1 Equipment required

The equipment needed to build a functional protype has been listed in detail in Table 4.

Beehive construction		*Remote monitoring*	
Amount	**Equipment type**	**Amount**	**Equipment type**
1	8-frame hive box	1	Arduino
1	8-frame hive lid	2	Sensors (temperature and humidity)
1	8-frame hive base with beetle trap	4	50 kilogram load cells
8	Full depth bee frames	1	Barometic sensor
16	Bee escapes	8	Infrared sensor
	Plywood	1	12-volt battery
	Pinewood	1	Battery
1 litre	White exterior paint	1	Antenna
			Wire
		1	Voltage regulator

Table 4: Equipment required to build the protype.

The equipment was selected with the view of replacement parts being able to be sourced from an accessible retailer. Most of the sensors were purchased at local electronic suppliers or online. Geopolitical factors affecting worldwide supply chains affected the ability to source some of the aforementioned items quickly and locally.

3.6.2 Measuring components

The functional design of the monitoring system includes sensors to measure weight, internal temperature, external temperature, humidity, pressure, lid tamper activity and bee counters (if time permits). The sensors were installed into the hive as follows:

- Two sensors placed inside the hive to measure temperature and humidity.
- Four infrared sensors placed on the out gates of the hive entrance and another four on the in gates to count the bees going in and out of the hive.
- Weight scales fitted on the bottom of the hive and a barometric sensor on the front of the hive to measure weight and humidity respectively.
- The power supply, voltage regulator and micro controller built into the top of the hive as a safety precaution, to keep a fire contained if the event of a short circuit caused by a fault.

Weight

An important consideration in the design process was the need for the scales to not only be reliable enough to measure minute changes in the weight of the hive, but also measure up to 150 kilograms.

The household human weight scale works with a simple 50-kilogram load cell in a Wheatstone bridge configuration with a total weight spread across all four light cells of 200 kilograms. It should be noted that a load cell is a device that measures electrical resistance in response to changes in the proportion on the strain of the pressure applied to the device. Normally, load cells are made up of very fine wire and set out in a grid pattern. This is done in such a way that any linear change allows for electrical resistance change when strain is applied to one direction. Most commonly these are found with resistances of 120 times 350 ohms and 1000 ohms.

A single box beehive without a honey super and only small amount of winter honey stores has an approximate weight of 18 kilograms. A single frame can weigh from 2.2 to three kilograms when full of honey. At maximum capacity, a super holding eight to 10 frames can therefore weight between 35 and 48 kilograms. This may double or even quadruple during the summer season when honey production peaks (BeeCraft 2018).

Given the weight of hive ranges between 18 and 100 (plus) kilograms, depending on the number of supers, it has been determined that using four load cells in the Wheatstone bridge configuration with a 200-kilogram capacity, will be sufficient to measure a beehive.

A HX711 semiconductor that amplifies a 24-bit analogue to digital (ADC) and operates in a range of -4285 degrees celsius will amplify the measurements from the Wheatstone bridge. This will examine the total weight of the hive, bees and honey at intervals to determine if foraging worker bees are in the hive or returning with nectar.

A Wheatstone bridge, which is a configuration of four resistors with a known voltage (Figure 35), will be applied as follows:

Where voltage in (V-in) is a known constant, the resulting voltage out (V-out) is measured as the signal. If there is a change to the value of one of the resistors, the V-out will have a resulting change that can be measured and is governed by the following equation using Ohm's law:

$$\frac{R1}{R2} = \frac{R3}{R4}$$

$$V_{out} = \left[\frac{R3}{(R3+R4)} - \frac{R1}{(R1+R2)}\right] * V_{in}$$

$$V_{out} = \left[\frac{R2}{(R1+R2)} - \frac{R4}{(R3+R4)}\right] * V_{in}$$

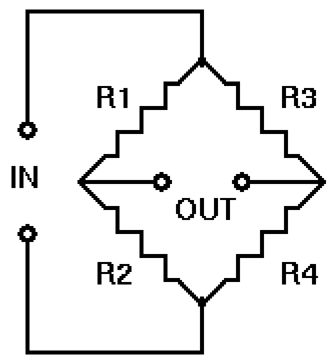


Figure 35: Wheatstone bridge (Sparkfun n.d.).

Any change in the resistance of the load cell will be able to be read via the HX711 by connecting the amplifier to a microcontroller.

The HX711 uses a two-wire interface (clock and data) for communication. It also has voltage connections required to power the HX711 (Sparkfun n.d.). The load cell amplifier from Sparkfun was chosen for this design due positive reviews other users gave it in regarding design stability.

The load cell amplifier can also be coupled with a load combinator (Figure 36) that takes the work out of forming the Wheatstone bridge configuration. This is beneficial, as the wires on the load cells (Figure 37) are very thin making it hard to connect together to form the Wheatstone bridge. However, it also means that the user needs to solder the wires to the board and test the resistance to make sure it has a clean joint. This design makes it easy for the user to change if required.

The load combinator and the load cell amplifier connect via jumper cables soldered on to the board. The load cell amplifier (HX711) then connects to the micro controller.

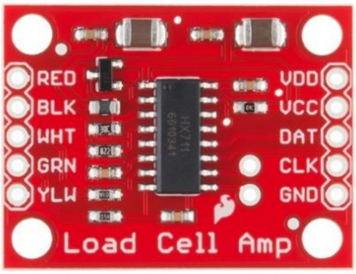


Figure 36: S-type load cell (Sparkfun n.d.).

Figure 37: Load Sensor - 50kg (Generic) - SEN-10245 (Sparkfun n.d.).

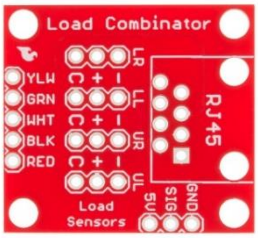


Figure 38: Load combinator Sparkfun n.d.).

When measuring the weight of a hive, it is important to note that a bee weighs approximately 0.05g and can carry 50 per cent of its body weight in nectar back to the hive. That makes the combined weight of a fully laden honey bee, approximately 0.07g. As nectar is the heaviest product the worker bee will carry, the load cells should be able to measure the number of bees entering and leaving a hive during the daytime. At night time, when the foraging bees are expected to be inside the hive, a total weight measurement should indicate how full the hive is of honey and whether another super box is required (Waikato Beekeepers n.d.).

The accuracy of this total weight measurement is limited by the fact that nectar is combined with other ingredients including water to form honey. And during the process of making honey, moisture within the cells evaporates before the cells are capped. The evaporation is likely to indicate declining weight at certain points during high temperature conditions. It will, therefore, be difficult to determine whether weight fluctuations are the result of bees entering and exiting the hive or the honey production process.

External factors including temperature changes from daytime to night time, may also disrupt the accuracy of the analogue to digital converter and therefore, distort the accuracy of some of the data.

Internal temperature and humidity

As bees prioritise keeping the brood chamber warm, different areas of a beehive will have different temperatures. The brood chamber is usually the bottom box of the hive, where the queen bee, nurse bees and the brood are located.

The temperature in the brood chamber fluctuates between 33 and 36 degrees although. The lower end of this range decreases in winter. Humidity ranges between 53 and 61 per cent. Comparatively, external humidity usually ranges between 40 and 100 per cent. Honey bees will continuously regulate the hive's microclimate to optimise honey production and protect the brood chamber (Campbell 2015).

In order to measure humidity inside a beehive, a DHT 11 has been included as part of the functional design, which measures relative humidity (RH). The device provides a full digital measurement of temperature and humidity on one digital input to the Arduino. According to Campbell (2015). The operating ranges of the DHT 11 are:

- Humidity range: 20-90% RH
- Humidity accuracy: ±5% RH
- Temperature range: 0-50 °C
- Temperature accuracy: ±2% °C
- Operating voltage: 3V to 5.5V

Relative humidity is the amount of water vapor in the air in comparison to the saturation point of water vapor in the air (Campbell 2015). The basic formula for RH where Pw is the density of water vapour, Ps is the density of water vapour saturation, is:

$$\left(\frac{P_w}{P_s}\right) * 100\% = RH$$

When the water hits saturation point, water vapor starts to condense and accumulate on surfaces, forming dew. At this point, water vapor changes with air temperature and becomes fully saturated. Cold air holds less water vapor then hot air. Hot air can hold more water vapor before it becomes saturated. At 100 per cent RH, condensation occurs, and at 0 per cent RH, the air is completely dry. Therefore, the formula to calculate relative humidity can be used (Campbell 2015).

The DHT11 detects water vapor by measuring the electrical resistance between two electrodes. As the humidity rises, the substrate absorbs water vapor resulting in the release of ions and a decrease in the resistance between the two electrodes. This change in resistance is proportional to the humidity, which can be measured to estimate relative humidity. Power comes from the voltage regulator supplied by the battery. A single signal wire is used to transmit data to the Arduino for both temperature and humidity.

The internal location of the temperature and humidity sensors will determine the accuracy of the readings obtained. It has been determined that placing one sensor on either side of the hive will indicate the internal location of the bees. This will be more so the case in winter when the bees form a ball to maintain their optimum temperature and protect the colony. A higher temperature reading on of the sensors will signal the location of the bees at any given time.

Reed switch

A reed switch will be installed into the hive to detect tamper activity. When accompanied by a few simple lines of code, the reed switch will be able to alert the beekeeper when the hive is opened.

The reed switch (Figure 39) will work off a single digital input. Multiple switches can be added at different points as the hive increases in size, by linking the wiring in series to the new switches. This keeping the inputs low to help minimise the amount of Input and Outputs required for the micro controller.

Reed switches are comprised of two units; one has a magnet inside, the other is known as the reed switch. A reed switch Normally open (NO) contact will close when the two units come together (Jaycar 2023).

Reed switches can be easily purchased from a local security supplier and can therefore be replaced if required.

Figure 39: Reed switch (Jaycar 2023).

Including the reed switch in the functional design has the potential to mitigate unwanted tampering and hive theft, both of which are becoming increasingly common problems in the honey industry. A single hive can cost a beekeeper up to $1000 to replace, when the value of the equipment, the honey stores, brood and bees, and the time spent building, painting and preparing the hive, are taken into consideration.

Beekeepers can spend up to six or eight months of their time splitting a hive or raising a queen (Jane-Ryan 2012). The cost of losing a good quality queen due of theft can impact a hive and the entirety of a beekeeper's operation for years. A beekeeper buys good quality queen bees for based on genetics and traits. To replace a breeding queen alone, can cost upwards of a $1000 (Jane-Ryan 2012).

External temperature and pressure

A Duinotech Arduino Compatible Barometric Pressure Sensor (Bosch BMP180 digital pressure sensor) will measure the external temperature and pressure at the hive site. The sensor (Figure 40) uses a I2C bus to connect to the Arduino. The I2C protocol uses two wires to send and receive data. One wire is a serial data pin (SDA) and the other is a serial clock pin (SCL). As the clock line changes from low to high, the rising edge of the clock pulses is a single bit of information that will form in sequence. The address of a specific device and a command or data is then transferred from the board to the I2C device over the SDA line. Communication is taken in turns between peripheral devices and the controller (BMP180 Digital pressure sensor, n.d.).

Many different devices can be connected on the I2C lines, as the protocol allows for each enabled device to have its own unique address. Simple code can also be used with the I2C functions to call in the pressure and temperature values.

The pressure range of the BMP180 is 300 to 1100 hectopascals (hPa), which translates to +9000m to -500m above and below sea level. It also requires an input voltage between 1.8 and 3.6 volts and comes fully calibrated from the factory (BMP180 Digital pressure sensor, n.d.). The small footprint of the sensor (3.6mm x 3.8mm x 0.93mm) means it can be discretely fitted to the front of the beehive.

The temperature component of the BMP180 will measure the external hive temperature and the subsequent correlation between the hive's internal temperature and the external temperature at the hive site. This is important in understanding the basis for high return rates of bees (further explained in 'Bee counters' below).

Bees instinctively return from foraging in large numbers when a storm is imminent as they can sense the barometric pressure change. Bees are also found to be less temperamental when the barometric pressure level rises. Some bees preferentially collect pollen over nectar when the weather conditions at the foraging site are warm. According to Peat and Goulson (2005), others prefer dry and windy conditions to collect pollen.

Figure 40: Duinotech Arduino-compatible barometric pressure sensor.

Bee counters

Including a bee counter in the functional design will aid in determining the effectiveness and rate of pollination. Data obtained through the bee counter will be able to be analysed to determine how many worker bees are in the field and to compare activity between multiple hives.

The design of the bee counter for this experiment is largely based on the design of Hudson (2021), who used infrared sensors in pairs to determine whether the bees were travelling in or out of the hive as part of their own research in 2021. As the bees passed two sensors in a sequence, the first sensor the bee triggered was used to indicate the direction it was travelling in. From there, Hudson (2021) was able to ascertain the number of bees travelling in and out of the hive at any given time. Similar infrared sensors to trigger inputs will be used in this research, however they will be accompanied by a device call a bee escape to funnel the bees through different shoots.

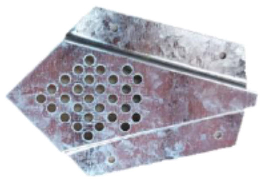


Figure 41: Bee escape.

A bee escape (Figure 41) is a bent sheet metal shape that has a wide opening at one end and a narrow cone shape at the other end. The bees enter the wide opening of the bee escape end and move through the cone hole at the other end. Once the bee passes through the narrow end of the bee escape, they are unable to return though the device. Bee escapes are normally used to separate bees from honey stores in a hive. They are placed between the brood and honey boxes, eventually forcing the bees to exit the honey super. The one directional feature the bee escapes will help simplify the bee count measurement for this experiment, as each device will only track inward or outward movement.

An infrared sensor will be placed along the tube of the bee escape to count the bees as they pass through. By cutting a hole in the tube, the sensor can be place in the correct spot and tuned by the trim pot on top to set the correct distance from the travelling bee (Figure 42). Using a bee escape on the other end of the tube ensures the bees cannot feed back through the wrong gate system. Four bee escapes per travelling direction have been included to avoid disrupting the flow of bees in and out of the hive during the experiment.

Figure 42: Infrared sensor used in the design of the bee counters.

The infrared sensors will send a 3.3-volt high signal to the micro controller when triggered by a bee passing through the bee escape. This will act as the counting mechanism for each bee escape. Having four bee escapes per direction will equate to eight digital inputs to the Arduino. The size of the sensor (32mm x 14mm x 1.26mm) makes it ideal to fit between the tubes that carry the bees between the hive and the exit. The sensors can be powered by three to five volts and outputs a 3.3 signal output (Mybotic 2023).

Figures 43 and 44 show how the gates were constructed. Holes were cut in the carbon fibre tubes so when the infrared sensor was placed beside the hole and screwed in, the passing bee would change the light reflection and trigger the 3.3-volt high signal from the sensor. The sensor was tuned by adjusting the trim pot on top of the infrared unit.

Figure 44: Construction of bee counters Showing the bee escapes and carbon tubes.

Figure 43: Construction of bee counters Showing IR sensor installed

Figures 45 and 46 show how the bee escapes were set up to optimise signals from the sensors and to minimise disruptions to the movement of bees throughout the experiment.

Figure 45:These bee escapes will count bees in the same way. This configuration however, which is different to Figure 36, will count the number of bees exiting the hive.

Figure 46: The placement of these bee escapes enables bees to enter the hive. When a bee lands on the top section of the board and starts to crawl through the bee escape towards the inside of the hive, the infrared sensor will send a signal to the micro controller.

3.6.3 Control strategy

Once the equipment has been installed in the hive, it should continuously collect data. The micro controller will call in at pre-set intervals and update the values on the cloud. Any missed call ins, while not critical to the overall collection of data, could be due to poor signal and should automatically resolve. If there are continuous discrepancies in the regularity of call ins however, a physical inspection may be required to diagnose and rectify the issue.

Due to the micro controller not being a critical system, it does not have a backup or hard reset built into the code for missed deadlines. The Arduino MRK1500 has a watchdog time built into the system and will reset if the code is stuck at a point for a set time. This time frame can be set by the user and range from 16 milliseconds to eight seconds (Arduino 2018).

3.7 Micro controller

The Arduino MRK1500 was selected as the microcontroller for this research project because of its functionality and the fact it can support the required number of inputs and outputs for this research project (Table 5). The Arduino MRK1500 is also appealing as it includes an on-board modem and can work on Cat M1 via a SIM card.

The process of setting up the sensors on the Arduino MRK1500 to call back into the Arduino cloud is already well documented online on Arduino forums (Arduino 2018). This removed the need for additional design work to be done to determine how data was going to be collected, stored and displayed and then delivered to the end-user. It also provided guidance to establish the required call-in rates via the code produced in the Arduino cloud when the Arduino is setup with its variables.

The MKR NB 1500 is an IoT-network-ready device that is compatible with prototyping with Cat M1/narrowband connectivity using an UBLOX SARA-R410M-02B module. The MRK NB 1500 Arduino features 22 input output digital pins (12 PWM) and seven analogue pins, all running on a SAMD21 Cortex-M0+ 32bit low powered ARM CPU. The required software for the Arduino MRK NB 1500 is Arduino's own IDE software that can be obtained freely on Arduino's website (Arduino 2018). Once the IDE is installed, the MKRNB library will need to be installed from the Library Manager. By connecting the micro-USB cable to an android device, programming can then commence without any additional costs.

As outlined in Chapter 2, there are a number of different micro controllers which can be used in this type of research project. However, the options in this case were limited by several factors, including the need for the micro controller to be able to operate in remote locations and without mains powers. This narrowed down the available options to 4G GSM or LoraWan.

After further investigations were conducted, it was determined that LoraWan would also not be suitable for this research project due to the fact that it relies on 240 volts of mains power or a big solar battery setup. Infrastructure would be required at both ends of the communication nodes; this cannot be guaranteed in remote locations.

The decision was therefore made to use a 4G GSM-compatible micro controller. There were few options on the market that were all-inclusive. Most devices in this range had the main micro controller with a add on hat for the 3G/4G GSM availability. As such, the Arduino MRK1500 model was selected as it was all in one shell.

3.7.1 Total input / output requirements

The total number of inputs and outputs required to support the functional design have been summarised in Table 5.

Device	**Number**	**Total input / output**
Weight	1	1
Humidity / Temperature	2	2
Outside the hive temperature	1	1
Pressure	1	0 (I2C bus linked with above)
Lid Tamper	1	1
Bee counters (if time permits)	8	8
	Total	13 inputs

Table 5: Total number of inputs and outputs required for the design.

The total number of inputs will determine the type of micro controller that can be used. It should be noted that no outputs required. All sensor data will be transferred to the cloud digitally.

3.7.1 Sim card

The MKR NB 1500 IoT-network-ready device requires a sim card to be able to function in remote locations.

As determined in Chapter 2, the Cat M1 NB IoT network has the broadest remote coverage across Australia. Telstra provides a range of connectivity options depending on the amount of data needing to be transferred. Telstra's $12.95 package was deemed suitable for this research project as it allows for multiple sims to be used as part of the package. It also includes 500 megabytes (MB) of data transfer. While this is more than what the project is anticipated to need, the additional allowance will be useful if the call-in rate increases and more data is required.

An integer on the Arduino MKR NB 1500 is a 32-bit value. Sending a single 32-bit integer every second for a month would use approximately 10MB of data. Sending 10 integers would use about 100MB per month. Additionally, sending one integer every 10 seconds would use just over one megabyte. Sending one integer every 30 seconds would reduce the data usage to 0.0108MB (Wyss 2020). On that basis, it was decided that a call-in rate of every 15 minutes would be the best option. This would provide four call-ins per hour, using about 0.00052MB each, which is well within the 500MB data allowance for the project.

The plan was setup to enable multiple sims using the same data pool to eventually allow multiple hives on the same site, either:

- using their own Arduino MRK NB 1500 with corresponding sensors
- using one Arduino MRK NB 1500 and connecting sensors on multiple hives over a I2C bus to the master device to send out the information.

Unfortunately, this was unable to be actioned due to time constraints.

3.7.2 Data storage and display on the Arduino Cloud

Arduino developed an IoT cloud to allow IoT applications to be created using the Arduino MRK NB 1500 and Telstra network. To receive and display data on compatible smart devices, an application (app) needs to be downloaded from the App Store. Using the app, which is available for free, a user can easily create an account and then login via a smart device. The app enables the user to check sensor data from the beehive. Using the data, a beekeeper can then make decisions on how best to respond to pest and disease indicators and other conditions within the hive.

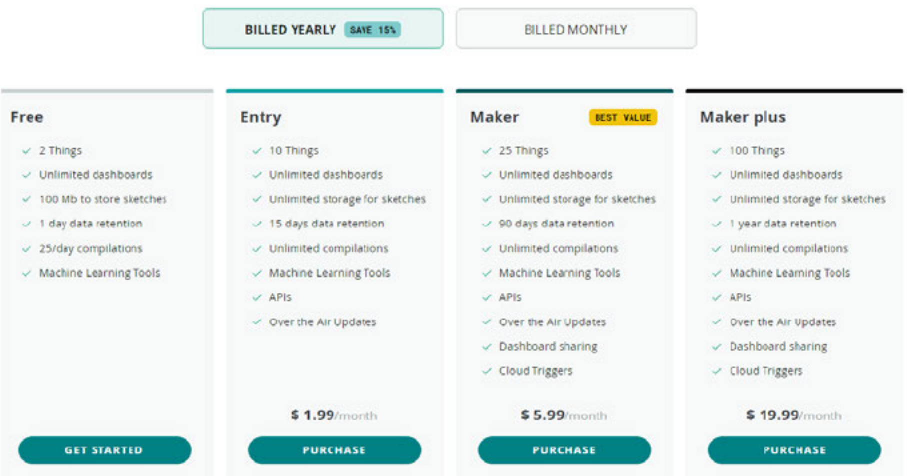


Figure 47: Plan costs associated with setting up the Arduino Cloud (Arduino 2018).

The cloud requires an account setup by the user. Different plan options were available, depending on the requirements of the project and the user's preference. The Arduino cloud plan selected for this project was the ‘Maker’ option, which had the benefit of 90-day data retention and allowed multiple devices to be added (Figure 47).

3.7.3 Setting up the Arduino MRK NB 1500

After installing the Integrated Development Environment (IDE) software and creating a cloud account, the Arduino MRK NB 1500 could be set up. This was done inside the user’s cloud account under the ‘devices’ section (Figures 49,50 and 51).

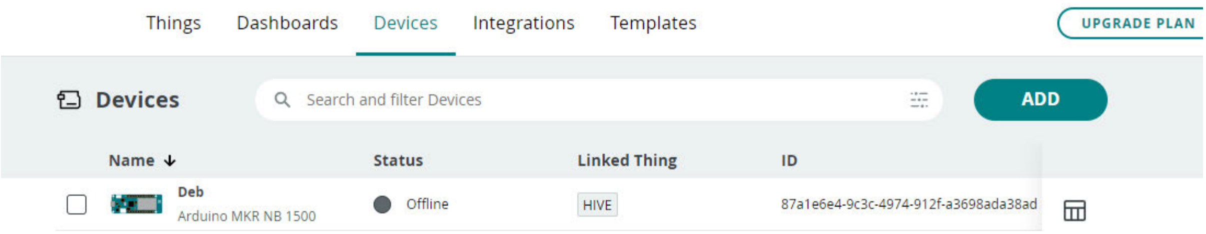


Figure 48: Arduino MRK 1500 device setup (Arduino 2018).

By clicking the ‘add’ button, the steps to set up the device will begin. Next, Select Arduino.

