UNIVERSITEIT TWENTE.

SMART ENVIRONMENTS PROJECT

DOCUMENTATION REPORT

<Modern Innovators of Life and Fuel Switching>

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Chapter 0: Introduction

Globally the bee population is facing rapid extinction. This rapid extinction makes it harder for plants to receive the pollination they desperately need to survive. This, in turn, causes the plant life on this planet to suffer greatly. This same plant life is essential to combat climate change. It is for this reason that this project aims to find a way to remedy this issue of bee extinction and play its role in securing the future of bees, through the use various sensors to collect data and track the health of the beehive, to help beekeepers globally take better care of their bees and give them more insight into how the hive is doing.

Chapter 1: Literature Review

1. *Is Carbon Capture Here?*
   Summary of [11]
   In Iceland there is a company called Orca that sucks CO2 from the air. The CO2 is shot into the ground about a 100m deep. Where it turns into rocks in 2 to 3 years. It is perfectly safe and a permanent solution. unlike trees, where the decay of the wood returns the CO2 back into the air.
   The company can extract 4000 metric tons a year from the air right now. If they want to make an impact on climate change, they need to grow to 5 billion metric tons quickly. This is possible by 2060 if they can attain the same grow rate as wind turbines did. However, there is an important distinction to be made. Wind turbines not only save the need of polluting energy resources, but it also makes energy. There is an economic gain being made by selling the energy. Which Orca cannot do.

2. *Permafrost: A ticking carbon time bomb*
   Summary of [12]
   Researchers are exploring and mapping the permafrost in the northern hemisphere.
   Due to climate change the scientists are concerned about this huge area containing of 1,700 billion tons of organic carbon. Methane, which is 25 times as potent as carbon dioxide. In comparison, it is twice the amount of carbon that is already in the air.
   If the Earth gets warmer the tawing permafrost is a ticking timebomb. In the last fifty years the permafrost area has seen an increase of over 3 degrees Celsius. It is one of the places with the fastest rise of temperature.
   Luckily, the gasses of the permafrost will not be released in short term, but rather over decades and centuries. The big issue is that once this system activated, we are not able to stop it.

3. *The Ocean is essential to tackling climate change. so why has it been neglected in global climate talks?*
   Summary of [13]
   Vital for our lives, the ocean plays a crucial role into keeping us alive. The focus in the climate change has always been the land. Just as important as the land is the ocean.
   The ocean has been our savior for a long time now, stabilizing the climate. The ocean absorbed 93% of human generated heat already. And a third of the carbon dioxide emissions. This is great, but there is also a darker side to it. The heating of the ocean is the cause of the rising sea level. Just as dangerous is the possibility that the role of the ocean will reverse. It will stop absorbing the greenhouse gasses and release it.

4. *research fossil fuels and the sustainability of current green energy sources*
   Summary of [17]
   Sustainable development according to the UN's sustainable development goals is defined as being the ability to meet the needs of the people today, without compromising on the needs and wants of future generations. Currently, the need for energy is high and the means of catering to that need are non-sustainable. This means that the current means of energy production doesn't meet the current demand of the people and is compromising on the

needs of future generations by introducing new problems in the form of harmful emissions. The current demand for energy is being met and there are still many people around the globe who require access to clean energy as it can greatly enhance their quality of life. Nuclear power can offer a solution to these issues as it is capable of; being able to produce large quantities of with a low level of carbon emissions, can be disposed of cleanly, is space efficient in that it requires less land than any other current power source, consequently causing less damage to the surrounding ecosystems and globally, is less harmful to humans, and is a great way to create new jobs for people (less important).

5. Summary of [18]
   According to the article posted by the US government's "office of Energy Efficiency & Renewable Energy". The advantages of wind power are; that it is cost effective, can create more jobs, that it is a sustainable source of energy, it is a clean source of energy, they don't require any additional space to be allocated specifically to them, and that they are a domestic source of energy. However, the article also lists some cons of wind energy; turbines threaten the local wildlife (specifically birds being killed by the turbine), turbines cause noise and aesthetic pollution, good locations for turbines are often far out of the way of cities where the energy is needed most, wind energy "might not be the most profitable use of land", and wind power must still compete with the current means of power generation.
   The main issue with the article is that since it is coming from the offices of renewable energy it may contain some degree of bias. This is evident in the list of cons not going too far in-depth on the negative sides of wind energy, and the back-peddling of the issues found in the final part of the challenges section. The article also fails to highlight many asked questions concerning wind energy (e.g. is it the most reliable source of energy, what is the carbon cost of constructing a windmill, and is the cost of that made back in the energy it produces, etc.).

6. Summary of [19]
   Hydrogen energy is capable of producing energy while creating virtually little to no emissions. The more renewable energy you have the more excess energy you have being produced (e.g. sunny and windy days), and this excess can be used to produce hydrogen through electrolysis.