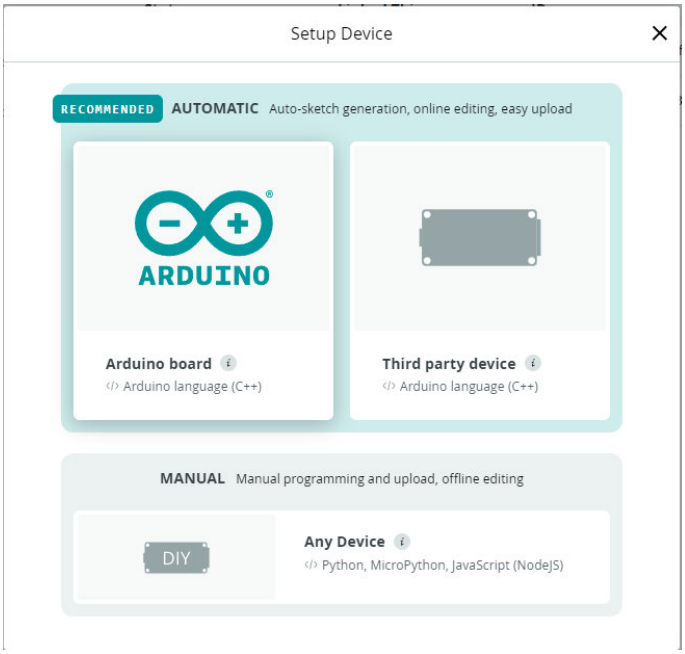


Figure 49: Arduino MRK 1500 device setup for Arduino Cloud use (Arduino 2018).

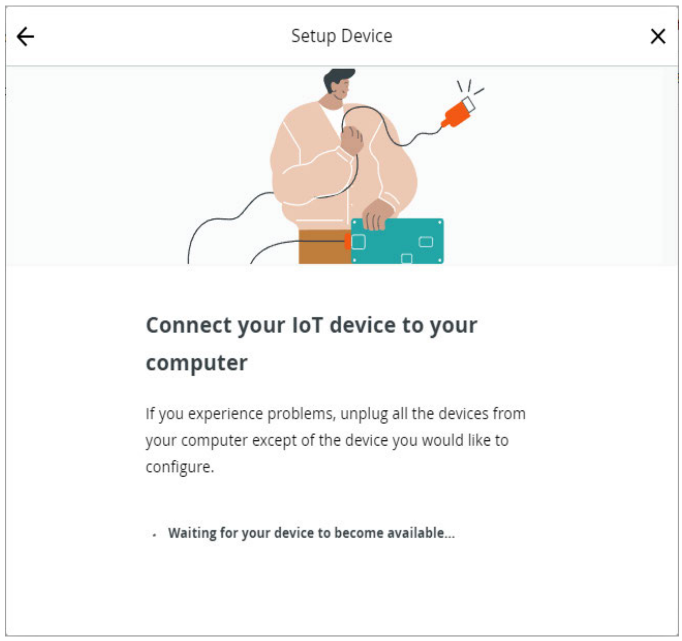


Figure 50: Arduino MRK 1500 device connected to compute (Arduino 2018).

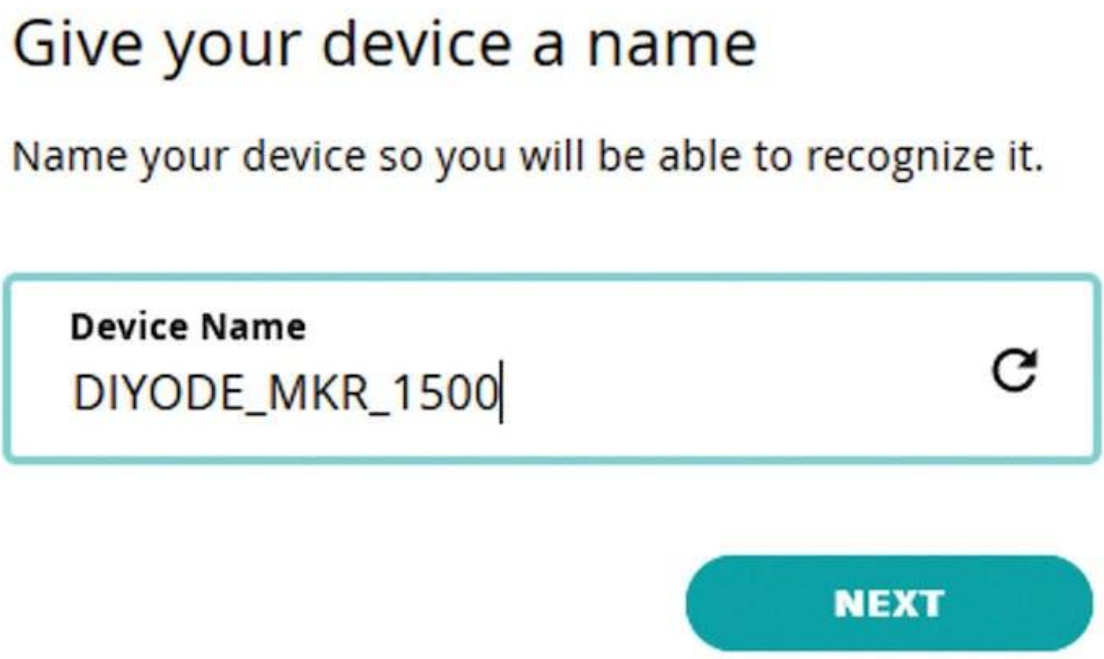


Figure 51: Arduino cloud naming the device, default names are given to each device in the setup (Wyss 2020).

Once the device has been named, click 'next' and the software set up will commence (Figure 51).

Figure 52: Device being setup ready for cloud use (Arduino 2018).

Once the setup has finished, a confirmation message will appear (Figure 53). This can take a couple of minutes.

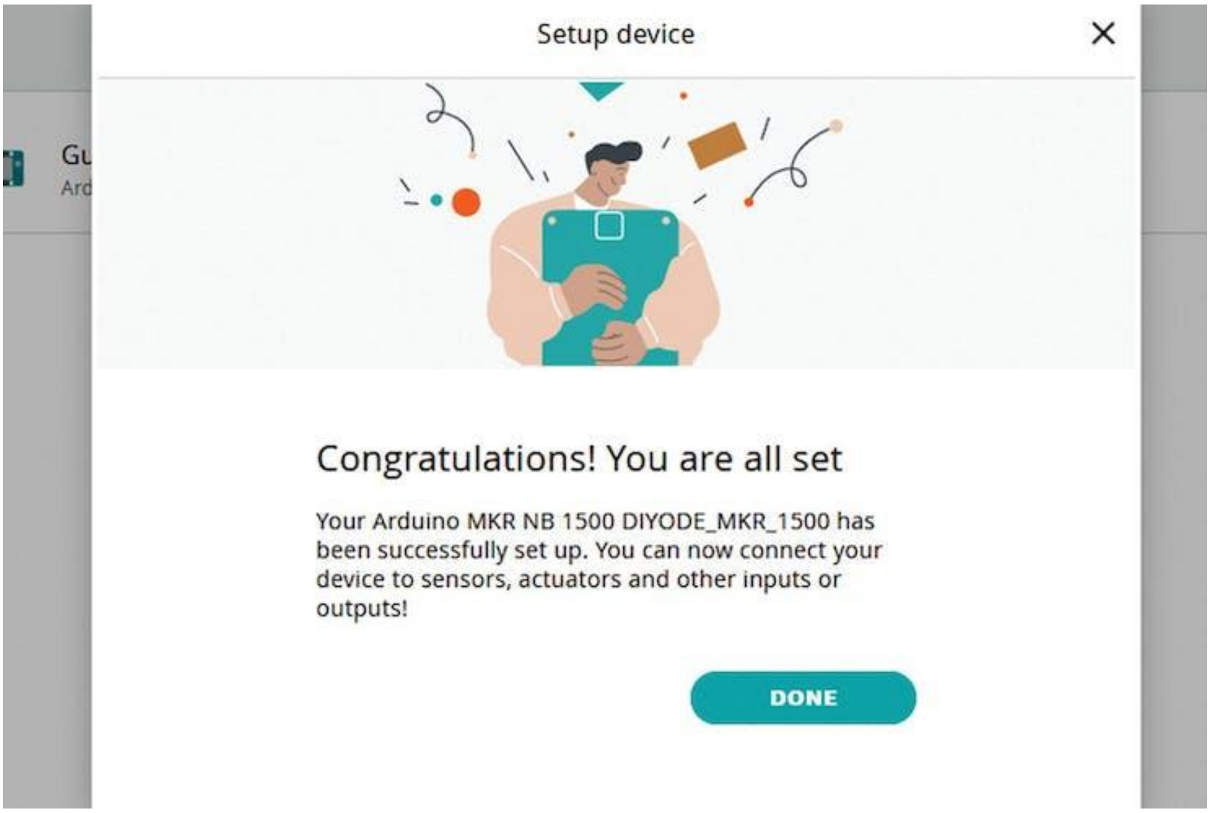


Figure 53: Confirmation device is setup and ready to use (Arduino 2018).

Once the device setup is complete, 'Things' need to be established (Figure 54). This is where sensors are setup and variable names are assigned. There are many variable types to choose from including float, int, String. There are many pre-loaded options to choose from. Most of the sensors used as part of this project were set to using an integer or a floating-point number (Figure 54).

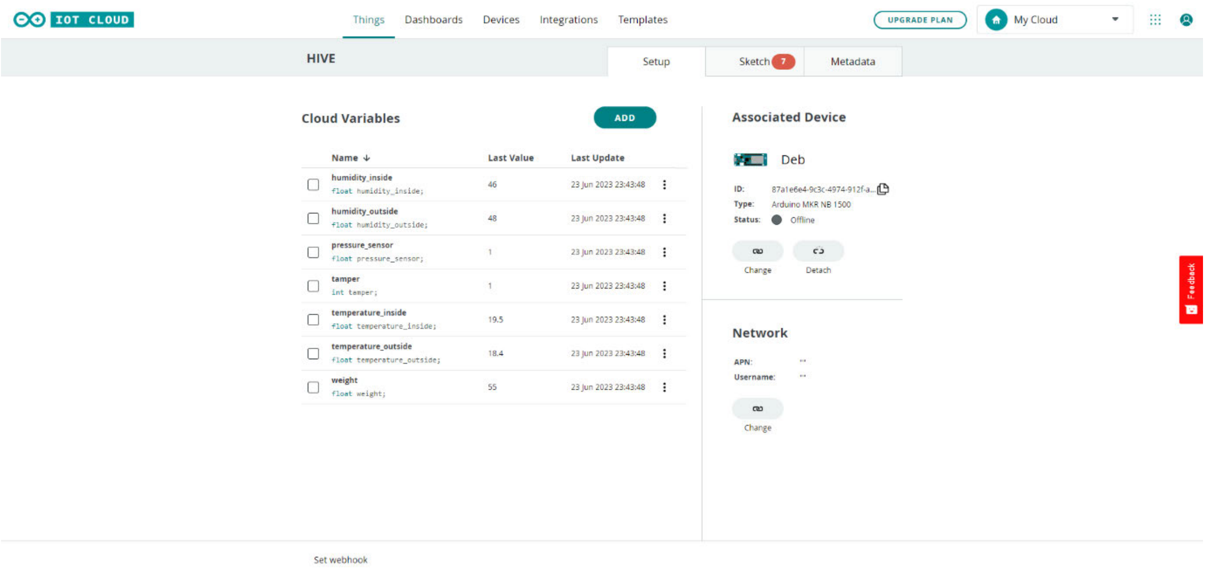


Figure 54: Device variables setup (Arduino 2018).

After the required sensors have been setup, the call rate can be determined. This is done at the bottom of the 'Variable' setup stage. It appears as Variable Update Policy where it can be decided if the cloud update is triggered from a change in the variable, or at a time designated by the user (Figure 55).

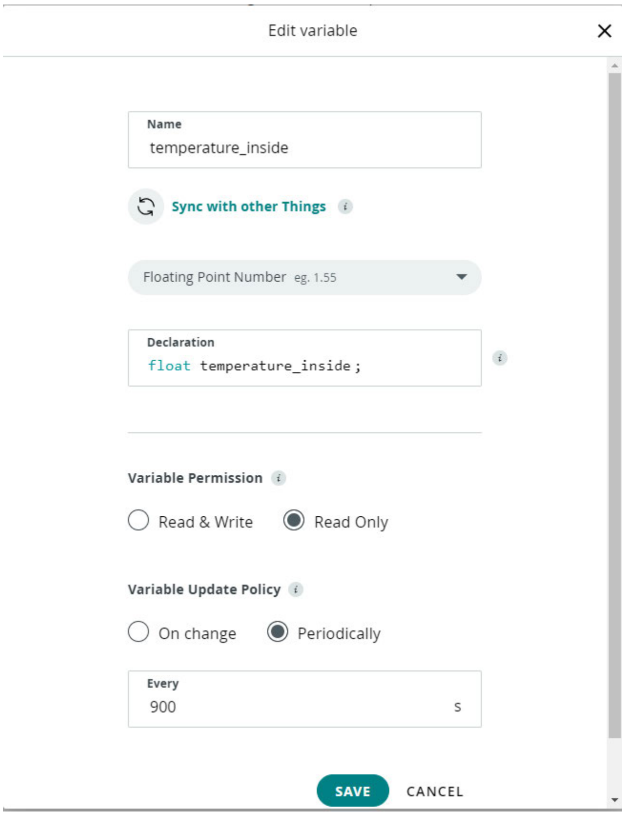


Figure 55: Variable' setup stage in Arduino cloud (Arduino 2018).

The next stage of setting up the Arduino MRK NB 1500 is the programming of sensors. This is done via the 'Sketch' tab (Figure 56). The preliminary setup of the outline code will appear on the page when the file is opened. This has the pre-loaded call-in rates and variables in the code. All that remains to be done is to add the code for the sensor.

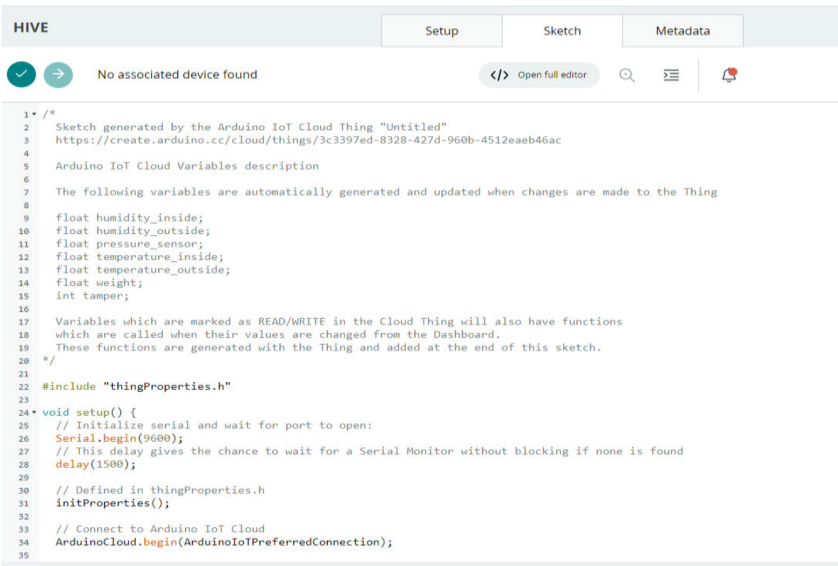


Figure 56: Project variables being loaded into the code (Arduino 2018).

Under the ArduinoCloud.update (); section in the code the set variables need to align with the sensor values (Figure 57). All internal calculations can be done within the code to transmit actual values. This means that conversions won't be required on the cloud end and less data can be transferred.

```
  // Add the callback function to be called when the button7 is pressed.
  button7.onPressed(onButton7Pressed);
  // Add the callback function to be called when the button8 is pressed.
  button8.onPressed(onButton8Pressed);

  /*
     The following function allows you to obtain more information
     related to the state of network and IoT Cloud connection and errors
     the higher number the more granular information you'll get.
     The default is 0 (only errors).
     Maximum is 4
 */
  setDebugMessageLevel(2);
  ArduinoCloud.printDebugInfo();
}

void loop() {
double local_pressure = 1011.3; // Look up local sea level pressure on google // Local pressure from airport website 8/22

    int currentReading = myScale.getReading();
   // Serial.print("Reading: ");
    //Serial.println(currentReading);
    int zerooffset = -1050552;
    int calibrationfactor = (-1029979 -zerooffset ) / 10000 ;
   // Serial.println(calibrationfactor);
    int cal = (currentReading - zerooffset);
    int weight2 = (cal/calibrationfactor);
    //Serial.print("weight: ");
    //Serial.println(weight2);


  ArduinoCloud.update();


  counter_in = count_in;
  counter_out = count_out;
  humidity_inside = dht0.readHumidity();
  humidity_inside2 = dht1.readHumidity();
  pressure_sensor = (get_pressure());
  temperature_inside = dht0.readTemperature();
  temperature_inside2 = dht1.readTemperature();
  temperature_outside2 = (get_temp_c());
  tamper = 1;
  weight= weight2;
```

Figure 57: Arduino code being written to transfer the sensor values.

Once complete, compiling testing can start. It is recommended to load a few scripts first to setup networks and set preferences for Cat M1 and NB-IoT network configuration. These are pre-coded in the MRK 1500 library setup and easy to navigate through using the Serial Monitor.

Once the code is all downloaded and installed on the Arduino, the Serial Monitor provides a live update of the connection between the cellular network and the Arduino cloud. As part of this process, the on-board Arduino will check that the sim is present and working before it connects to the network (figure 58). Once connected to the cloud, the Arduino links the Thing ID to the cloud (this is the identification on the device calling in). After this, the Message Queuing Telemetry Transport (MQTT) transmission will start and the data transfer will take place (Figure 58,59 and 60).

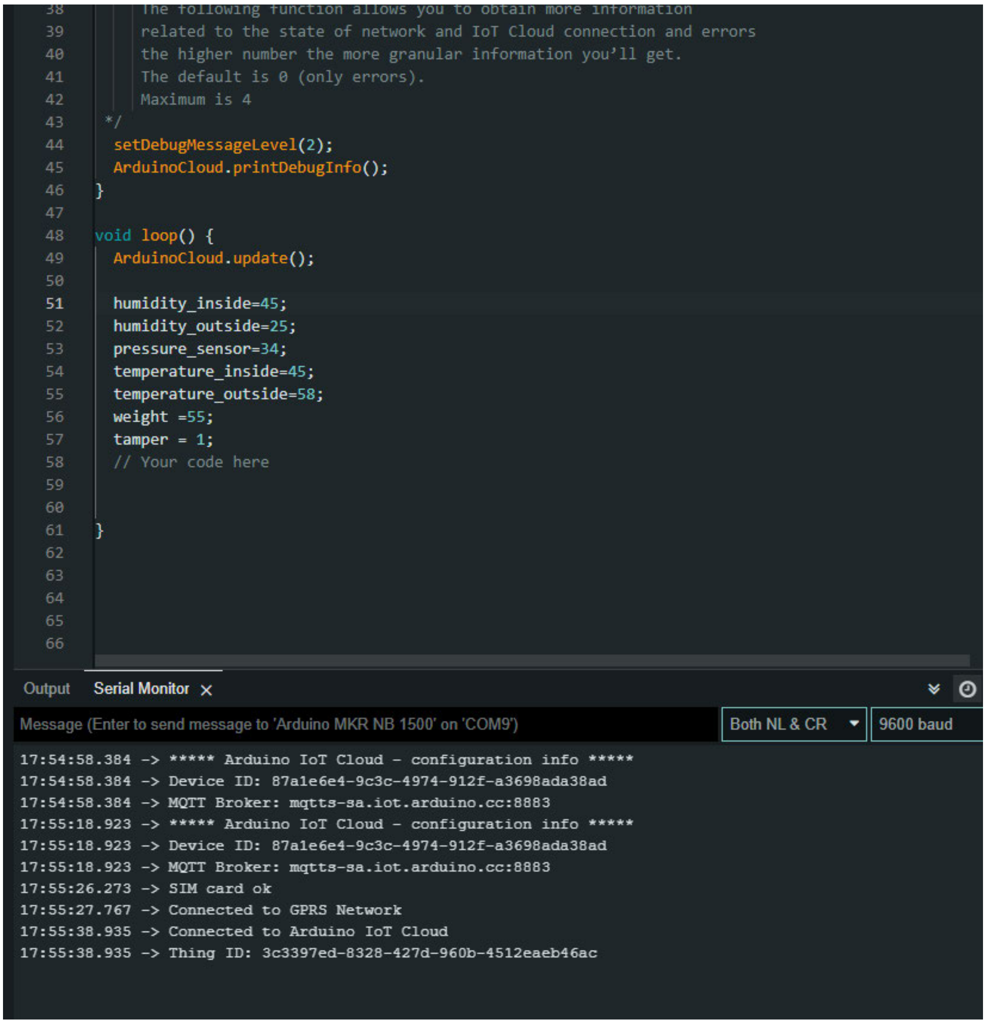


Figure 58: Arduino code showing connection to network and IoT cloud.

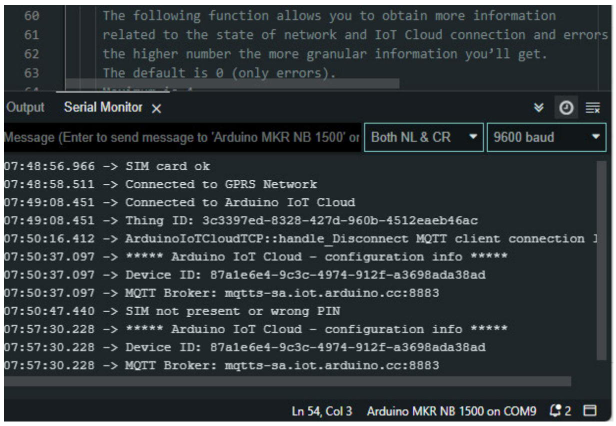


Figure 59: Arduino IDE serial port showing the Arduino connecting.

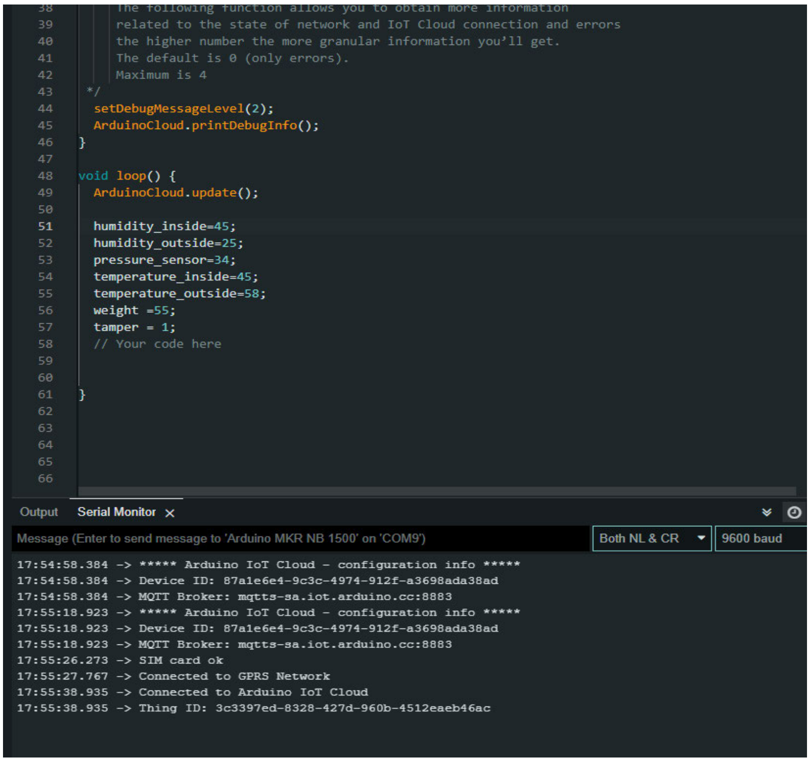


Figure 60: Arduino IDE serial port showing the Arduino connecting.

3.7.4 Testing code and Arduino connection

On 23 June 2023, the MRK NB 1500 Arduino stopped connecting to the cloud as it was set up to do so. While it was difficult to ascertain the reason for the stoppage, some online troubleshooting revealed a way to integrate the modem commands and determine why the connection was disrupted. A serial pass-through code allowed the AT command to be sent to the u-blox SARA-R410M-02B (figure 61-62). Messages were then received back to which indicate where the failures exist. (Arduino n.d.).

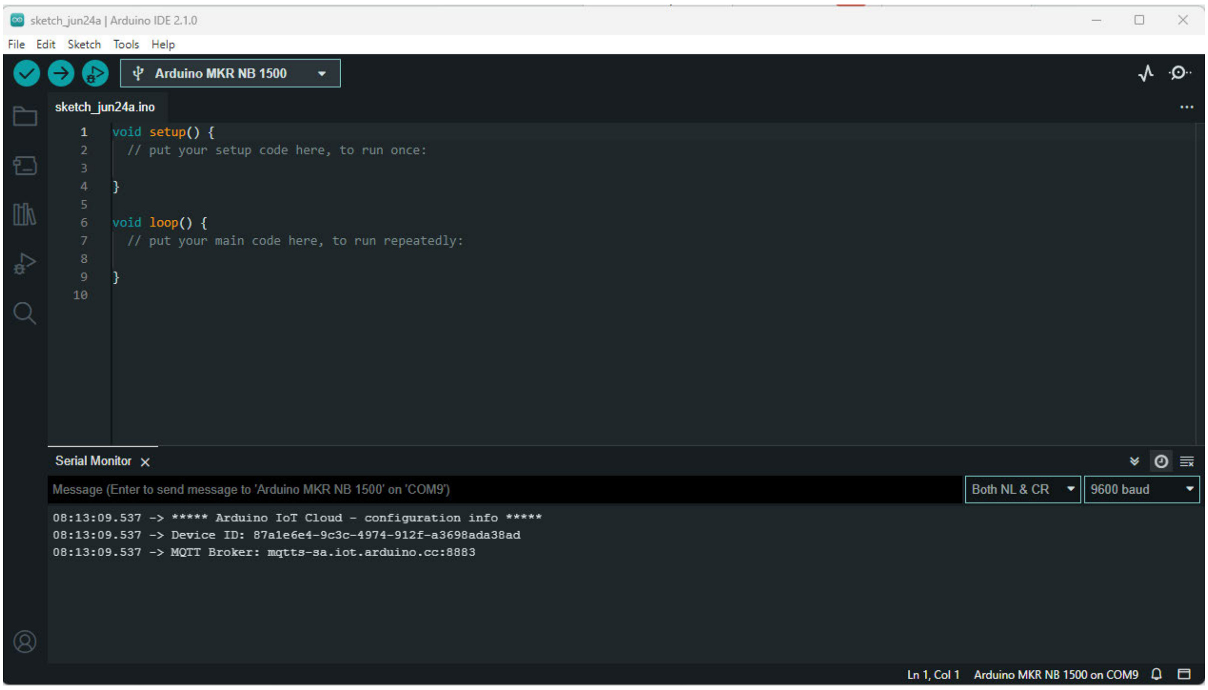


Figure 61: Arduino code showing fault as it tries to connect to the cloud (Serial Monitor).

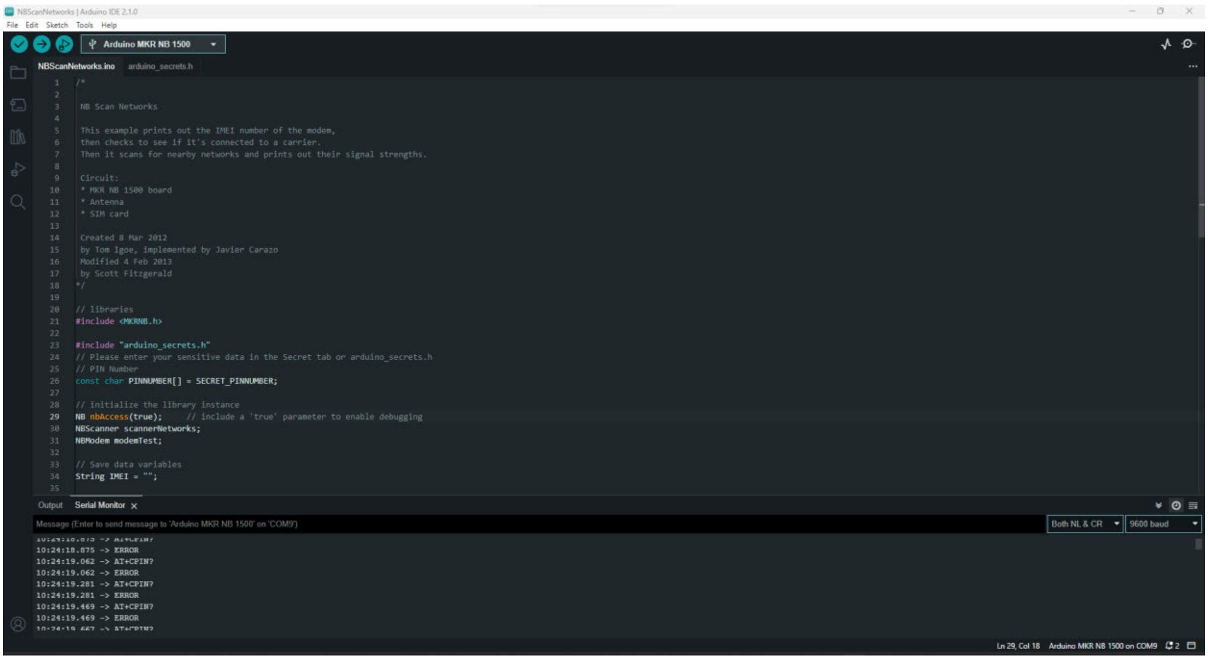


Figure 62: Debugging AT by reading the modem code from the serial port.

3.7.5 Testing the SIM

The Serial Pass Through can assist in integrating the SIM card by typing 'ALT+CPIN?' into the command prompt (Figure 62). When this action was executed, the message displayed was 'SIM not inserted' (Figure 63). After confirming the SIM was correctly installed, a fault test was conducted using a mobile phone SIM. The message displayed for the mobile phone SIM was 'Ready' and 'OK'. This indicated that the SIM card for the Arduino was faulty. A new SIM card was subsequently acquired, which restored the operations of the Arduino MRK NB 1500 (figure 64).

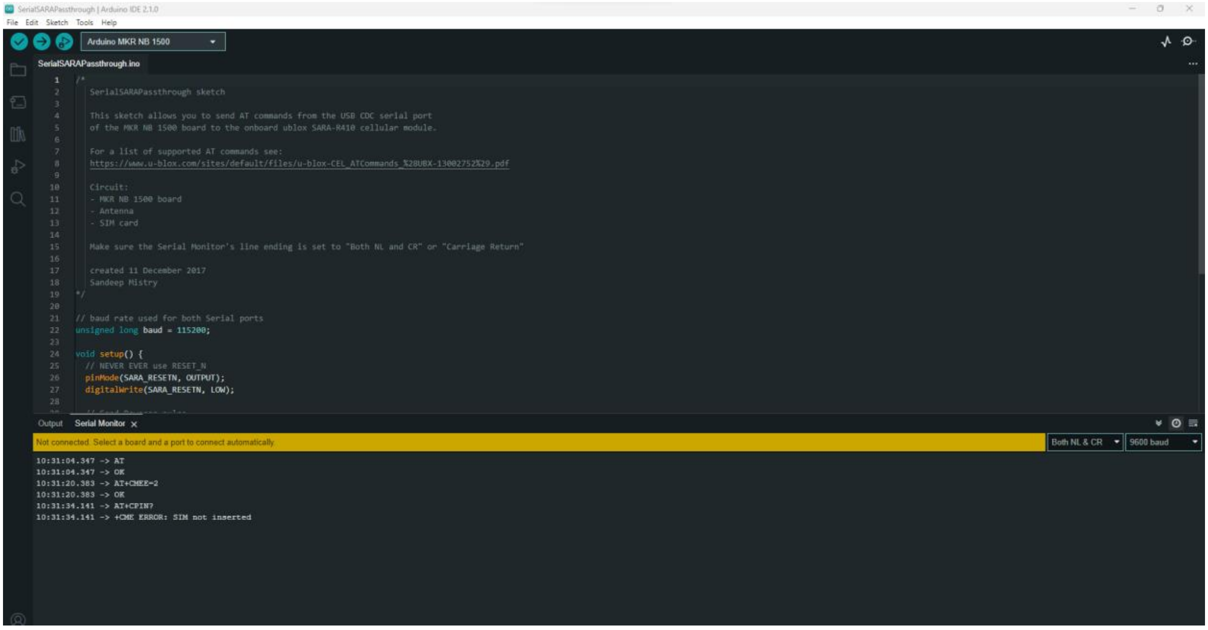


Figure 63: Optus sim test proved fault sim as seen in the Serial Monitor.

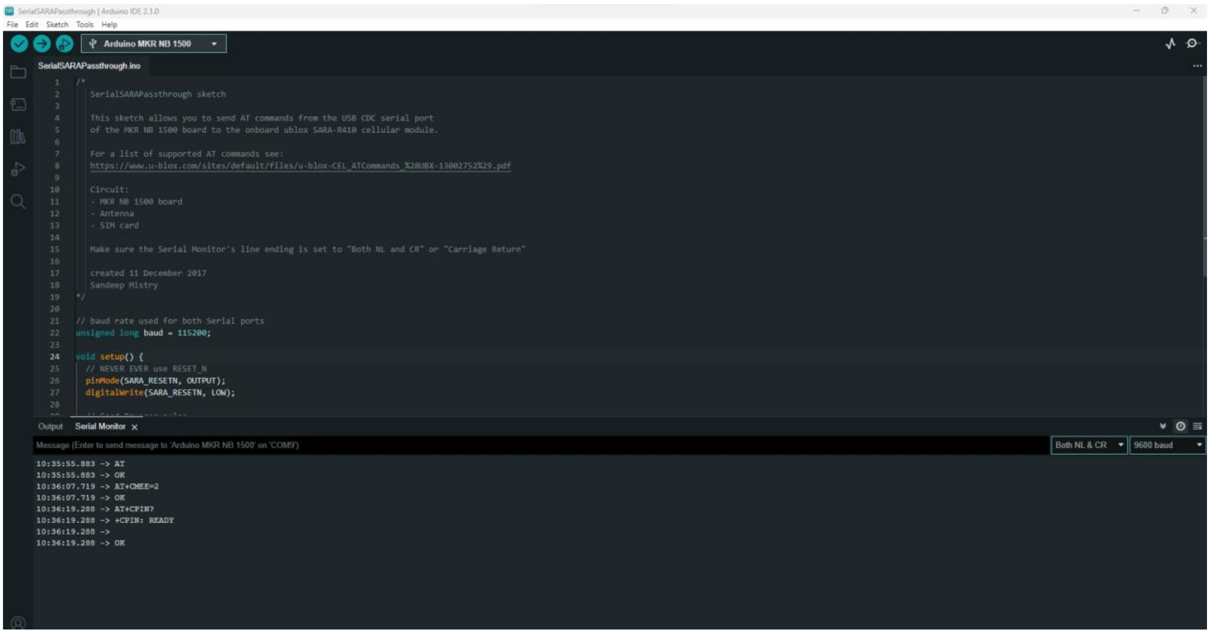


Figure 64: Further AT modem testing with a new SIM card.

The Arduino MRK NB 1500 was bench tested at the beginning of June 2023. Before the SIM card failed, the Arduino MRK NB 1500 was calling-in every 15 mins with data from the temperature, humidity and pressure sensors that were connected.

A download of historic data from the Arduino cloud, emails a zip file containing an Excel file for each of the parameters selected for a specified date range. From there, the data can be easily populated into graphs through Excel to illustrate. The graphs are from the testing data that was collect during the equipment test period (Figure 65 and 66).

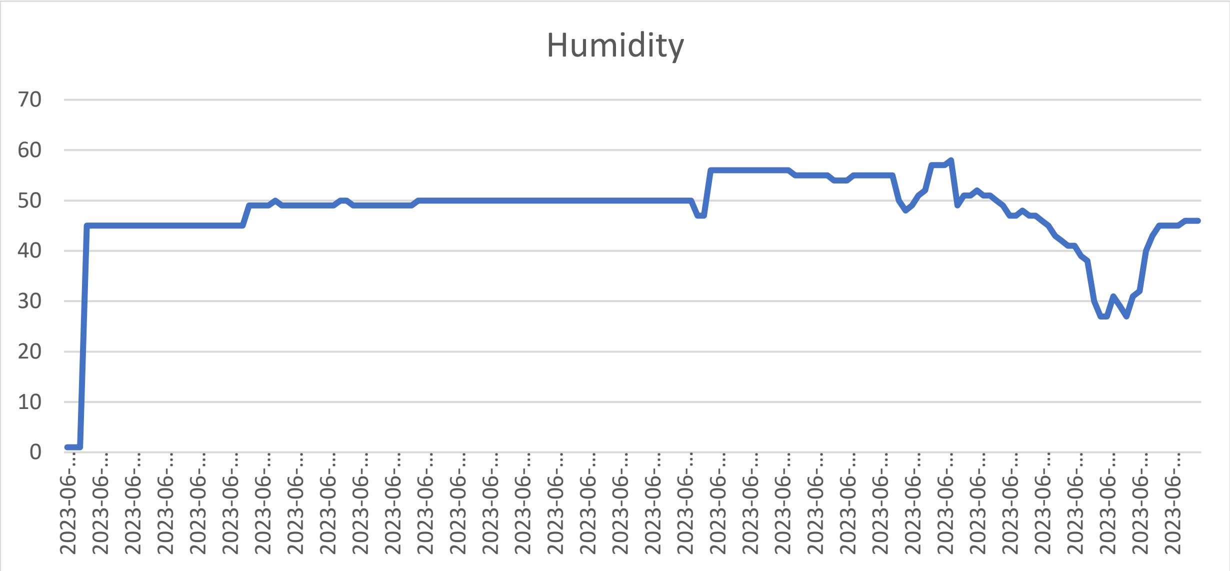


Figure 65: Sample humidity from the test stage with the Arduino MRK NB 1500 calling in.

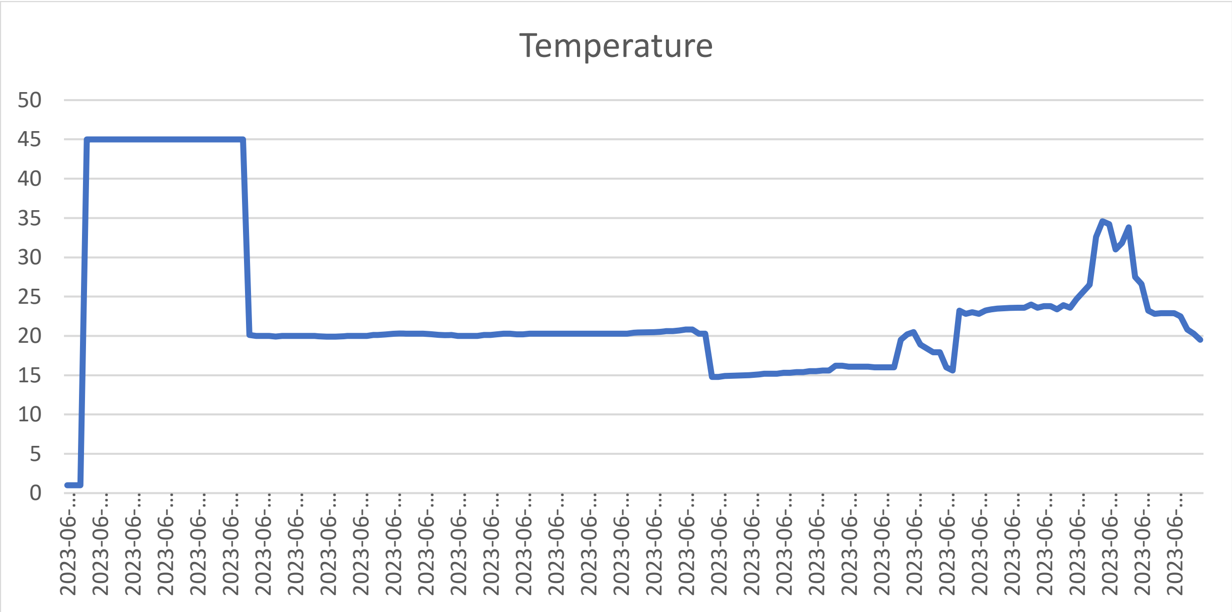


Figure 66: Sample data temperature from the test stage with the Arduino MRK NB 1500 calling in.

3.7.6 Arduino cloud display

One of the benefits of using the Arduino cloud service is that remote monitoring can be set up. This can be simply done by clicking 'add' through the Dashboard tab of on the app. Aa drop-down menu will then appears with a selection of different graphs a user can choose from, along with many other control options.

The main graphs used for the purposes of this project, were the 'chart' (Figure 67) and 'advanced chart' (figure 68). The 'chart' option provides a visual line graph that updates with each call-in. The 'advanced chart' enabled two different variables to be monitored over a set period of time.

Figure 67: Single variable display of parameters inside and outside the hive.

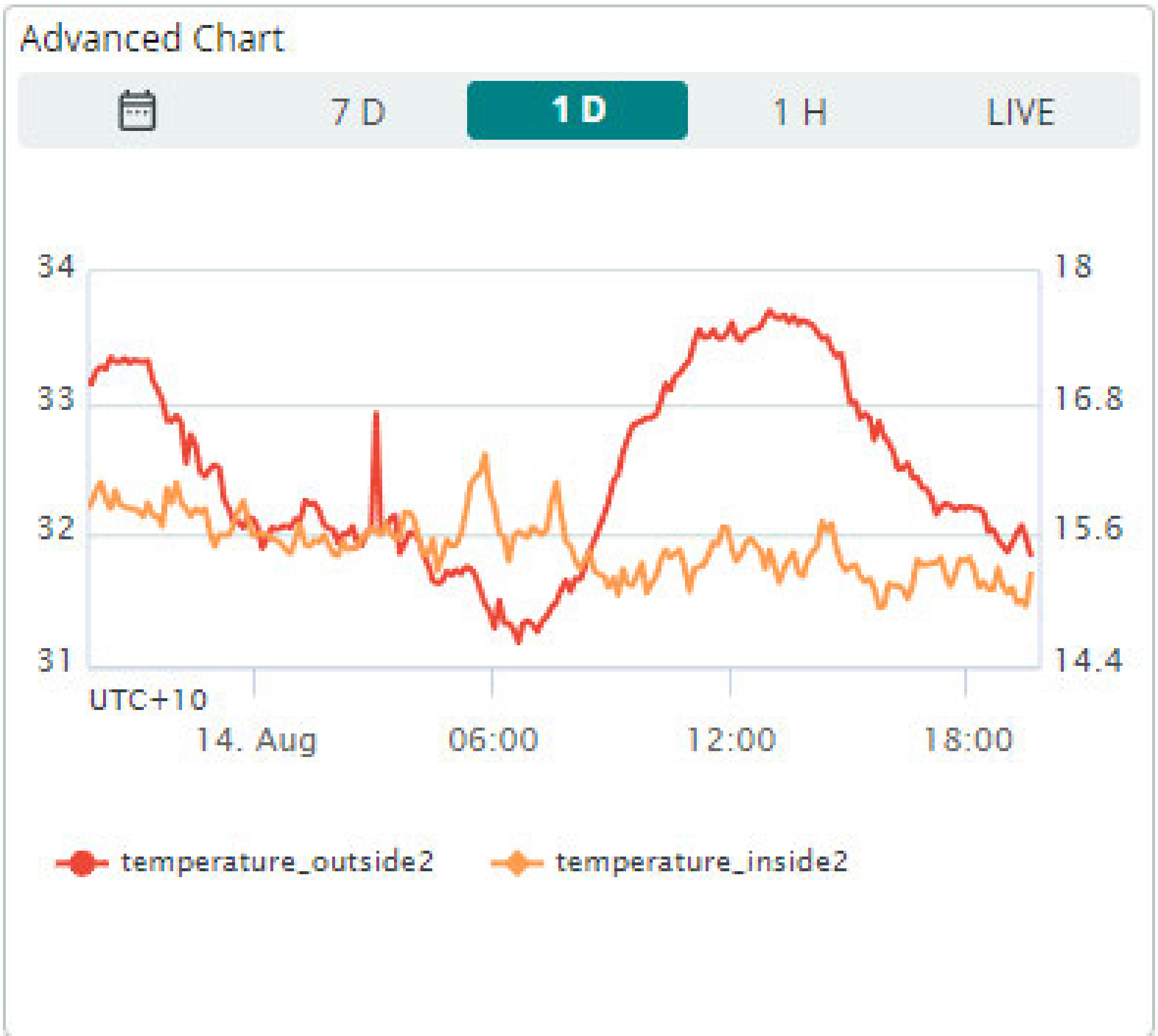


Figure 68: Dual variable display between inside and outside temperature.

The graphs can display data in different time intervals from one hour, one day to seven days or across the required time frame. Alternatively, as mentioned in section 3.8.6, data can be downloaded by selecting 'download historic data' and populating the data into graphs and charts accordingly. Using this function, the limits of the data sets can be altered as required.

3.8 Power and battery supply

This design is powered by a lead acid battery. The battery has a capacity of 22-amp hours of power at 12 volts. The voltage can be reduced using a DC voltage regulator module. The DC voltage regulator module allows the user to tune the voltage to the desired level. This is done using a screwdriver to adjust the variable resistor on top of the device. By placing a multi-meter across the output, a visual reduction can be seen and the set point determined, before connecting damaging voltage to the device.

The DC voltage regulator module can handle an input voltage of 4.5 to 35 volts with a maximum output of 2.5 amps. The Arduino MRK NB 1500 power consumption is rated between 100 milliamps (mA) and 190mA. It has been suggested that during long transmission, the power can draw up to two amps for several seconds (Arduino 2018).

Outlined below is the electrical characteristics of each component of the design and the corresponding power consumption.

Arduino MRK NB 1500

Power supply	DC 2.7～5V
Supply current	Measurement 190 mA
Measurement power	$P = \frac{V}{I} = \frac{4.2}{190mA} = 0.798 \text{ watt (W)}$

Temperature and Humidity sensor

Power supply	DC 3.5～5.5V
Supply current	Measurement 0.3mA standby 60µ A
Sampling period	More than 2 seconds
Measurement power	$P = \frac{V}{I} = \frac{4.2}{0.3mA} = 0.00126\ watts\ (W)$
Standby power	$P = \frac{V}{I} = \frac{4.2}{060uA} = 2.52E^{-5}\ watts\ (W)$

As there are two temperature and humidity sensors inside the internal brood box of the hive, the power consumption needs to be doubled to 0.00252 watts.

The weight scales and the Analogue to Digital converter

Power supply	DC 2.7～5V
Supply current	Measurement <1.5 mA
Measurement power	$P = \frac{V}{I} = \frac{4.2}{1.5mA} = 0.0063 \text{ watt (W)}$

Duinotech Arduino Compatible Barometric Pressure Sensor (BMP180 Digital pressure sensor by Bosch)

Power supply	DC 1.8～5V
Supply current	Measurement 5 miro Amps constant
Measurement power	$P = \frac{V}{I} = \frac{4.2}{0.005mA} = 2.1\text{E}^{-5} \text{ watt (W)}$

Infrared sensor (IR Infrared Obstacle Avoidance Sensor Module)

Power supply	DC 3.3～5V
Supply current	Measurement 20 mA
Measurement power	$P = \frac{V}{I} = \frac{4.2}{1.5mA} = 0.084 \text{ watt (W)}$

There is a total of 8 The IR Infrared Obstacle Avoidance Sensor Module used in the project therefore the power for 8 models is 0.672 watts

Using the above measurement power calculations, the total power consumption of the design components can be determined (Table 6).

Device	*Watts*
Arduino MRK NB 1500	0.798
Temperature and humidity sensor	0.00252
Weight scales and the analogue to digital converter	0.0063
Duinotech Arduino Compatible Barometric Pressure Sensor	0.000021
Infrared sensor	0.672
Total	1.4788 Watts

Table 6: Power consumption of each device.

The total watts should then be converted back to amps:

$$I = \frac{P}{V} = \frac{1.4788\,Watt}{4.2volts} = 0.35209523809524 \text{ Amps or } 352.09523809524 \text{ milliampere (mA)}$$

Battery runtime

The runtime of a battery is calculated using the following equation:

$$Battery\ life\ = Capacity\ /\ Consumption\ \times\ (1\ -\ Discharge\ safety)$$

In the above formula, capacity of the battery is measured in ampere-hours. Consumption represents the average current drawn from the electronic device and is expressed in amperes. The discharge safety is the percentage of battery capacity that is never used. A battery should never be discharged below 20 per cent, otherwise damage may occur (Rebelcell n.d.)

Sleep mode

Sleep mode can be added to the design code to help prolong the life of the battery. Sleep mode is calculated using the following equation:

$$Battery\ life\ = \frac{22}{352.09523809524(\text{mA})} \times\ (1\ -\ 20\%) = 49.99\ hours$$

$$Average\ consumption\ = \frac{(Consumption1\ \times\ Time1\ +\ Consumption2\ \times\ Time2)}{Time1\ +\ Time2)}$$

$$Average\ consumption\ = \frac{(352.095\,mA\ \times 20sec\ +\ 1\,mA\ \times\ 880sec)}{900)} = \frac{213554\,mins}{60}$$

$$= 148.3\ days$$

In the above equation, awake time is the time that the device is not sleeping during one operational cycle. Sleep time is the time the device spends sleeping during one operational cycle. Consumption represents the average power consumption of the device in sleep mode. It should be noted that this value is lower than the consumption during normal operation.

3.9 Testing site

The testing site for this experiment was a private parcel of land situated between Middle Dural and Glenorie (Figure 69) The testing size was over 10 acres in size. The beehives were located at the bottom of a hill by a creek, in the remotest part of the site. This site was chosen due to its remoteness. Other available sites were too close to roads and residential homes. The test site was approximately 1.5 kilometres off the main road.

Figure 69: Aerial view of the test site (Google Maps, n.d.).

Figure 70: Beehive at test site with remote monitoring.

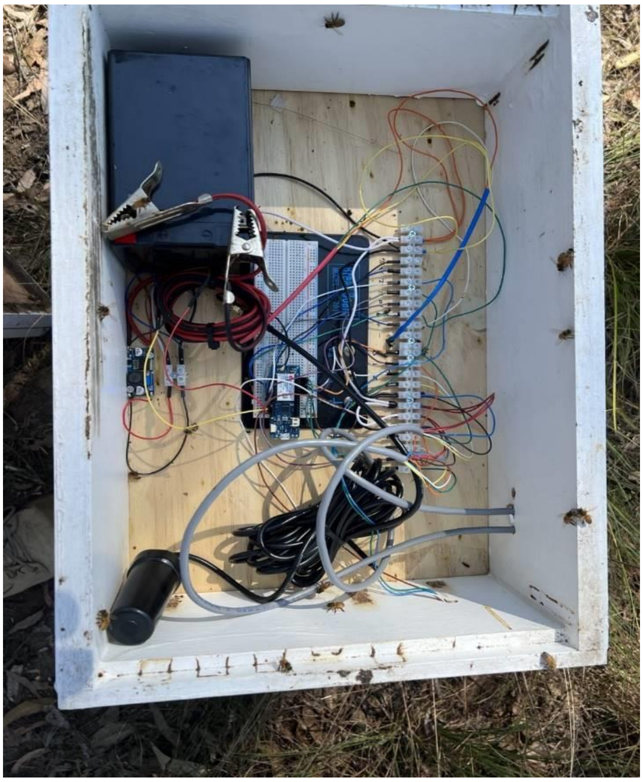


Figure 71: Picture of remote monitoring equipment at the testing site.

Figure 73: Beehive at test site with remote monitoring.

Figure 72: Beehive at test site with remote monitoring.

3.10 Project disruption

On 11 July 2023, the DPI declared a Varroa Mite Eradication Zone in North-west Sydney. Figure 74 shows the extent of the zone, including the experiment's testing site. As a result of the declaration, a number of restrictions were immediately imposed on the movement and handing of bees and beehives in the zone. It also meant data collection for the purposes of this experiment had to cease.

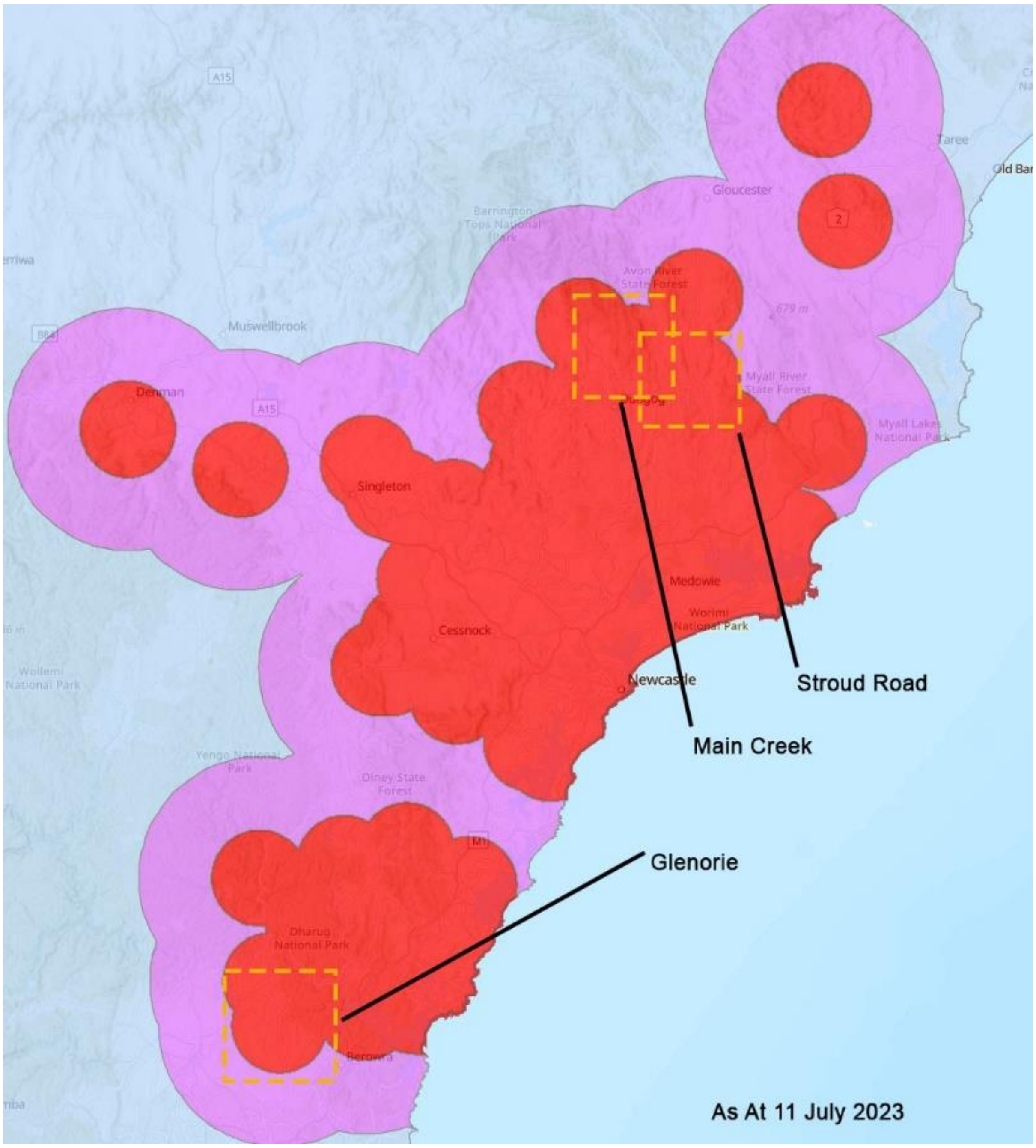


Figure 74: Varroa Mite map showing the spread of the mite (ahbic-admin, 2023).

When this project commenced, Varroa Mite was limited to Newcastle, the Central Coast and the Mid North Coast of New South Wales. By the time data collection was underway, Surveillance and Eradication zones had been declared in North-west Sydney (ahbic-admin, 2023).

Figures 75 and 76 show the gradual spread of Varroa Mite from Newcastle, the Central Coast and the Mid North Coast to North-west Sydney between 29 June 2022 and 28 August 2023.

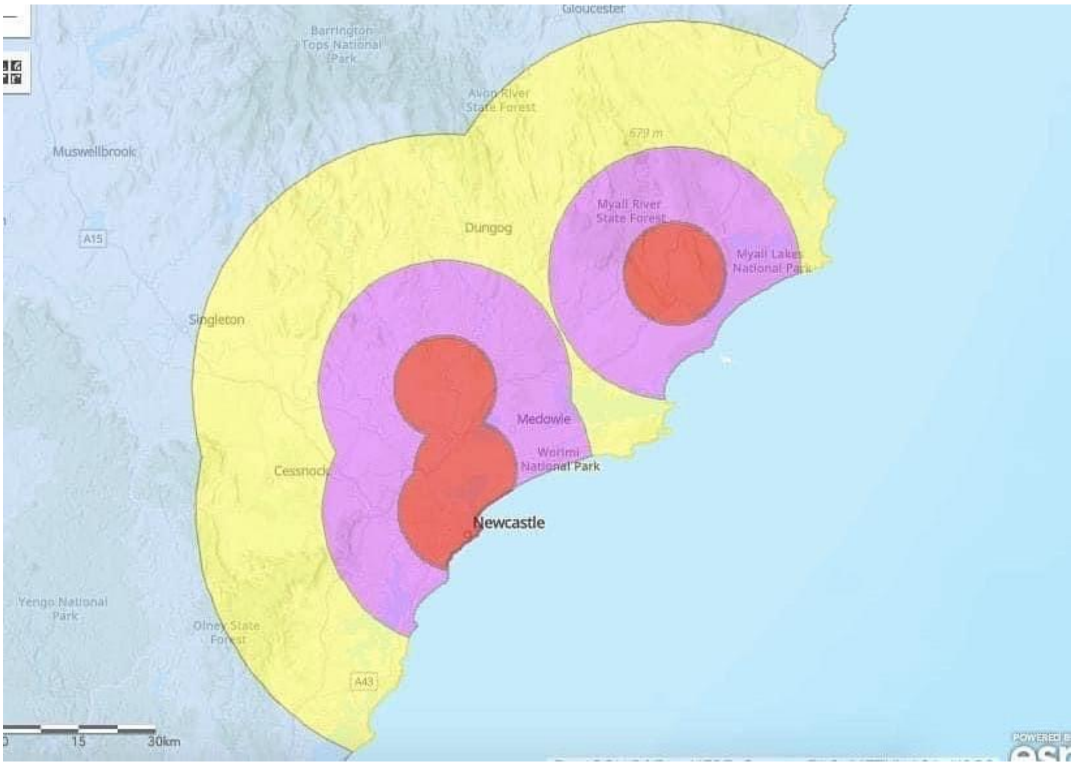


Figure 75: Varroa Mite spread as at 29 June 2022 (NSW Department of Primary Industries 2022).

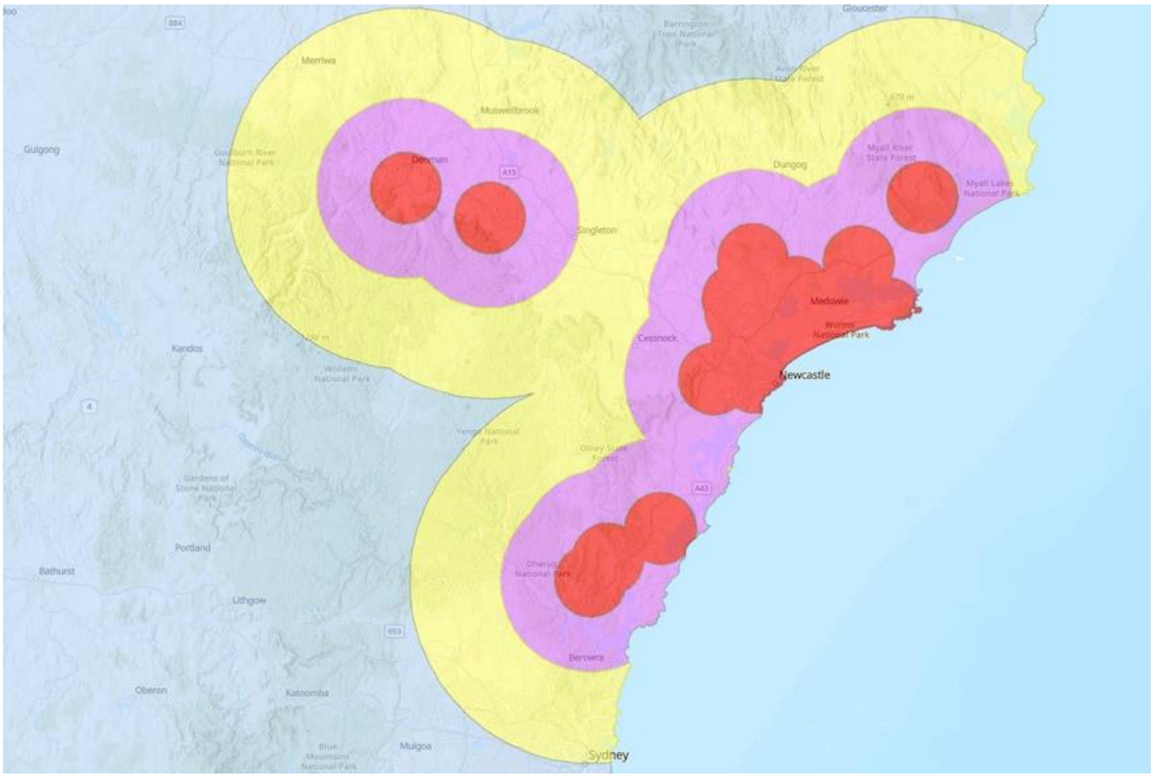


Figure 76: Varroa Mite spread as at 11 July 2022 (NSW Department of Primary Industries 2022).

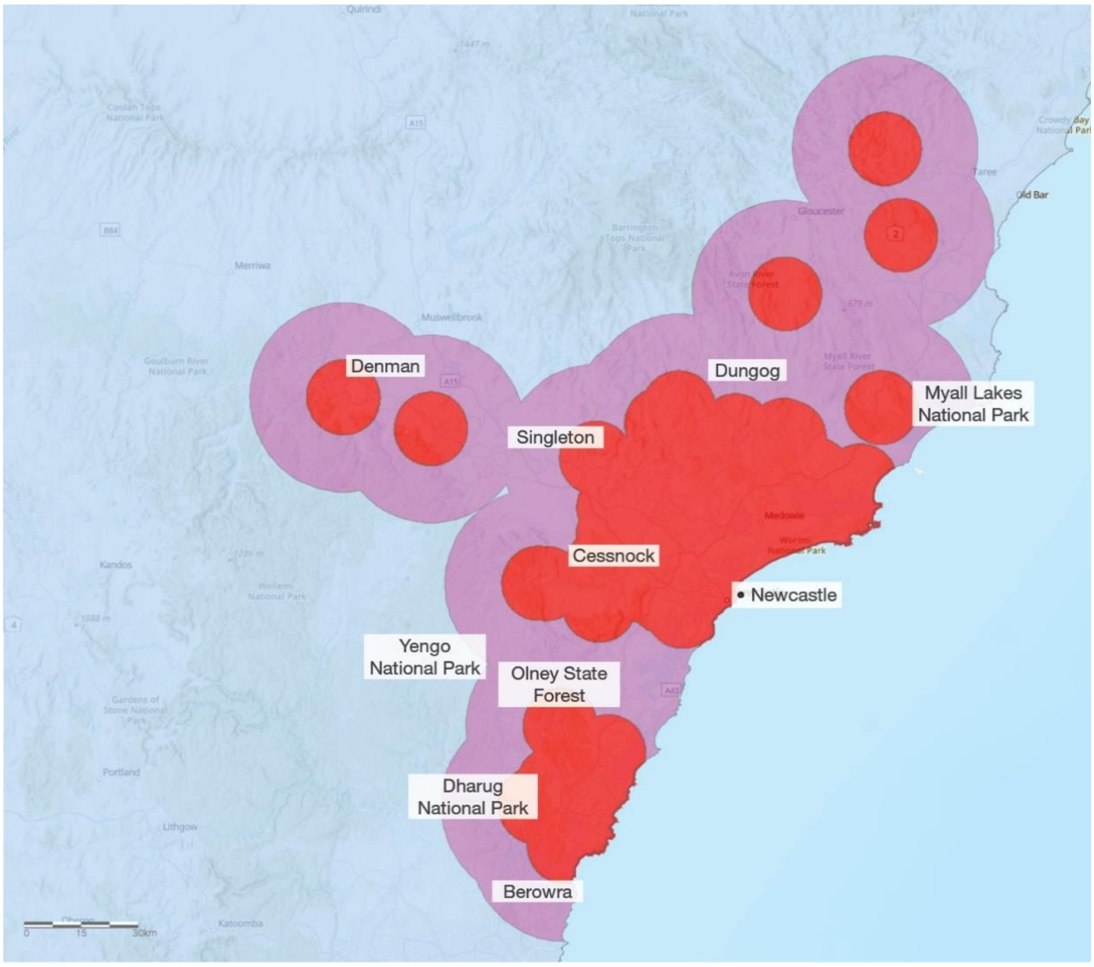


Figure 77: Varroa Mite spread as at March 14 2023 (NSW Department of Primary Industries 2022).

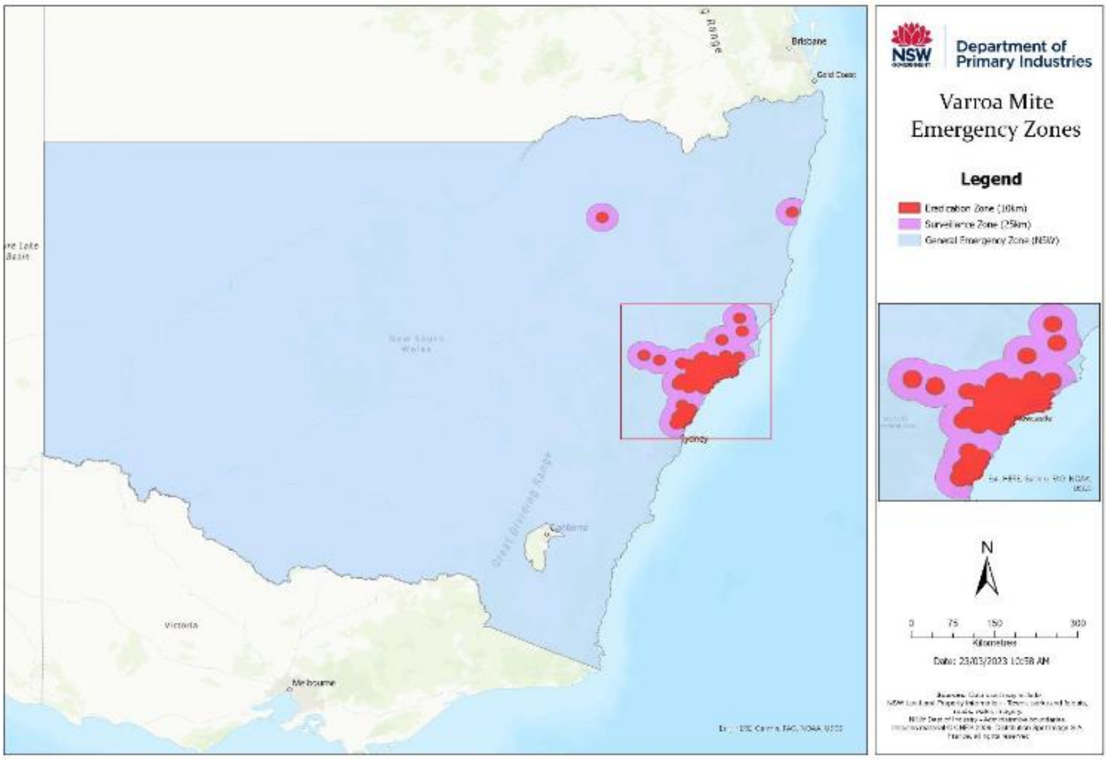


Figure 78: Varroa Mite spread as at May 2023 (NSW Department of Primary Industries 2022).

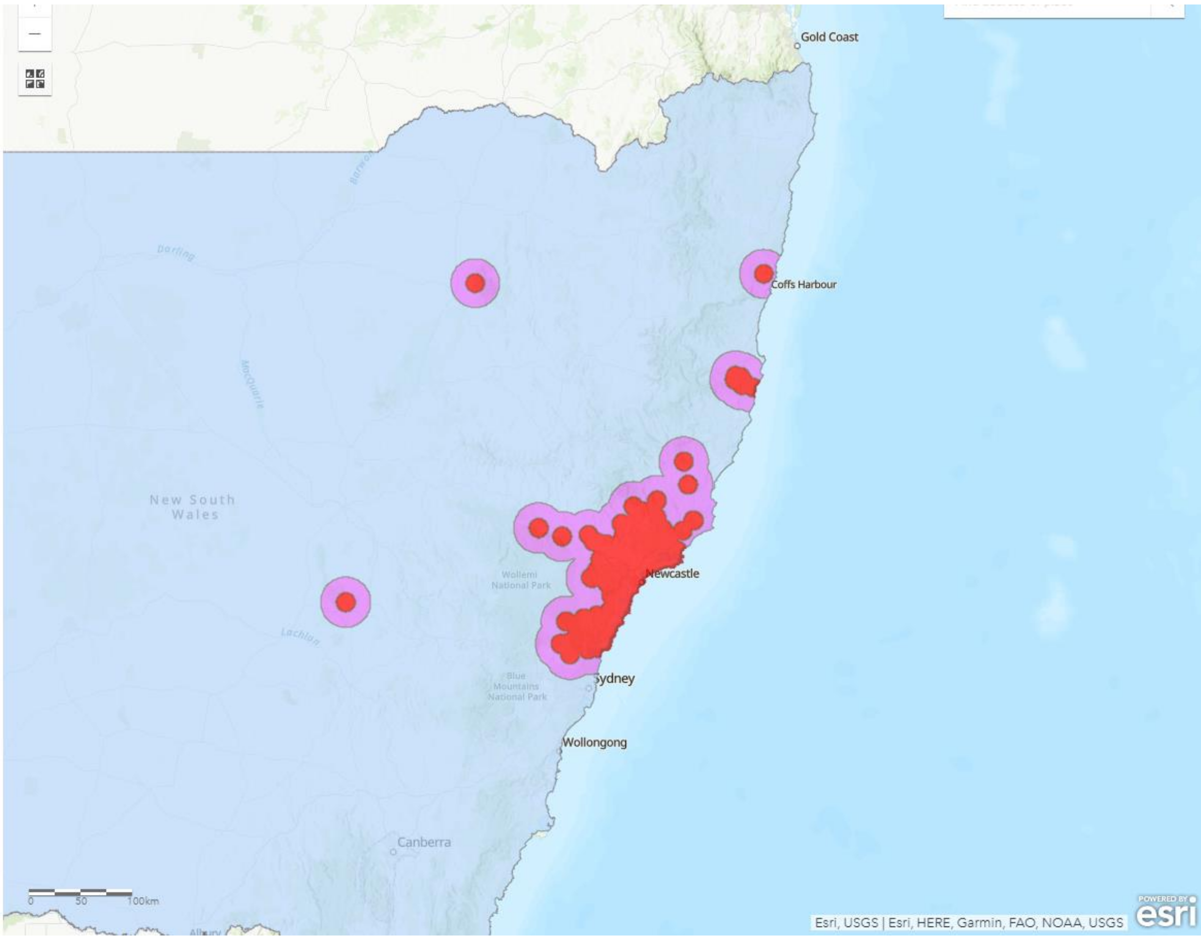
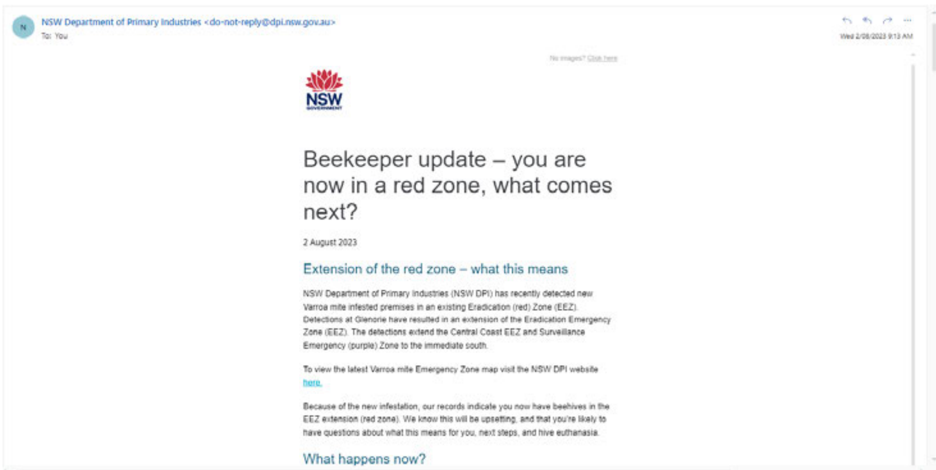


Figure 79: Varroa Mite spread as at 23 August 2023 (NSW Department of Primary Industries 2022).

Only beehives in the designated Eradication Zones were earmarked for destruction. Conversely, all beekeepers in Surveillance Zones (purple) were required to notify the DPI of the location of their hive or hives. Any beehives within the Surveillance Zones were unable to be moved (NSW Department of Primary Industries 2022).

Beehives in the General Emergency Zone (blue) however, were able to be moved with a DPI permit. Penalties of up to $2000 applied to anyone found moving beehives without a permit NSW Department of Primary Industries 2022).



NSW Department of Primary Industries <do-not-reply@dpi.nsw.gov.au>
To: You
Wed 2/08/2023 9:13 AM

NSW

Beekeeper update – you are now in a red zone, what comes next?

2 August 2023

Extension of the red zone – what this means

NSW Department of Primary Industries (NSW DPI) has recently detected new Varroa mite infested premises in an existing Eradication (red) Zone (EEZ). Detections at Glenorie have resulted in an extension of the Eradication Emergency Zone (EEZ). The detections extend the Central Coast EEZ and Surveillance Emergency (purple) Zone to the immediate south.

To view the latest Varroa mite Emergency Zone map visit the NSW DPI website here.

Because of the new infestation, our records indicate you now have beehives in the EEZ extension (red zone). We know this will be upsetting, and that you're likely to have questions about what this means for you, next steps, and hive euthanasia.

What happens now?

Figure 80: DPI email informing myself that I was now in a red zone and my bees are to be euthanised. (NSW Department of Primary Industries 2023, pers. comm., 2 August 2023).

3.10.1 Destruction of beehives

As a result of Varroa Mite spreading to North-west Sydney, the DPI confirmed that it was necessary to euthanise all beehives within the newly declared Eradication Zone (Figure 80). This included the beehives at the testing site, which we set to be euthanised on 21 August 2023.

All hives at the testing site where euthanised as planned on Monday 21 August 2023. This included the hives being used as part of the experiment, as well other hives that have been part of a successful honey production operation for the past 13 years.

Figure 81: Once euthanized, the bees were wrapped in plastic and taped, ready to be taken to a deep burial landfill.

Varroa Mite update (24 August 2023)

The National Varroa Mite response, led by NSW Department of Primary Industries, detected new infections at Euroley in the Riverina and Euston in the Sunraysia region. These infections were suspected to be the cause of transport movements from the Kempsey area before positive infections were detected (NSW Department of Primary Industries 2022).

Authorities were more concerned about these infections, as bees from the affected hives had been pollinating almonds and would have come into contact with thousands of other bees from other parts of NSW and Victoria.

Varroa Mite update (5 September 2023)

The DPI announced a number of new Eradication and Surveillance Zones across Sydney, as well as further infection sites in South-west NSW.

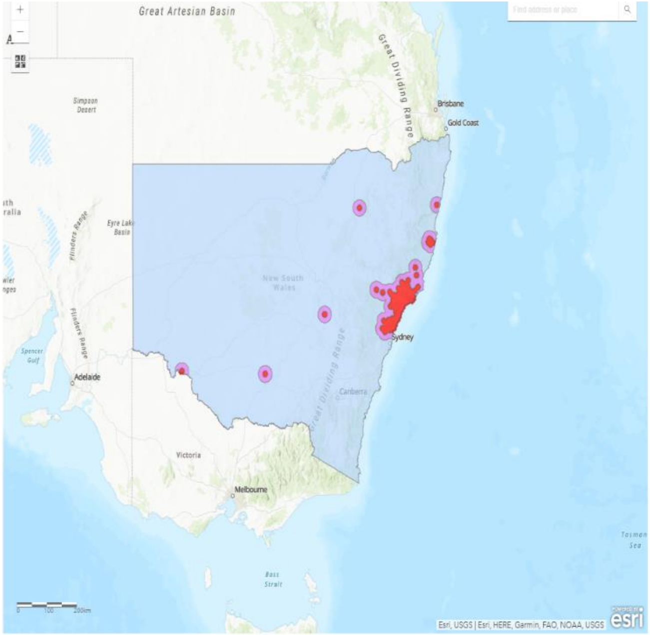


Figure 82: Map of Varroa Mite infection sites as at 24 August 2023. The NSW Department of Primary Industries detected new infections at Euroley in the Riverina and Euston in the Sunraysia region (NSW Department of Primary Industries 2022).

Varroa mite emergency zone map

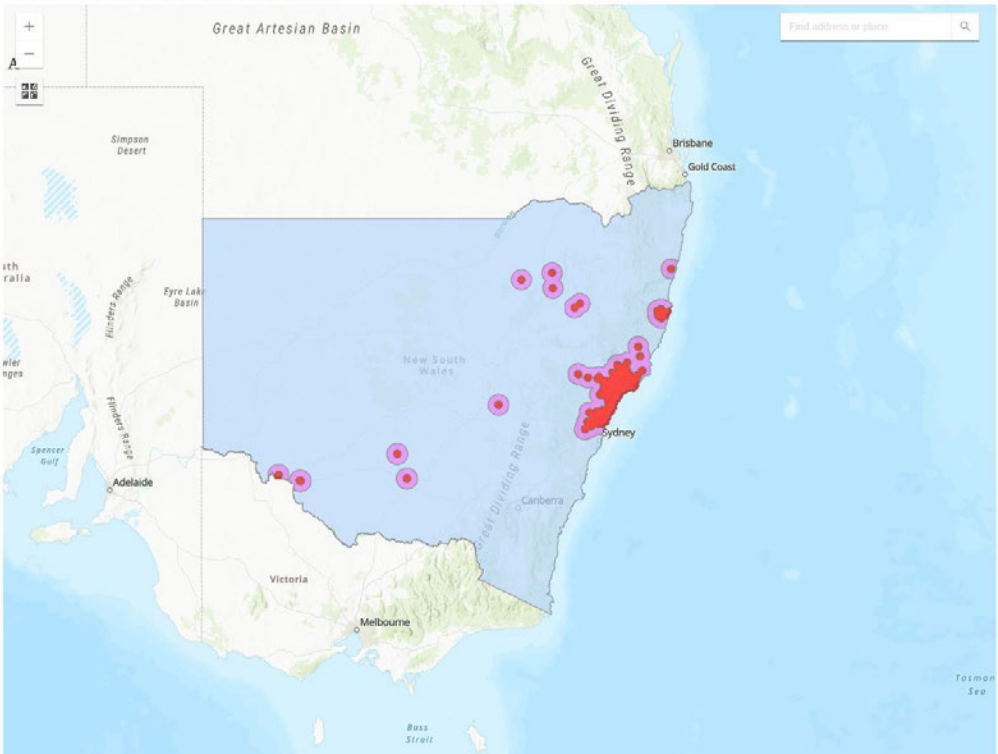


Figure 83: Map of Varroa Mite infection sites as at 5 September 2023. The NSW Department of Primary Industries detected further infections at Euroley in the Riverina and Euston in the Sunraysia region (NSW Department of Primary Industries 2022).

3.10.2 Eradication of Varroa Mite

The NSW DPI has been battling the spread of Varroa Mite since June 2022, when a sentinel hive at the port of Newcastle was found to be infected. Since the detection, the DPI has inspected and taken samples from more than 130,000 across NSW. As a result, more than 28,000 hives have been euthanised over approximately one million hectares of land (Middleton 2023).

Using funding from the Commonwealth Government, the DPE is working to eradicate the Varroa Mite entirely. The NSW Government has already spent more than $33 million to control Varroa Mite, including $13.7 million to reimburse the 2,500 commercial and recreational beekeepers affected (Stephens and Proust 2023).

Beekeepers have a significant role to play in DPI's control strategy, testing for Varroa Mite. Testing involves collecting a cup of bees (without the queen bee), pouring alcohol into the cup, closing the lid and shaking it. While the cup is settling, any Varroa Mites will drop off the bees and sink to the bottom. The results of these tests, which should be conducted at least every 16 weeks, need to be reported to the DPI (NSW Department of Primary Industries 2022).

Once an infected hive has been identified and euthanised, bait stations are setup within the Eradication Zone to kill any feral hives within the area. The bait stations contain a mixture of sugar syrup and fipronil which is akin to nectar in smell and taste, however fatal to beehives. Once in the hive, the bait kills the hive.

Chapter 4 Results and Analysis

4.1 Observations and limitations of data collection

Data was gathered between 14 July 2023 and 14 August 2023 from the outside temperature and pressure sensor, the internal temperature and humidity sensor, and the infrared sensors indicating the bee count.

General observations and notable limitations of the data collection are outlined below.

4.1.1 Bee counters

The bee counters did not work as intended. The results displayed on the Arduino app suggested thousands of bees were leaving during the night and none were returning via the incoming gates. This has led to the conclusion that the sensors had a false trigger. This resulted in a faulty count.

4.1.2 External temperature and pressure

External temperature and pressure readings were provided by the BMP180 Digital Pressure Sensor, which also served as an external temperature sensor, throughout the period of the experiment. As the BMP180 Digital Pressure Sensor was drilled onto the front of the hive and only slightly protruding, it is likely the readings were elevated and not a true reflection of the outside air temperature. Radiant heat from the hive or the insulated lid also could have contributed to the elevated temperature.

4.1.3 Temperature and humidity

There were two DHT11 sensors placed inside the hive. The sensors were placed off centre and to the left and right. This indicated where the bees were located within the hive at the time the data was collected. When a higher temperature on one side of the hive was recorded, signalling the presence of the brood nest, the other sensor produced readings consistent with the outside temperature.

If data was collected over the spring and summer months, it is expected that the temperature would have evened out across the hives and both sensors would have provided similar readings. This is because the queen bee lays more eggs to increase bee numbers and improve the hive's productivity when conditions are optimal.

The right-side sensor was Number 2 temperature and humidity sensor. Only data from the Number 2 sensor was used in the analysis of results as the internal location of the bees negated the need for the other sensor. Similarly, only data from the Humidity 2 variable was used.

The temperature and humidity values obtained from the DHT11 two-in-one sensor were in line with what was suggested by previous researchers in this field. The sensors recorded a consistent hive brood temperature between 30-33 degrees celsius.

4.1.4 Hive weight scales

The hive weight reading displayed on the Arduino cloud read was unusually high and not a true reflection of what the actual hive weight was at the time of the data collection. As a result, this data was omitted from the results analysis.

4.1.5 Reed switch and GPS

The reed switch and GPS locator were not installed into the hive as it was determined that neither would provide a measurable benefit for the purposes of this experiment.

Undoubtedly however, the reed switch and its subsequent data would benefit a remote operation, giving peace of mind to a beekeeper whose hives are susceptible to theft and or tampering. A simple code change would enable the reed switch to provide data through the Arduino.

The same considerations were applied to the installation of the GPS locator. In order for the GPS locator to function, a MKR GPS Shield would need to be procured. The code required for the GPS locator is available online in Arduino documentation (Arduino 2018).

4.2 Data processing and cleaning

The IoT cloud enables data from the sensors to be downloaded as Excel files; one of each of the individual variables written in the code.

Once the files have been downloaded, they need to be combined into a single Excel spreadsheet to facilitate the data cleaning process. This could be achieved using a script, however as it was a once-off task in this instance, it was practical to do it manually.

With the data in one combined Excel file, it can be programmed in Python (a well-known programming language) using Pandas library tools in Visual Studios (Pandas n.d.) (Figure 84). The library will then sort and arrange the data into a clean data set (Figure 85).

1. Data Processing & Cleaning

```
# Read in data from csv file and print out the first 5 rows
df = pd.read_csv('data\Hive_Data.csv').iloc[1:,]
df = df.reset_index(drop=True)
df.head(5)
```

[2] ✓ 0.0s

	Unnamed: 0	Humidity	Inside Temperature	Outside Temperature	Pressure
0	2023-07-14T06:07:15.205Z	75	19.200001	22.354519	1014.296265
1	2023-07-14T06:08:15.775Z	75	19.200001	22.445366	1014.288208
2	2023-07-14T06:09:15.613Z	75	19.200001	22.343016	1014.329285
3	2023-07-14T06:18:27.01Z	77	18.600000	22.369616	1014.323181
4	2023-07-14T06:19:27.492Z	77	18.600000	22.311186	1014.352356

```
# Rename the Date Column
df.rename(columns={'Unnamed: 0': 'Date_Time'}, inplace=True)
```

[3] ✓ 0.0s

```
# Look at the structure of the data
df.info()
```

[4] ✓ 0.0s

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 37157 entries, 0 to 37156
Data columns (total 5 columns):
 #   Column               Non-Null Count  Dtype  
---  ------               --------------  -----  
 0   Date_Time            37157 non-null  object 
 1   Humidity             37157 non-null  object 
 2   Inside Temperature   37157 non-null  float64
 3   Outside Temperature  37157 non-null  float64
 4   Pressure             37157 non-null  float64
dtypes: float64(3), object(2)
memory usage: 1.4+ MB
```

Figure 84: Data being uploaded from an excel spreadsheet into Visual Studio to be sorted and arranged into a clean data set.

```
# Drop the date column as it isn't required in the model
# Also convert the Humidity column to a float as it is a string at the moment
# df = df.drop(['Unnamed: 0'], axis=1)
df['Date_Time'] = pd.to_datetime(df['Date_Time'], format='mixed')
df['Humidity'] = df['Humidity'].apply(lambda x: np.float32(x))
```
✓ 0.1s

```
# Change the date time format to be more readable
df['Date_Time'] = df['Date_Time'].apply(lambda x: dt.datetime.strftime(x, '%Y-%m-%d %H:%M:%S'))
df['Date_Time'] = pd.to_datetime(df['Date_Time'])
```
✓ 0.2s

```
# Make the date time the index column
df.set_index('Date_Time', inplace=True)
```
✓ 0.0s

```
# Check everything looks normal
df.head(5)
```
✓ 0.0s

	Humidity	Inside Temperature	Outside Temperature	Pressure
Date_Time				
2023-07-14 06:07:15	75.0	19.200001	22.354519	1014.296265
2023-07-14 06:08:15	75.0	19.200001	22.445366	1014.288208
2023-07-14 06:09:15	75.0	19.200001	22.343016	1014.329285
2023-07-14 06:18:27	77.0	18.600000	22.369616	1014.323181
2023-07-14 06:19:27	77.0	18.600000	22.311186	1014.352356

Figure 85: Once the cleaning process has taken place, Visual Studio displays the data in a data set consistent with the parameters of the experiment.

To ensure consistency in the datasets, summary statistics from the data including percentile, mean and standard deviation of the numerical values, need to be calculated. To obtain these statistics, the Pandas [df.info()] function needs to be input into Visual Studio. This will provide the necessary data to ensure the data sets are equal to maintain integrity in the modelling (Figure 86).

2. Data Analysis

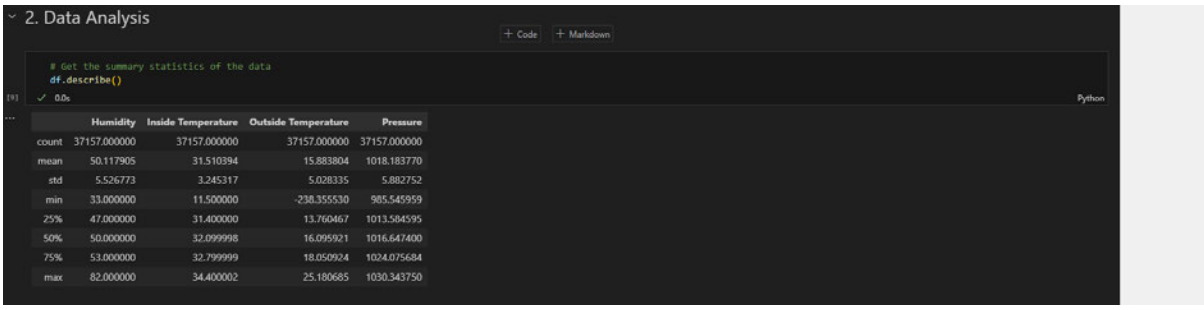
```
# Get the summary statistics of the data
df.describe()
```
✓ 0.0s Python

	Humidity	Inside Temperature	Outside Temperature	Pressure
count	37157.000000	37157.000000	37157.000000	37157.000000
mean	50.117905	31.510394	15.883804	1018.183770
std	5.526773	3.245317	5.028335	5.882752
min	33.000000	11.500000	-238.355530	985.545959
25%	47.000000	31.400000	13.760467	1013.584595
50%	50.000000	32.099998	16.095921	1016.647400
75%	53.000000	32.799999	18.050924	1024.075684
max	82.000000	34.400002	25.180685	1030.343750

Figure 86: Statistics displayed in the data analysis section of Visual Studio

Online tutorials are available to provide guidance on the process of conditioning data ready for modelling (Pandas Tutor n.d.). This includes the Pandas 'Describe' function, which helps to identify corrupt data and other potential inconsistencies.

Using this function, a minimum outside temperature reading of -238.355530 was found. It was determined that this was likely caused by a faulty sensor reading taken when new code was uploaded to the Arduino.



2. Data Analysis

```
# Get the summary statistics of the data
df.describe()
```

	Humidity	Inside Temperature	Outside Temperature	Pressure
count	37157.000000	37157.000000	37157.000000	37157.000000
mean	50.117905	31.510394	15.883804	1018.183770
std	5.526773	3.245317	5.028335	5.882752
min	33.000000	11.500000	-238.355530	985.545959
25%	47.000000	31.400000	13.760467	1013.584595
50%	50.000000	32.099998	16.095921	1016.647400
75%	53.000000	32.799999	18.050924	1024.075684
max	82.000000	34.400002	25.180685	1030.343750

Figure 87: Data analysis showing the data set counts and other statistical data which determines clean data sets.

In order to define the timeframe in which data was corrupted and its frequency, the data was plotted into a graph. As illustrated by Figure 88, the data corruption was a one-off event.

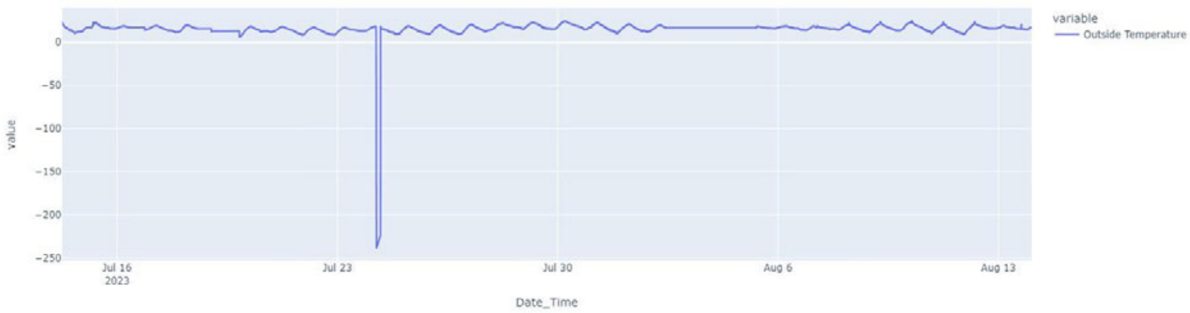


Figure 88: Errors in data shown in line graph.

Upon further investigation, it was determined that the data corruption occurred before 6:00 am and lasted for approximately three hours (Figure 89). This suggests it can be attributed to a sensor fault.

Figure 89: Faulty sensors corrupted the data time frame.

The corrupted data was removed from the experiment's dataset to ensure it did not distort modelling and future predictions.

4.3 Scatterplot matrix

A scatterplot matrix is a useful tool that visually represents the relationship between different variables (moonheadsing 2013). Scatterplot matrices can also be used to determine the correlation between the research parameters and how they aid in the early detection of hive pests and diseases. Even more effective however, is a pair plot function, which combines several scatterplot matrices into one display and then provides the distribution diagonally as a line graph.

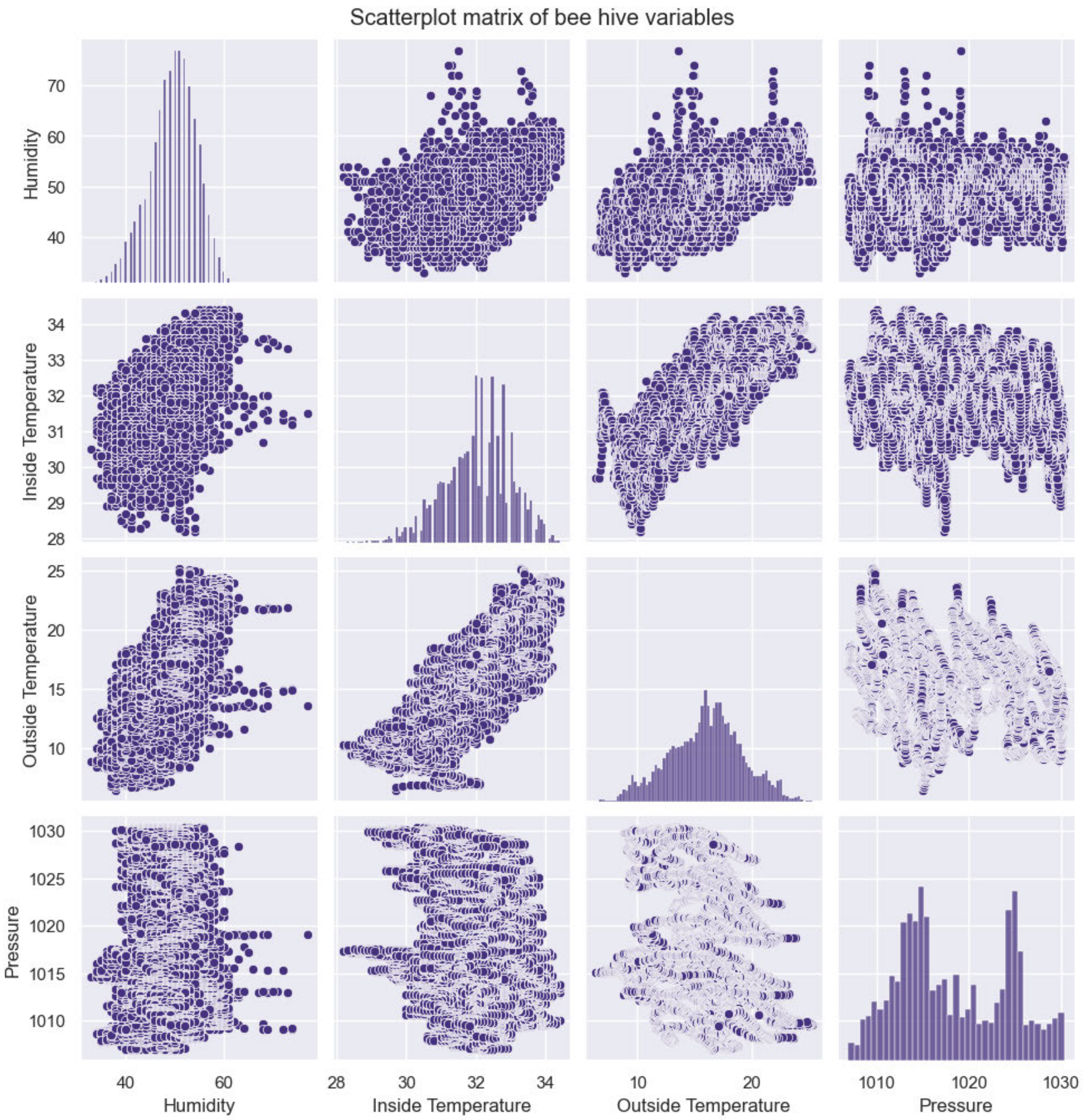


Figure 90: Scatterplot maxtrix of the variables measured within the hive.

The pair plot function, which was used to arrange data from this experiment, facilitates explore data analysis (EDA). The histogram on the diagonal illustrates the distribution of a single variable, while the scatter plots on the upper and lower triangles show the relationship between the variables (Figure 90 and 91).

The following code was added to Visual Studios to create the pair plot (Figure 90 and 91):

```
# Plot a pairplot to check all the bad data has been removed
fig = plt.figure(figsize=(16, 6))
sns.set_theme(style="darkgrid", palette="viridis")
sns.pairplot(df)
plt.suptitle("Scatterplot matrix of bee hive variables", y=1.01) plt.show()
```

4.3.1 Interpretation of Scatterplot matrices

The Scatterplot matrices show a correlation between the internal hive temperature and the external temperature. As indicated by Figure 91, the hive temperature did not move more than three or four degrees (either above or below) the 32-33 degree celsius range. These readings were slightly lower than expected, based on the experience of other researchers in the field who reported a consistent hive temperature of 35 degrees celsius. They also serve to disprove the hypothesis that the internal hive temperature will fluctuate between 32 and 35 degrees celsius during the winter period when the testing phase of the experiment will take place.

From the matrices, it is evident that the internal hive temperature drops relatively in line with the outside temperature (Figure 91).

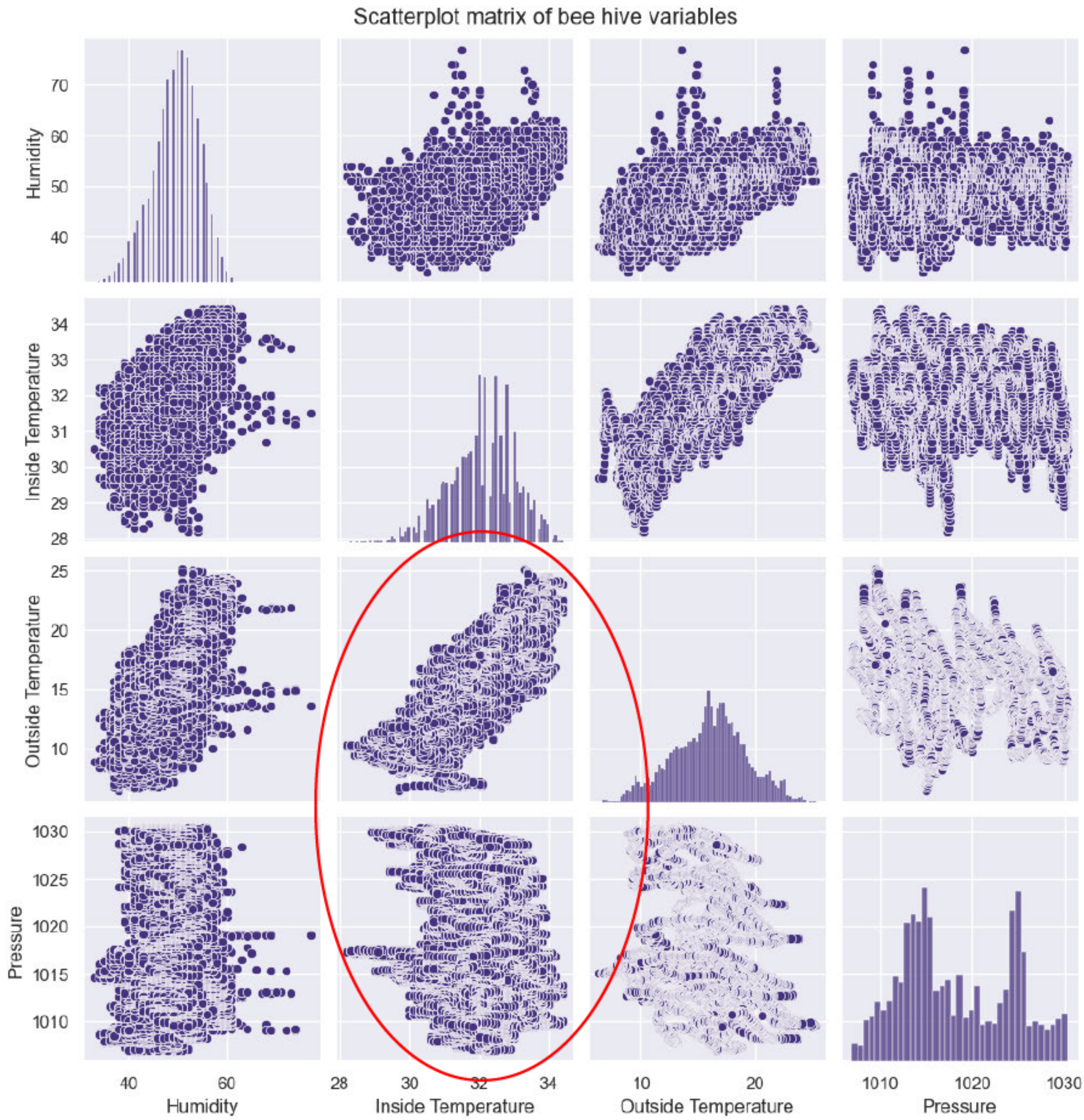


Figure 91: The Scatterplot matrix showing a strong correlation between the inside hive temperature and the outside temperature.

Data plotted in Figure 92 shows that as the temperature drops overnight, there is a relative decrease in the internal hive temperature.

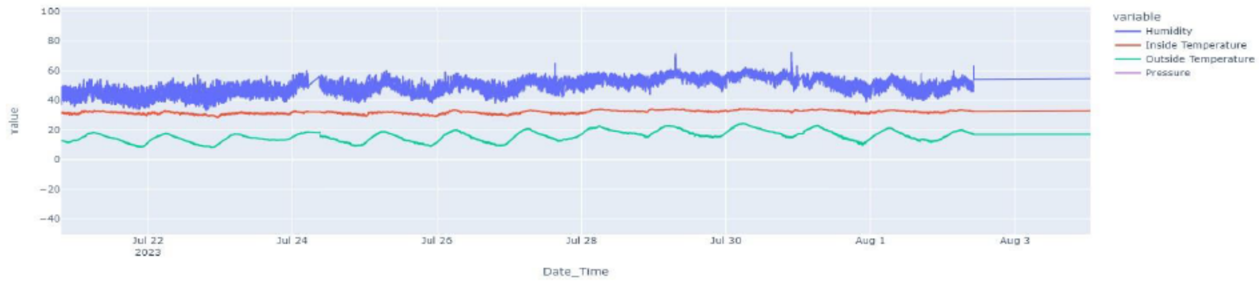


Figure 92: This graph depicts the internal temperature, humidity, external temperature and pressure trends from the hive.

Further in-dept analysis shows the internal temperature shifting in line with a decrease in the external temperature (Figure 93).

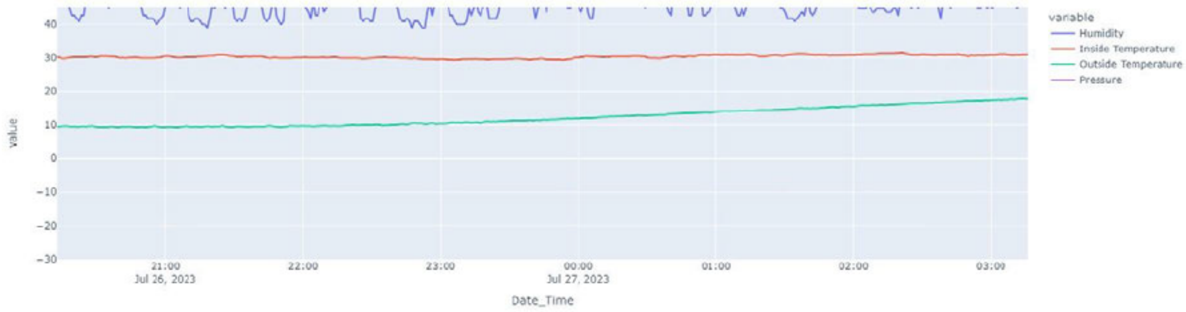


Figure 93: This graph depicts the internal temperature, humidity, external temperature and pressure trends from the hive, with a close up look at cold night time conditions.

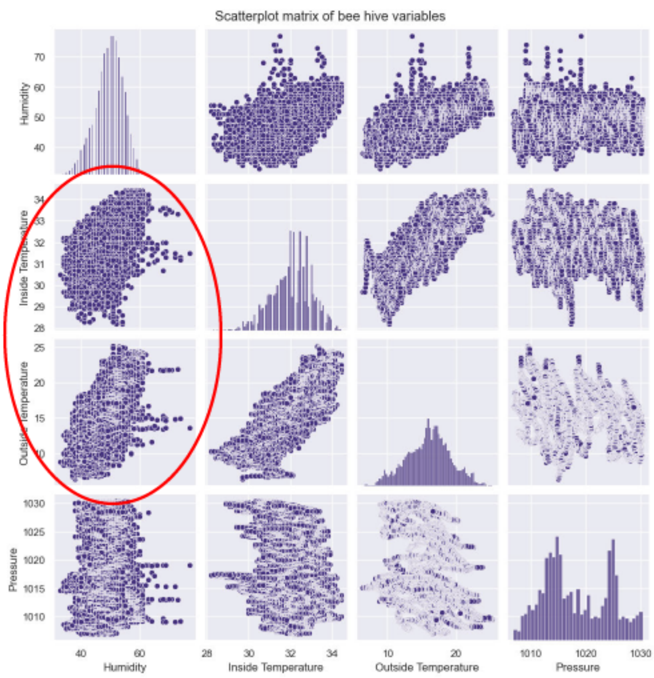


Figure 94: A Scatterplot matrix showing the strong correlation between the inside hive temperature and outside temperature.

The results show the correlation between the internal and external temperatures is mirrored between the outside temperature and humidity (Figure 94).

It is acknowledged that as humidity changes, so too does the outside temperature. Notwithstanding, bees should be able to stabilise humidity within the hive between 50 and 60 per cent, which is largely regarded as the optimum humidity level. However, this is inconsistent with the findings of this research.

The data obtained shows lower external temperature resulted in a lower internal humidity. Conversely, a higher external temperature resulted in a higher internal humidity. The humidity level was recorded over 60 per cent which is above the optimum range for a beehive.

A Scatterplot matrix of the external temperature and humidity (Figure 91), shows the humidity level largely between 40 and 55 per cent, which is less than the optimum range of 50 to 60 per cent.

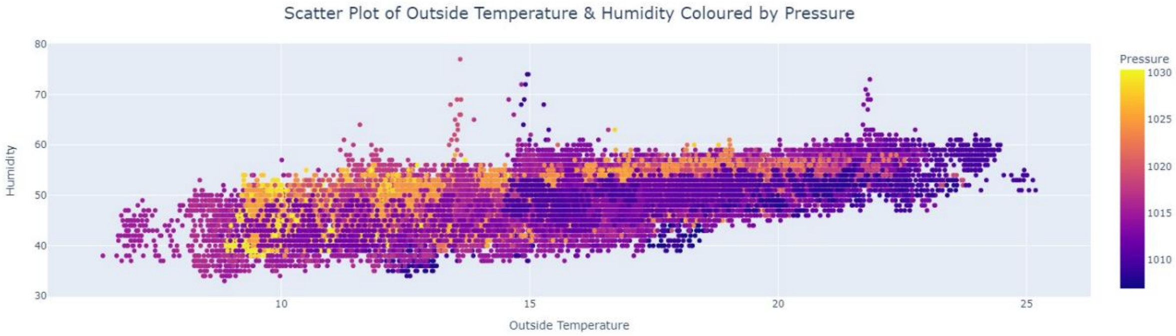


Figure 95: Scatterplot matrix of temperature and humidity; the colour change represents a change in pressure.

```
fig = px.scatter(data_frame=df, x='Outside Temperature', y='Humidity',
olor='Pressure')
# Center the title
fig.update_layout(
    title=dict(
        text='Scatter Plot of Outside Temperature & Humidity Coloured by
Pressure',
        font=dict(size=20),
        x=0.5,
        xref="paper"
    )
)
```

To verify the validity of the data interpretation, the subsequent inferences made and the correlation between variables, a simple variable correlation heatmap was run. This was done by adding the following code into Visual Studios:

```
# Lets look at the correlation between variables
correlations = df.corr()

plt.figure(figsize=(16, 6))
heatmap = sns.heatmap(correlations, vmin=-1, vmax=1, annot=True, cmap='mako')
heatmap.set_title('Variable Correlation Heatmap', fontdict={'fontsize':16},
pad=12)
```

```
heatmap.set
plt.show()
```

The closer the numbers are in a heatmap, the closer the correlation match.

The heatmap at Figure 96, confirms that there are strong correlations between some of the variables including internal and external temperature, with a correlation value of 0.8, and external temperature and humidity with a correlation value of 0.6.. low value numbers or the same number for different variables shows a close correlation. This is shown in Figure 96 with outside temperature and inside temperature.

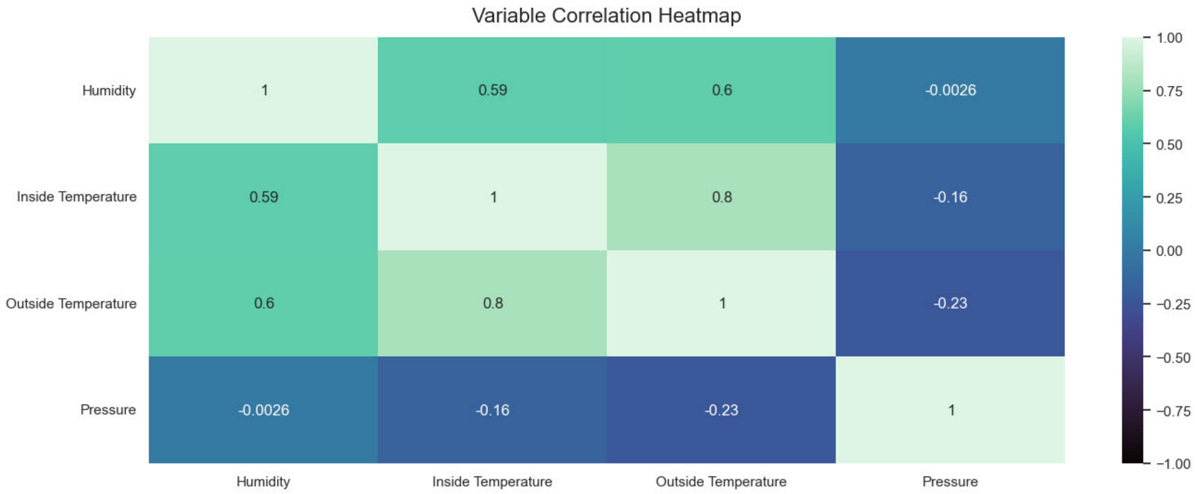


Figure 96: Correlation heat map showing the relationship between variables.

4.4 Regression models

Regression models are useful in determining the relationship between one or more variables (IMSL 2021). Regression analysis is a way of mathematically sorting out the important data variables by using dependent variables like inside hive temperature and independent variable like humidity, pressure and outside hive temperature (IMSL 2021).

In this research, the predictions obtained through regression modelling serve as a reference point to determine the validity of the internal hive temperature. This is particularly useful in Australia, where extreme cold and hot weather conditions are commonplace.

4.4.1 Linear regression

Linear regression, which is simplest form of regression, is used to study the mathematical relationship between variables. It provides an easy-to-interpret mathematical formula for predictions. Linear-regression models are proven to make reliable future predictions (IMSL 2021).

A simple example of linear regression in the context of this research, is finding the internal temperature of the hive, as the external temperature and other variables change. Being able to predict what is happening inside the beehive is critical in enabling a beekeeper to detect pest and disease early, implement control measures and avoid hive damage and the loss of bees.

In the linear regression model for this research project, the independent variables or predictors were:

- Pressure
- Outside Temperature
- Humidity

The dependent variable or criterion was the internal temperature.

The regression analysis allows the influence of one or more variable on another variable to be measured. It also enables one variable to be predicted using one or more different variables.

To use linear regression modelling, the following code was inserted into Visual Studios:

```
# Plot the actual vs predicted inside temperature
lr_fig = px.line(lr_preds_df,
            labels={
                        "Date_Time": "Date",
                        "value": "Temperature",
                    })

lr_fig.update_layout(
    title=dict(
        text='Line chart of actual and predicted inside temperature using Linear Regression',
        font=dict(size=20),
        x=0.5,
        xref="paper"
    )
)

lr_fig.show()
lr_fig.write_image('plots/Lr_Plot.png')
```

Linear regression modelling of the internal hive temperature shows a high level of accuracy between the actual (blue) and predicted (red) data. As illustrated in Figure 97, the lines are generally mirrored, with only a small variation in the peaks. This confirms that the linear regression model can be used to accurately predict hive temperatures.

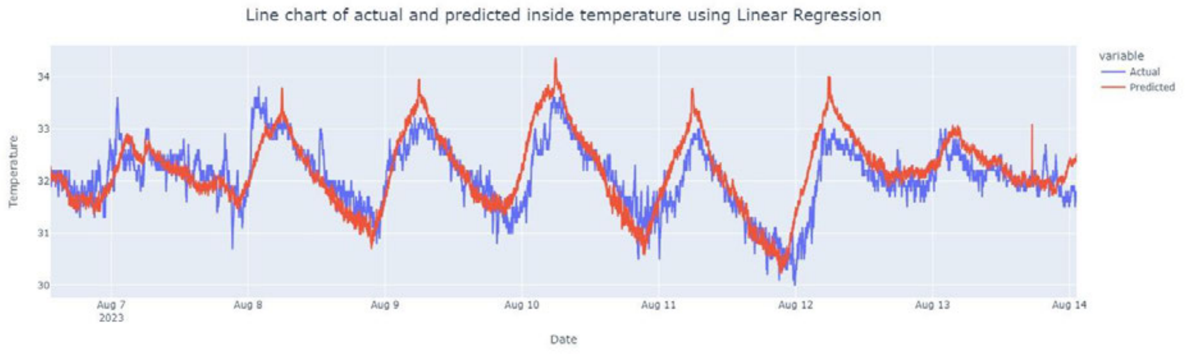


Figure 97: Linear regression modelling showing actual temperature and predicted temperature.

4.4.2 Random Forest Regressor

There are three main hyperparameters that need to be set for Random Forest algorithms; node size, the number of trees and the number of features sampled. The Random Forest Regressor uses a decision tree comprised of a data sample drawn from a training set to predict the class or value of the target variable by learning simple decision rules inferred from the training data (Aswathisasidharan 2021).

The training set is determined before the model is run. During this process, the amount of collected data that will be used for the training and the amount that will be used for the model, needs to be determined. It is recommended that one third of data should be used as test data. During modelling, all of the individual trees in the random forest analyse a subset of the data and return a class prediction.

To use the Random Forest Regressor, the following code was inserted into Visual Studios:

```
# Plot the actual vs predicted inside temperature
rf_fig = px.line(rf_preds_df,
            labels={
                        "Date_Time": "Date",
                        "value": "Temperature",
                    })

rf_fig.update_layout(
    title=dict(
        text='Line chart of actual and predicted inside temperature using Random Forrest',
        font=dict(size=20),
        x=0.5,
        xref="paper"
    )
)

rf_fig.show()
rf_fig.write_image('plots/Rf_Plot.png')

```

A graph of the Random Forest Regressor modelling for the internal hive temperature, shows some large variations between the actual temperature (blue) and the predicted temperature (red). The modelling poorly tracked most of the lower peaks of the actual temperature. While the modelling before 8 August 2023 shows some consistency with the actual temperature (Figure 98), discrepancies throughout the modelling are too high to consider it to be an accurate and reliable predicator of internal temperature throughout the entire period.

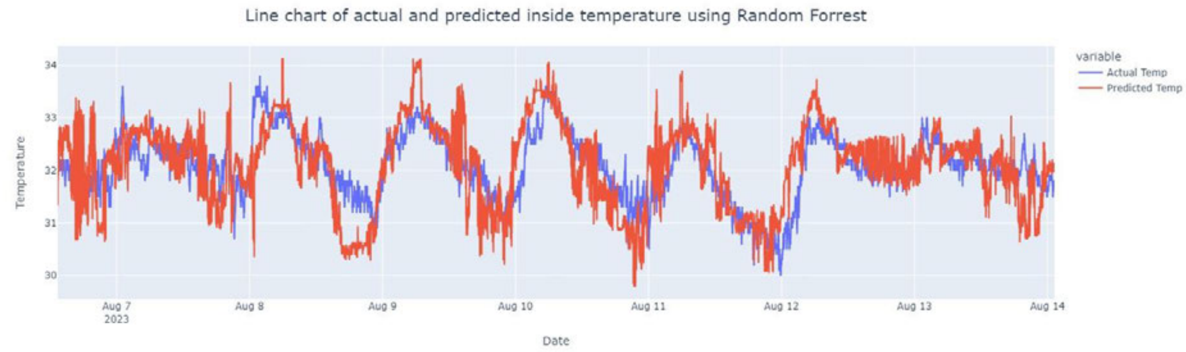


Figure 98: Random Forest Modelling showing actual temperature and predicted temperature.

Further detailed analysis of the Random Forest Regressor modelling, shows that while the predicted temperature was often close to the actual values internal temperature, there was a predicted temperature discrepancy at worst, of approximately one to 1.5 degrees (Figure 99).

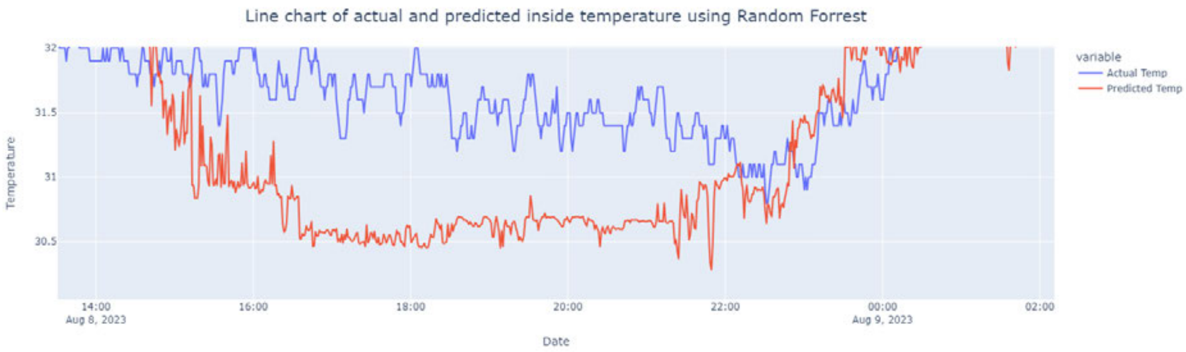


Figure 99: closeup look at random forest predicted model drifting

4.4.3 Support Vector Machine

Support Vector Machine (SVM) is another type of algorithm for classification and regression. SVMs are considered to be an efficient machine learning tool, because of their ability to manage high-dimensional data and nonlinear relationships (Aswathisasidharan 2021).

To use SVM modelling, the following code was inserted into Visual Studios:

```
# Plot the actual vs predicted inside temperature
svr_fig = px.line(svr_preds_df,
            labels={
                        "Date_Time": "Date",
                        "value": "Temperature",
                    })

svr_fig.update_layout(
    title=dict(
        text='Line chart of actual and predicted inside temperature using
Support Vector Machine',
        font=dict(size=20),
        x=0.5,
```

```
        xref="paper"
    )
)

svr_fig.show()
svr_fig.write_image('plots/SVM_Plot.png')
```

A graph of the SVM model for the internal hive temperature, shows only minor variations between the actual temperature (blue) and the predicted temperature (red). On that basis, the SVM modelling is considered to be highly accurate (Figure 100).

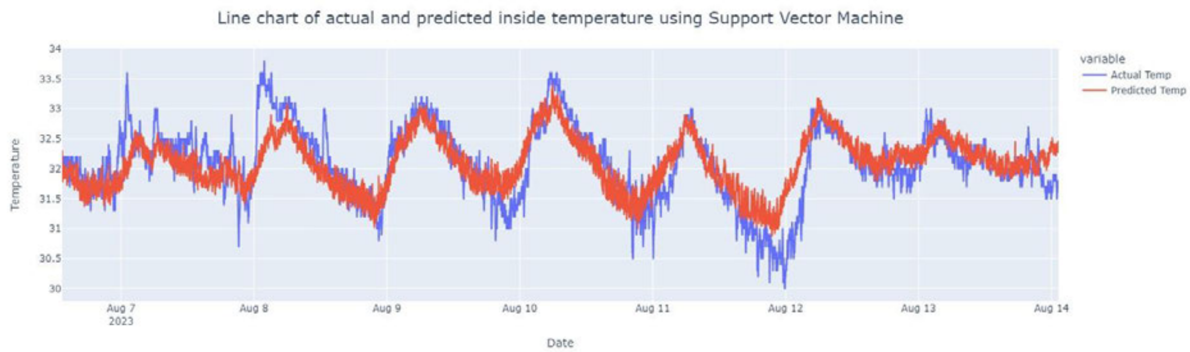


Figure 100: Support Vector Machine modelling showing minor variations between the actual temperature and predicted temperatures.

4.4.4 Results of modelling

The modelling results provided a visual representation of how well the models preformed but to get a true understanding of the best model that could get the closest match to the actual temperature from a prediction would have to be worked out using performance metrics. The performance metrics elevate the models to understand the benefits and disadvantages by using a number of mathematical calculations (Table 7).

	Linear Regression Model	**Random Forest Regressor**	**Support Vector Machine**
MSE	0.1811915568716637	0.3175325423856418	0.16267004289103665
RMSE	0.42566601564097606	0.563500259437067	0.40332374451677977
MAE	0.3268338655594555	0.44001661422047855	0.303890330206987
R2	0.5241494361221448	0.16608675397166583	0.5727911776233532

Table 7: Mathematical calculations of performance metrics.

Performance metrics

Table 6 provides the means squared error, the root means squared error, the mean absolute error and R-squared for all three regression models. The function of these values and the calculation methods used, are outlined below.

Mean Squared Error

The Mean Square Error (MSE) is calculated by taking the average, specifically the mean, of errors squared from the data.

$$\mathrm{MSE}(\mathrm{Y},\mathrm{Y}^{\wedge}) = \frac{1}{n_{samples}} \sum_{i=0}^{-1} \left(Y_i - Y^{\wedge}\right)^2$$

As it relates to a function, a higher MSE indicates that the data points are dispersed widely around its central moment. A MSE indicates that the data points are dispersed closely around its central moment. A smaller MSE is preferrable as it means the data is not skewed and has fewer errors (Padhma 2021).

Root Mean Squared Error

The Root Mean Squared Error (RMSE) provides an estimation of how well the model can predict the target value. By measuring the average difference between values predicted by a model and the actual values, the accuracy of the model can be determined. A perfect model would have a RMSE of 0. On that basis, a lower the RMSE, the better the model is (Padhma 2021).

To calculate RMSE, the following equation is used:

$$RMSE = \sqrt{\frac{\Sigma(yi - yp)^2}{n}}$$

In this equation, y_i is the actual value, $\hat{Y}_p$ is the predicted value and n is the number of observations.

The RMSE measures the average difference between a statistical model’s predicted values.

Mean Absolute Error

Mean Absolute Error (MAE) is the average absolute error between the actual and predicted values. It is a measurement of the average size of the mistakes in a collection of predictions, which helps provide an understanding of the model’s performance across the whole dataset. The closer the MAE is to 0, the more accurate the model is (Padhma 2021).

The MAE is calculated using the following equation, where y_i is the actual value, $\hat{Y}_p$ is the predicted value and n is the number of observations:

$$MAE = \frac{[(yi - yp]}{n}$$

R-squared

R-squared (R^2) indicates the percentage of the variance in the dependent variable that the independent variables explain collectively. The R^2 value measures the strength of the relationship between the model and the dependent variable on a convenient on a scale of 0 to 100 per cent. It evaluates the scatter of the data points around the fitted regression line. The larger the value of R^2, the better the regression model fits your observations (Padhma 2021). .

R^2 is calculated using the following equation:

$$R^2 = \frac{Variance\ explained\ by\ the\ model}{Total\ variance}$$

To obtain the performance metrics for regression modelling, the following code was added to Visual Studios:

```
# Function that prints out the performance metrics
def results(y_test, y_hat):
  return f'MSE: {mean_squared_error(y_test, y_hat)}, RMSE: 
{np.sqrt(mean_squared_error(y_test, y_hat))}, MAE: 
{mean_absolute_error(y_test, y_hat)}, R2: {r2_score(y_test, y_hat)}'

lr_results = results(y_test, y_hat_lr)
svr_results = results(y_test, y_hat_svr)
rf_results = results(y_test, y_hat_rf)
```

As indicated by Table 7, the SVM provides the most accurate determination of the relationship between one or more variable. The value of the SVM's Root Mean Squared and RMSE, which would be zero under perfect conditions, are the smallest. SVM's R^2 value is also the highest out of the three models. This indicates the SVM model will be able to produce the most accurate temperature predictions.

4.5 Hive Temperature Predictor

A hive temperature predictor application was built using Streamlit, which is a purpose-built data sharing application (Streamlit.io. n.d.). The aim of the hive temperature predictor was to allow a beekeeper to look at the current status of a beehive via the Arduino application. If irregularities were identified in the internal hive temperature from the Arduino application, the Hive Temperature Predictor could be used to determine the actual internal hive temperature through the other parameters displayed on the Arduino app.

The hive temperature predictor uses a machine learning model to predict the internal hive temperature, by determining the relationship with other variables, including outside temperature, humidity and pressure. Data from a live beehive is input directly into the application.

The application can support Linear Regression, Random Forrest Regressor or the SVM. It is also compatible with 'I Can't Decide', which uses the average from the three aforementioned regression models.

Once the application has been set up, selecting the 'Get Prediction' button will run the regression model and provide the predicted internal hive temperature (Figure 101). This provides beekeepers with a user-friendly platform to remotely monitor the health of their hives and aid in the early detection of pests and diseases.

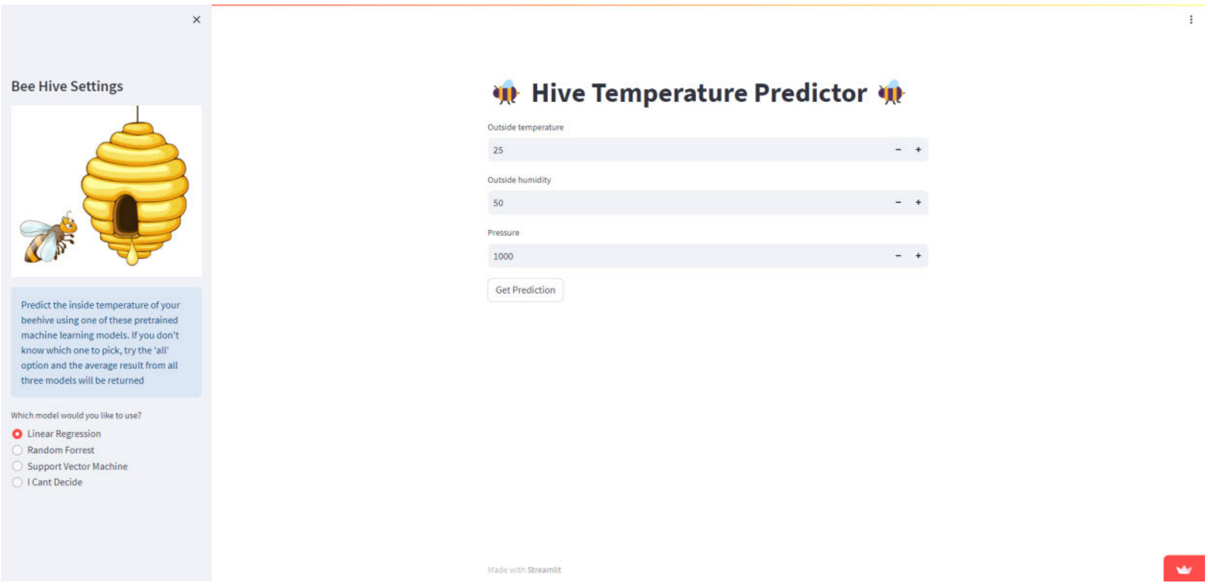


Figure 101: The homepage of the hive temperature predictor application.

The hive temperature predictor application can be accessed at https://hutchingshiveapp.streamlit.app/.

Chapter 5 Conclusions and Further Work

5.1 Reflecting on the research questions

As indicated at the beginning of Chapter 3, this research sought to answer the following research questions:

Can critical hive attributes be measured remotely?

The experiment confirmed that critical hive attributes can be measured remotely. This was successfully achieved using the Arduino MRK NB 1500 to measure internal temperature, humidity, pressure and external temperature. The Arduino MRK NB 1500, along with the Arduino Cloud, supported the project sensors placed inside and outside the hive.

The Arduino MRK NB 1500 read the sensor data and exported the values by transmitting the data over the Telstra Cat M1 network. The wide coverage made it a viable option for the experiment.

The Arduino Cloud stored and displayed the critical data from the hive. The cloud retained the data and made it easily accessible. The Cloud app also made remote monitoring via a smart phone feasible, providing for real time updates.

It is acknowledged that while some of the parameters included in this experiment may have extended beyond what most researchers in this field would consider to be critical hive attributes, they were important in determining the remote monitoring capacity of the functional design. It should also be noted that hive weight and bee count were also recognised as critical hive attributes, however both parameters were excluded from this experiment due to technical issues.

Does the data obtained accurately reflect conditions inside the beehive?

The research suggests that data obtained through the remote monitoring system can accurately reflect actual conditions inside a beehive. The bench testing of sensors in June 2023 helped to verify this notion. During the bench test, the temperature and humidity readings recorded from the sensors were the same as the readings obtained independently of the remote monitoring system. These bench test results provided confidence in the ability of the sensors to take accurate measurements when deployed in the field.

The accuracy of the measurements was also confirmed when the experiment was disrupted due to the spread of Varroa Mite. A physical site inspection was conducted at the conclusion of data collection period. The conditions within the hive at the time of the inspection, were consistent with the data recorded by the remote monitoring system.

The findings of this research were also in line with existing research on the internal hive temperatures which suggested the brood chamber temperature would fluctuate between 30 and 33 degrees celsius. The same temperatures were recorded by one of this experiment's internal temperature sensors, indicating that it was amongst the brood at the time the data was recorded.

Can inferences be made from the data to accurately detect pest and diseases?

Early pest and disease indicators strongly relate to the measurable characteristics of the brood chamber. The microclimate that the bees create inside the brood chamber is key to the survival of the hive. Any fluctuation in temperature above or below the optimum microclimate, can signify the death of the brood. It can also indicate the presence of pest or disease.

This research confirmed that the single most important indicators of declining health and the incidence of pest and diseases within a hive, are internal temperature and humidity. These are measured through the temperature and humidity sensors within the brood box.

Major fluctuations in temperature are signs of pest and diseases. In such situations, bee numbers will either quickly reduce, or the bees will relocate within the hive, away from the diseased or pest-infected frame. For this reason, it was critical to have multiple internal temperature and humidity sensors within the hive for this experiment. The number and placement of these sensors provided critical insights about the movement of the bees within the hive using their heat signature. This information enabled definitive inferences to be made about the impact of pests and diseases on a hive and how the behaviour patterns of bees change as a result.

The weight sensors would have provided similar valuable insights about the condition of a hive. However due to technical constraints, accurate data on the weight of the hive was unable to be obtained. As hives increase in weight during the spring and summer seasons, any sharp drops in overall weight during that same period, would indicate that the hive has become infested with a small hive beetle grub which feeds on the hive's honey stores. Such a rapid decline in the hive's weight would therefore provide an immediate and definite indication of the presence of the small hive beetle grub.

The bee counter could have also provided helpful insights into the ability of the remote monitoring system to accurately detect pests and diseases. Unfortunately, due to technical issues, the bee counters were unable to be properly activated. Theoretically however, these sensors would be able to detect a reduction in foraging activity during optimal weather conditions. Such circumstances would indicate that the bees and or hive have succumbed to disease like American foulbrood or DWV, and are underperforming as a result.

Can machine learning predict patterns in hive conditions to reduce the incidence of pest and disease?

There are promising signs to suggest that machine learning can help reduce the incidence of pests and diseases by predicting patterns in hive conditions. However, in order to provide a definitive answer to this question, a significantly longer monitoring period is required to gather data and undertake further modelling.

To facilitate accurate machine learning predictions, the extended monitoring would need to provide crucial data on the characteristics of hives infected with different pests and diseases, and during different stages of infection. It would also need to provide data on the seasonal variations in the conditions of a healthy hive.

Initial modelling undertaken as part of this research, suggests that using this additional data, machine learning could predict the onset of pests and diseases by learning from the relationship between critical hive attributes. Regression modelling would be an important part of this process. The effectiveness of machine learning in the early detection and subsequent reduction of pest and disease in beehives, would also be dependent on how often the Arduino application is monitored.

The Hive Temperature Predictor application was designed to be a point of reference for the real-time data presented on the Arduino application. Machine learning has an important part to play with these applications, by helping the user to identify discrepancies in what the data says and what the data should say, based on the regression modelling.

In Australia, rapid climatic changes regularly produce conditions which are conducive to pests and diseases. In the case of the small hive beetle grub, the Arduino application would show a decline in the overall hive temperature. This would occur when the bees move out of the brood chamber as it is destroyed by the grub and try to raise brood elsewhere in the hive. During this process, the sensors would detect a decline in the temperature of the original brood.

It should be noted that the original concept plan for this research involved a webhook to send data to the hive prediction tool. The actual and the predicted temperatures were to be plotted together and if the variation between the two went outside a pre-determined range, an alarm would be raised via a text message or email. This concept could be applied to other parameters of research to aid in the early detection of pests and diseases.

5.2 Further Work

There is still much work to be done to refine the remote monitoring system for practical application across Australia. Further work is also needed to investigate how the design can be enhanced to support the accurate detection of pests and diseases and to further integrate machine learning to facilitate early detection.

Acknowledging the spread of Varroa Mite as a significant limiting factor of this research, the primary focus of further work should be on additional data collection. Consideration should also be given to expanding the number of hives being monitored to obtain detailed and accurate data about the seasonal variations in the conditions of a healthy hive. This data could then be referenced against relevant data on characteristics of hives infected with different pests and diseases and during different stages of infection, noting that the latter could only be obtained by letting nature take its course. With the prevalence of some pests and diseases including Small hive beetle and American foulbrood however, an opportunity to collect such data would be inevitable.

Once the data has been obtained, further analysis can be undertaken to determine the relationships between all the set parameters and identify any precursor conditions to the better-known pests and diseases which would facilitate remote early detection.

This research would also benefit from further work to integrate the scales and bee counting mechanism into the existing working code. Additionally, the design of the bee counting mechanism could be revised. Instead of using bee escapes, a camera could be added to the front of the hive to detect the bees travelling over a photo plate. This would allow their direction of travel to be determined using machine learning.

Using the same photo technology, the detection of Varroa Mite could be investigated by differentiating the colours between the bees and the mite itself. The original concept plan involving a webhook could be used to raise an alarm via text message or email upon detection of the Varroa Mite. This has the potential to help slow the spread of the Varroa Mite and other pests and diseases.

Finally, it is acknowledged that as new technologies emerge, the design specification will need to be revised to ensure the system operates productively and efficiently.

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Appendix A

ENG4111/4112 Research Project

Project Specification

For: Ian Hutchings

Title: Low Powered Remote Monitoring for Smart Beehives

Major: electrical & electronic

Supervisors: Catherine Hills

Enrollment: ENG4111 – EXT S1, 2023

ENG4112 – EXT S2, 2023

Project Aim: The project aim is to setup remote monitoring on beehives to investigate hive health some of the main parameters such as hive temperature, outside temperature, humidity and hive weight assist in early detection on poor health. Once data has been gathered analyse and research the use of AI to investigate hive health and correlations between the data sets and look for early detection of Colony Collapse Disorder (CCD) or worse, Varroa Mite.

Programme: Version 1.1, 22 May 2023

Example below:

- Conduct initial background research hive health and what keeps a beehive alive.
- Conduct initial background research on pests and disease that affect bees, and what are the signs or effects of contaminated hives and heathy hives.
- Conduct initial background research into algorithms for use of artificial intelligence.
- Establish import parameters to monitor such as temperature, humidity and hive weight.
- Research and establish technical requirements for remote hive monitoring.
- Design a hive monitoring system and build functional code to match the hardware chosen
- Acquire hardware, build and bench test a prototype.
- Install prototype hardware into field with bees (pending ethics approval).
- Monitor data and inspect field hardware to verify correct data samples
- Collated data and conduct initial background research into algorithms for use of AI
- Develop a scale to measure how critical data sets are compared with bee health

If time and resource permit:

12. Evaluate experimental data.
13. Investigate counting the bees leaving the hive and then re-entering the hive as a measure of pollination rate.

Appendix B

Project Resources

A number of resources are required for this research project. These include:

- Micro controller
- SIM card
- Water proof housing for micro controller
- Wiring
- Sensors
- Batteries
- Solar panels
- Bees
- Beehive
- Computer
- Cloud storage
- 2 Computer monitors
- Software to program the micro controller.

Appendix C

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland **Offline Version**

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Low Powered Remote Monitoring for Smart Beehives	Assessment Date:	23/05/2023
Workplace (Division/Faculty/Section):	Box Hill, Sydney - desktop work and testing Dural, Sydney - location of bee hives	Review Date:(5 Years Max)	31/12/2024
Context			
Description:			
What is the task/event/purchase/project/procedure?	1. Conduct initial background research hive health and what keeps a beehive alive. 2. Conduct initial background research on pests and disease that affect bees, and what are the signs or effects of contaminated hives and heathy hives. 3. Conduct initial background research into algorithms for use of artificial intelligence. 4. Establish import parameters to monitor such as temperature, humidity and hive weight. 5. Research and establish technical requirements for remote hive monitoring. 6. Design a hive monitoring system and build functional code to match the hardware chosen 7. Acquire hardware, build and bench test a prototype. 8. Install prototype hardware into field with bees (pending ethics approval).		

	9. Monitor data and inspect field hardware to verify correct data samples 10. Collated data and conduct initial background research into algorithms for use of AI 11. Develop a scale to measure how critical data sets are compared with bee health If time and resource permit: 12. Evaluate experimental data. 13. Investigate counting the bees leaving the hive and then re-entering the hive as a measure of pollination rate. Purchases 1. micro controller 2. sim card and plan 3. sensor components 4. hive components 5. battery What is the course code? ENG4111, ENG4112

Why is it being conducted?	Research Project		
Where is it being conducted?	Box Hill, Sydney - desktop work and testing Grose Vale, Sydney - location of bee hives		
Course code (if applicable)	ENG4111 ,ENG4112	Chemical name (if applicable)	

What other nominal conditions?	
Personnel involved	I will be conducting the research project with no aid onsite
Equipment	IoT and beekeeping equipment
Environment	Indoors and outdoors activites
Other	N/A
Briefly explain the procedure/process	The project aim is to setup remote monitoring on beehives to investigate hive health some of the main parameters such as hive temperature, outside temperature, humidity and hive weight assist in early detection on poor health.

	Once data has been gathered analyse and research the use of AI to investigate hive health and correlations between the data sets and look for early detection of colony collapse disorder (CCD) or worse Varro mite.
Assessment Team - who is conducting the assessment?	
Assessor(s)	Catherine Hills
Others consulted:	N/A

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide
E=Extreme Risk – Task ***MUST NOT*** proceed
H=High Risk – Special Procedures Required (See USQSafe)
M=Moderate Risk – Risk Management Plan/Work Method Statement Required
L=Low Risk – Use Routine Procedures

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35º C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Working with Bees	Sting - non anaphylaxis	Insignificant	Remove sting apply first aid if required	Likely	Moderate	Yes or No	stop and call 000 for help if signs of anaphylaxis.	Insignificant	Likely	Moderate	Yes or No
Working with Bees	Sting - anaphylaxis do not work with bee if you are a known anaphylaxis	Major	Remove sting apply first aid - follow anaphylaxis action plan below - call 000 or 162 if unable to speak - get as far as possible away from hives carmly	Likely	Extreme	Yes or No	call 000	Catastrophic	Likely	Extreme	Yes or No
Working with Bees	Snakes	Moderate	-Keep a look out -Keep bee site grass short and tidy. -Snake banage in first aid kit -Kill bees if varroa mite expands	Possible	Moderate	Yes or No	If snake is seen stop work and move away. if biten by snake stop work move away from snake and bee. call for help (000) and apply snale banage. call for help from property owns.	Moderate	Possible	Low	Yes or No
Slips, Trips and Fall on bee site	Bee site has unevan rocky ground - sprains- falls - trips	Minor	Keep site tidy and clean.	Unlikely	Moderate	Yes or No	Wear work boots with strong ankle support. watch where you are walking.	Insignificant	Rare	Low	Yes or No
Working in high and low temperatures	Heat stress/ stroke leading to exhaustion	Moderate	keep up with fluids intake of water. stop and break use car A/C if required	Possible	Moderate	Yes or No	use car A/C during breaks and when finished work	Insignificant	Rare	Low	Yes or No
fire	Bush fire caused from bee smoker	Moderate	-don't use on total fire ban days	Possible	Moderate	Yes or No	have water drum ready to put out fire use small in car fire extinguisher	Insignificant	Unlikely	Low	Yes or No

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35º C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
			-light smoker on back of ute tray in controlled setting. - Have water insite for fire fighting - use water to put smoker out once work is finished								
Bush Fire	injury or death	Catastrophic	Use Fires near me App - known the conditions and leave site if bush fire spotted - don't go to site if fire is seen Bush Fire is seen on Fires Near Me App	Unlikely	Moderate	Yes or No	known the conditions	Insignificant	Rare	Low	Yes or No
Driving	injury or death	Major	-Hold a valid licence - Don't drink and drive - Don't drive if tired - Don't speed -leave plenty of time	Possible	High	Yes or No	driver training there are not controls for others on the road	Insignificant	Rare	Moderate	Yes or No
Power Tools	injuery	Moderate	Use eye and hand protection. competent in using required tools	Possible	Moderate	Yes or No	further training or pay someone else to do required work that has the correct skill	Insignificant	Unlikely	Low	Yes or No

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35º C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Working at desk	strain injuery	Minor	breaks stand working stretch	Possible	Low	Yes or No	breaks stand working stretch	Insignificant	Rare	Low	Yes or No
Psychologi cally Safe	stress breakdown	Moderate		Possible	High	Yes or No	split time between project and personal time	Insignificant	Unlikely	Moderate	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
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			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.

Step 6 - Approval			
Drafter's name:		Draft date:	Click here to enter a date.
Drafter's comments:			
Approver's name:		Approver's title/position:	
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			

Approver's signature:		Approval date:	Click here to enter a date.

ascia
www.allergy.org.au

ACTION PLAN FOR Anaphylaxis

For use with Anapen® adrenaline (epinephrine) autoinjectors

Name:

Date of birth:

Confirmed allergens:

Family/emergency contact name(s):

1.

Mobile Ph:

2.

Mobile Ph:

Plan prepared by doctor or nurse practitioner (np):

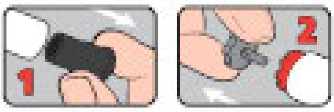
The treating doctor or np hereby authorises medications specified on this plan to be given according to the plan, as consented by the patient or parent/guardian.

Whilst this plan does not expire, review is recommended by DD/MM/YY

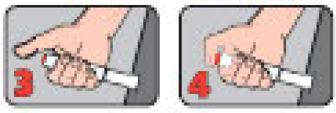
Signed: SIGN HERE

Date:

How to give Anapen®



1. PULL OFF BLACK NEEDLE SHIELD
2. PULL OFF GREY SAFETY CAP from red button



3. PLACE NEEDLE END FIRMLY against outer mid-thigh at 90° angle (with or without clothing)
4. PRESS RED BUTTON so it clicks and hold for 3 seconds. REMOVE Anapen®

Anapen® is prescribed as follows:

- Anapen® 150 Junior for children 7.5-20kg
- Anapen® 300 for children over 20kg and adults
- Anapen® 500 for children and adults over 50kg

SIGNS OF MILD TO MODERATE ALLERGIC REACTION

- Swelling of lips, face, eyes
- Hives or welts
- Tingling mouth
- Abdominal pain, vomiting - **these are signs of anaphylaxis for insect allergy**

ACTION FOR MILD TO MODERATE ALLERGIC REACTION

- For insect allergy - flick out sting if visible
- For tick allergy ☐ seek medical help or ☐ freeze tick and let it drop off
- Stay with person, call for help and locate adrenaline autoinjector
- Give antihistamine (if prescribed)
- Phone family/emergency contact

Mild to moderate allergic reactions (such as hives or swelling) may not always occur before anaphylaxis

WATCH FOR ANY ONE OF THE FOLLOWING SIGNS OF ANAPHYLAXIS (SEVERE ALLERGIC REACTION)

- **Difficult or noisy breathing**
- **Swelling of tongue**
- **Swelling or tightness in throat**
- **Wheeze or persistent cough**
- **Difficulty talking or hoarse voice**
- **Persistent dizziness or collapse**
- **Pale and floppy (young children)**

ACTION FOR ANAPHYLAXIS

1 LAY PERSON FLAT - do NOT allow them to stand or walk

- **If unconscious or pregnant, place in recovery position - on left side if pregnant, as shown below**
- **If breathing is difficult allow them to sit with legs outstretched**
- **Hold young children flat, not upright**

2 GIVE ADRENALINE AUTOINJECTOR

3 Phone ambulance - 000 (AU) or 111 (NZ)

4 Phone family/emergency contact

5 Further adrenaline may be given if no response after 5 minutes

6 Transfer person to hospital for at least 4 hours of observation

IF IN DOUBT GIVE ADRENALINE AUTOINJECTOR

Commence CPR at any time if person is unresponsive and not breathing normally

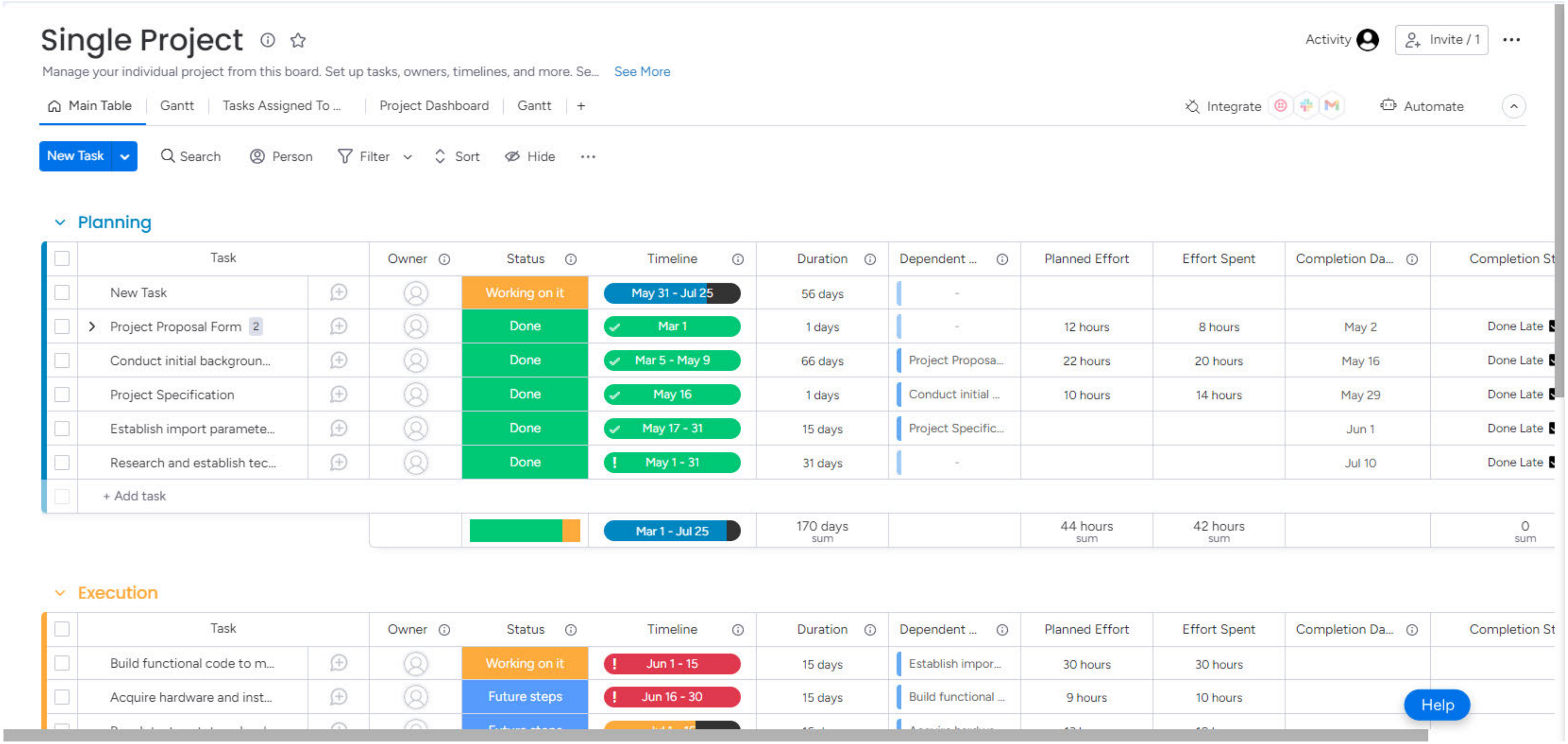
ALWAYS GIVE ADRENALINE AUTOINJECTOR FIRST, and then asthma reliever puffer if someone with known asthma and allergy to food, insects or medication has SUDDEN BREATHING DIFFICULTY (including wheeze, persistent cough or hoarse voice) even if there are no skin symptoms

Asthma reliever medication prescribed: ☐ Y ☐ N

Note: If adrenaline is accidentally injected (e.g. into a thumb) phone your local poisons information centre. Continue to follow this action plan for the person with the allergic reaction.

Appendix D

Project Planner



Single Project

Manage your individual project from this board. Set up tasks, owners, timelines, and more. Se... See More

Main Table | Gantt | Tasks Assigned To ... | Project Dashboard | Gantt | +

Integrate | Automate

New Task | Search | Person | Filter | Sort | Hide

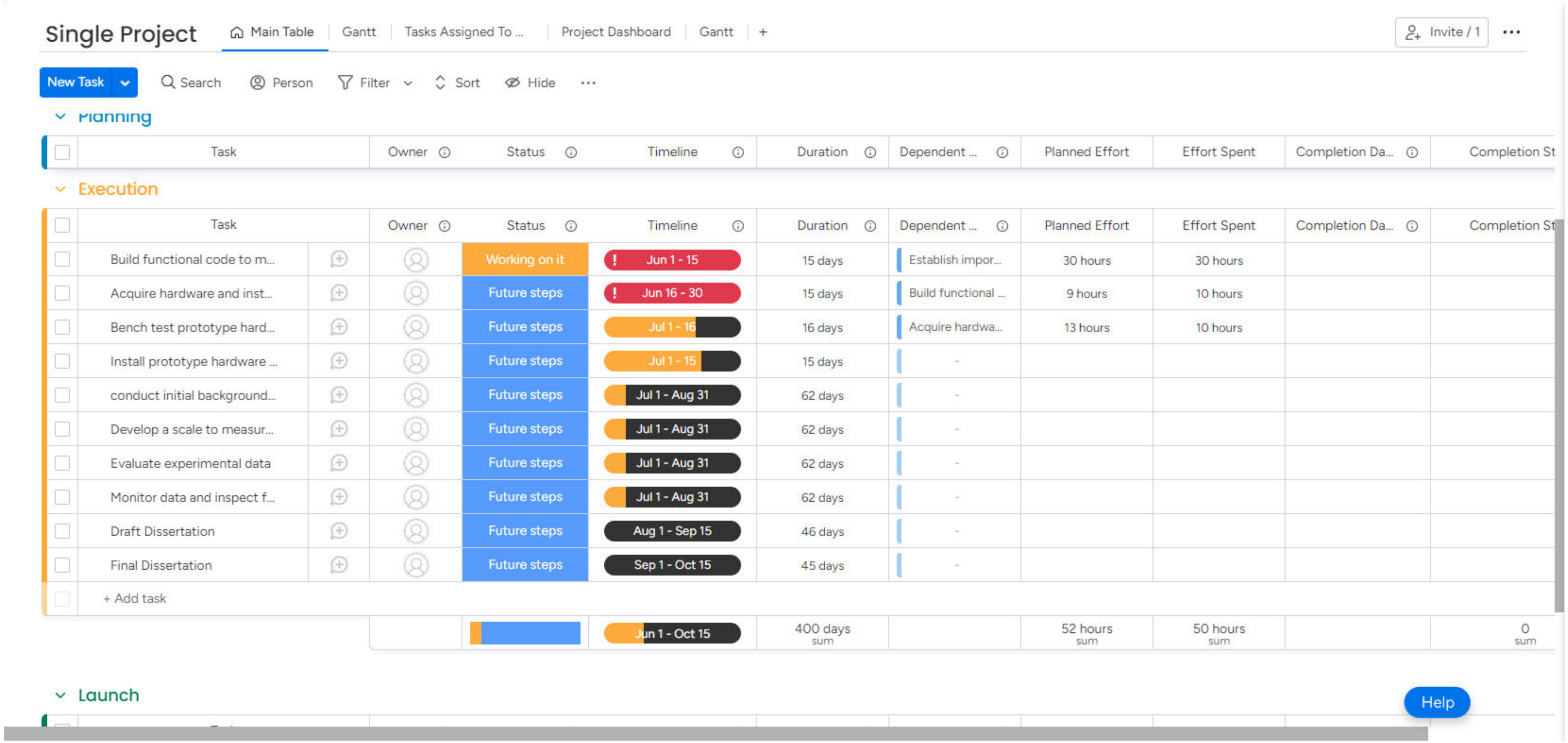
Planning

Task	Owner	Status	Timeline	Duration	Dependent ...	Planned Effort	Effort Spent	Completion Da...	Completion St
New Task		Working on it	May 31 - Jul 25	56 days	-				
Project Proposal Form 2		Done	Mar 1	1 days	-	12 hours	8 hours	May 2	Done Late
Conduct initial backgroun...		Done	Mar 5 - May 9	66 days	Project Proposa...	22 hours	20 hours	May 16	Done Late
Project Specification		Done	May 16	1 days	Conduct initial ...	10 hours	14 hours	May 29	Done Late
Establish import paramete...		Done	May 17 - 31	15 days	Project Specific...			Jun 1	Done Late
Research and establish tec...		Done	May 1 - 31	31 days	-			Jul 10	Done Late
+ Add task									
			Mar 1 - Jul 25	170 days sum		44 hours sum	42 hours sum		0 sum

Execution

Task	Owner	Status	Timeline	Duration	Dependent ...	Planned Effort	Effort Spent	Completion Da...	Completion St
Build functional code to m...		Working on it	Jun 1 - 15	15 days	Establish impor...	30 hours	30 hours		
Acquire hardware and inst...		Future steps	Jun 16 - 30	15 days	Build functional ...	9 hours	10 hours		

Help



Single Project

Main Table | Gantt | Tasks Assigned To ... | Project Dashboard | Gantt | +

Invite / 1

New Task | Search | Person | Filter | Sort | Hide

Planning

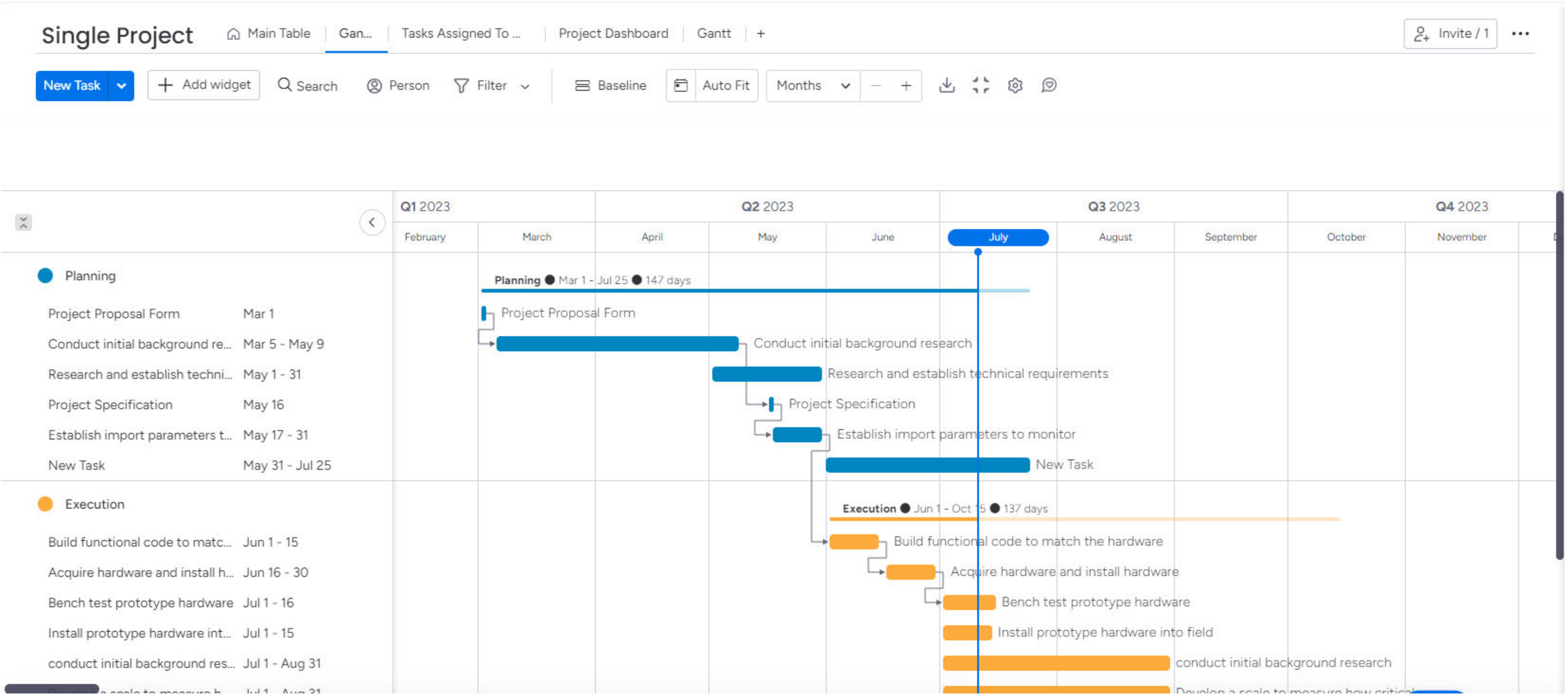
Task	Owner	Status	Timeline	Duration	Dependent ...	Planned Effort	Effort Spent	Completion Da...	Completion St

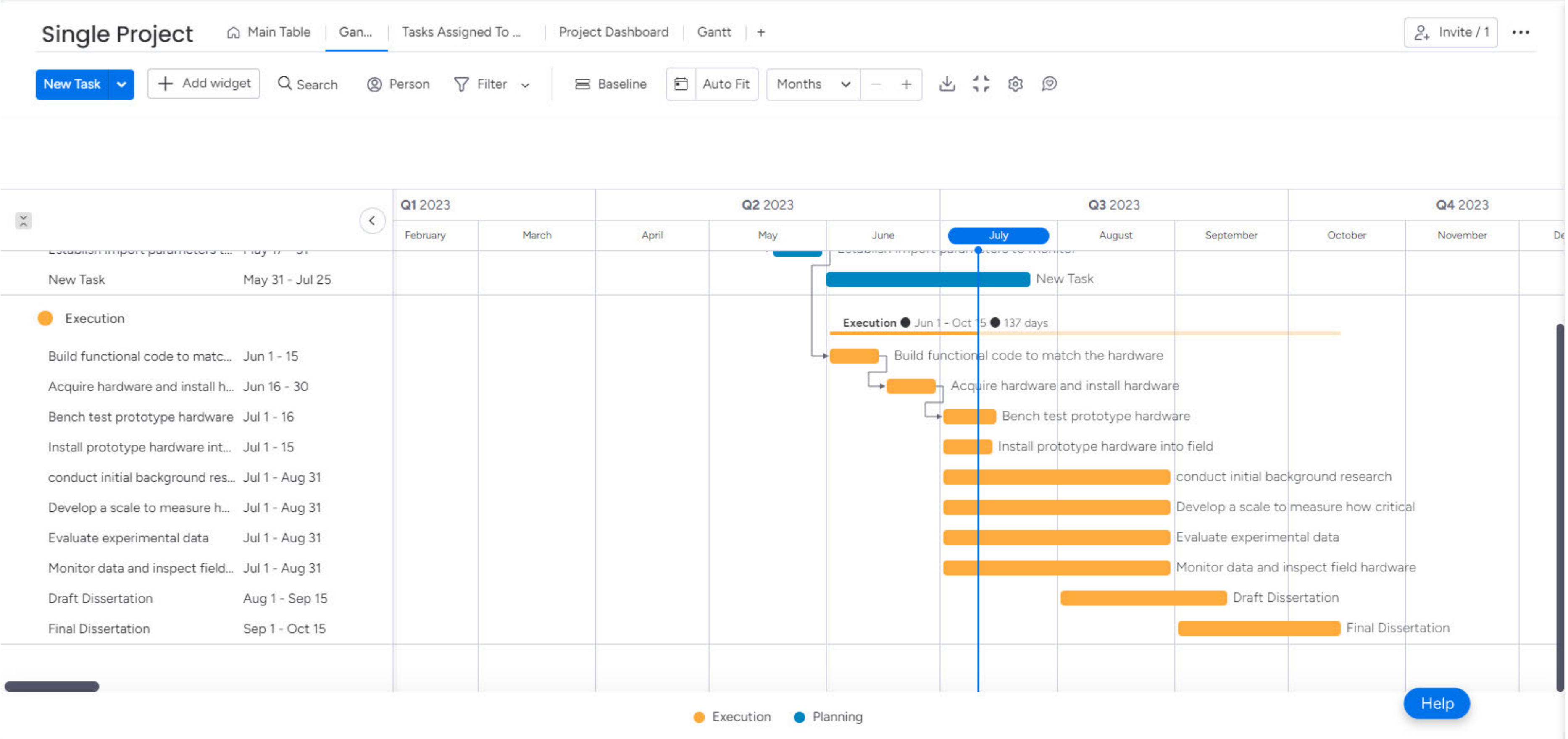
Execution

Task	Owner	Status	Timeline	Duration	Dependent ...	Planned Effort	Effort Spent	Completion Da...	Completion St
Build functional code to m...		Working on it	Jun 1 - 15	15 days	Establish impor...	30 hours	30 hours		
Acquire hardware and inst...		Future steps	Jun 16 - 30	15 days	Build functional ...	9 hours	10 hours		
Bench test prototype hard...		Future steps	Jul 1 - 16	16 days	Acquire hardwa...	13 hours	10 hours		
Install prototype hardware ...		Future steps	Jul 1 - 15	15 days	-				
conduct initial background...		Future steps	Jul 1 - Aug 31	62 days	-				
Develop a scale to measur...		Future steps	Jul 1 - Aug 31	62 days	-				
Evaluate experimental data		Future steps	Jul 1 - Aug 31	62 days	-				
Monitor data and inspect f...		Future steps	Jul 1 - Aug 31	62 days	-				
Draft Dissertation		Future steps	Aug 1 - Sep 15	46 days	-				
Final Dissertation		Future steps	Sep 1 - Oct 15	45 days	-				
+ Add task									
			Jun 1 - Oct 15	400 days sum		52 hours sum	50 hours sum		0 sum

Launch

Help


Single Project
Main Table
Gan...
Tasks Assigned To ...
Project Dashboard
Gantt
Invite / 1
New Task
Add widget
Search
Person
Filter
Baseline
Auto Fit
Months
Q1 2023
Q2 2023
Q3 2023
Q4 2023
February
March
April
May
June
July
August
September
October
November
Planning
Project Proposal Form Mar 1
Conduct initial background re... Mar 5 - May 9
Research and establish techni... May 1 - 31
Project Specification May 16
Establish import parameters t... May 17 - 31
New Task May 31 - Jul 25
Execution
Build functional code to matc... Jun 1 - 15
Acquire hardware and install h... Jun 16 - 30
Bench test prototype hardware Jul 1 - 16
Install prototype hardware int... Jul 1 - 15
conduct initial background res... Jul 1 - Aug 31
Planning Mar 1 - Jul 25 147 days
Project Proposal Form
Conduct initial background research
Research and establish technical requirements
Project Specification
Establish import parameters to monitor
New Task
Execution Jun 1 - Oct 15 137 days
Build functional code to match the hardware
Acquire hardware and install hardware
Bench test prototype hardware
Install prototype hardware into field
conduct initial background research


Single Project
Main Table
Gan...
Tasks Assigned To ...
Project Dashboard
Gantt
Invite / 1
New Task
Add widget
Search
Person
Filter
Baseline
Auto Fit
Months
Q1 2023
Q2 2023
Q3 2023
Q4 2023
February
March
April
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June
July
August
September
October
November
New Task May 31 - Jul 25
Execution
Build functional code to matc... Jun 1 - 15
Acquire hardware and install h... Jun 16 - 30
Bench test prototype hardware Jul 1 - 16
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conduct initial background res... Jul 1 - Aug 31
Develop a scale to measure h... Jul 1 - Aug 31
Evaluate experimental data Jul 1 - Aug 31
Monitor data and inspect field... Jul 1 - Aug 31
Draft Dissertation Aug 1 - Sep 15
Final Dissertation Sep 1 - Oct 15
Execution Jun 1 - Oct 15 137 days
Build functional code to match the hardware
Acquire hardware and install hardware
Bench test prototype hardware
Install prototype hardware into field
conduct initial background research
Develop a scale to measure how critical
Evaluate experimental data
Monitor data and inspect field hardware
Draft Dissertation
Final Dissertation
Help
Execution
Planning