7. *papers on biodiversity/agriculture, especially on bumble bees, (plankton, other insects).*
   Summary of [1] and [6]:
   Bumblebees are declining because of climate change. Scientist found that bees are less abundant to extreme temperatures or extreme temperature swings – there is a limit on their adaptability. Because of Climate change, bees have to tolerate temperatures they haven't had to tolerate before, causing them to die or to move elsewhere. This decline in bees could have unknown consequences for the provision of ecosystem services, such as biodiversity loss. One of the reasons is that their pollination is necessary for many flowering plants to reproduce

8. Summary of [5] and [7]
   Besides the dexterity of bumblebees, other insects can cause a lot of damage to agriculture. According to this article, Global yield losses of the grains: rice, mice and wheat, are projected to increase by 10 to 25% per degree of global mean surface warming. This is because climate change increases among other things both insect populations and their per capita metabolic rate. Because of the rising temperatures, insects must eat more to survive which can result in more crop damage. To prevent crop damage, we need more insect monitoring so that we can develop adaptation strategies

9. Summary of [2], [3] and [4]
   Plankton is a microscopic plant or animal, which are the foundation of our seawater food pyramid (food source for whales for example). Phytoplankton (the plant version) uses photosynthesis and because of that, it absorbs a lot of CO_2 and nutrients and contribute a lot to the oxygen we breath today. Unfortunately, which doesn't look bad at a first glance, the amount of plankton is increasing in the arctic area with 40% (and decreasing in the tropical area). But this leads to a decrease of the pH of the ocean (ocean acidification), because CO_2 absorption leads to lowering the ph. This acidification has impact on marine food webs, including fisheries and has impact to some plankton too. Not only that, the fast shift of plankton from the tropical to the arctic can also have a big impact on the ecosystem and the fish stock. With nearly half of humanity reliant on fish for some 20 percent of their animal protein, this could be devastating [9].

   effects of/on agriculture, especially nitrogen and livestock
10. *Human Alteration of the Global Nitrogen Cycle*
    Summary of [27]
    The document linked above is quite large, so we will only use the important sections.
    For centuries, humankind constantly altered the nitrogen cycle. We took nitrogen out of the circulation or added it in the wrong places. We used to do this by deforestation and combustion, but one of the main causes of human caused alteration is the use of industrial Nitrogen fertilizer. It is used way too much, and in a wrong manner. When using too much fertilizer, the excess nitrogen can get airborne, or seep out of the fields, into the ditches, and into the soil. This constant nitrogen "abuse" has completely altered the chemistry of the earth's atmosphere, but it does not get as much attention as, for instance, CO_2. Nonetheless, nitrogen can have devastating effects on the earth when both airborne and on the ground. For instance, excess nitrogen can cause acidic rain, produce ozone and ammonia and harm the health of forests, soil and waterways.

11. *Cows and Climate change*
    Summary of [28]
    The livestock industry is responsible for about 14% of all worldwide greenhouse gas emissions, making it the no. 1 producer of greenhouse gas in this planet. Ruminants like cattle produce CH_4 (methane), clocking in at 220 pounds per cow, annually.
    The two major differences in the greenhouse effect between methane and carbon dioxide are lifespan and potency;
    While CO_2 can stay in our atmosphere for hundreds, or even thousands of years, methane only lives for about 12 years.
    Methane is about 27% more potent than CO_2 in warming up the atmosphere.
    Even though methane has a relatively short lifespan, as long as we keep relying on the livestock industry there will be a massive constant stream of an even more dangerous greenhouse gas.

12. *Climate 101: Deforestation*
    Source [8]
    Although trees still cover large parts of the world they are disappearing at a high rate. Trees disappear due to multiple reasons like; farming, mining, wildfires etc. and of course logging for the wood and paper industry. Forests provide a home to many people but also to around 80% of the wildlife population, but that's not all. Some forests even affect regional or global water cycles thus affecting our clean water supply. Deforestation adds co_2 into the air and simultaneously decreases the possibility of removing this co_2.

13. *Why are glaciers and sea ice melting?*
    Source [9]
    Glaciers are masses of ice that have formed on land, this ice reflects heat back into space and keeps our planet cool. Since 1900's this ice has been melting mostly due to human activity. The increase in Co2 emissions has also increased the temperature of the earth which has started the rapid melting of our glaciers. The water coming from the Greenland ice sheet alone is contributing 20% of the rising sea levels. The glacial melt is affecting the Atlantic Ocean circulation. Due to the melting of the ice a ton of wildlife are losing their homes.

14. *Is sea level rising?*
    Source [10]
    The global sea level has been rising at an accelerated rate for the past century. The higher sea levels cause storm surges to push farther inland which also increases the frequency of floods. The two main causes are thermal expansion by warming of the water and the melting of the ice caps. The oceans are absorbing even more than 90% of the increased atmospheric heat caused by human activity. Sea level rise can also be different from global sea rise due to local factors such as withdrawal of ground water and fossil fuels. The rising sea levels threaten all human infrastructure.[3]

15. *Ocean acidification:*
    Source [14]
    Summary: Since the beginning of the industrial evolution, the pH-value of the oceans has risen by about 0.1 which is equivalent to roughly 30% acidification. This is because the carbon dioxide reacts with the water and the contained carbonate ions to form bicarbonate ions. The main problem that arises from this is a decline in calcifying organisms because they need carbonate from the seawater to make calcium carbonate but the carbonate ions bond with hydrogen ions which are produced a biproduct of the acidification process. Because of the change in environment the balance of oceanic ecosystems is shifted because certain species of bacteria for example thrive in more acidic environments while others diminish.

16. *Nuclear energy to reduce emissions:*
    Source [15]
    Summary: 76% of all emissions are a result of the energy production sector, with the biggest one being fossil fuels. Compared to fossil fuels, nuclear energy produces very little greenhouse gas emissions. One problem nuclear energy faces is acceptance from the public. Another problem is that research on reactors has not been funded as much as the other energy technologies. That's why most of the reactors today are outdated and not representative of the possibilities of their technology. A potential solution would be to use a combination of renewable- and nuclear energy sources to drastically reduce the use of fossil fuels.

17. *Deforestation and climate change:*
    Source [16]
    About 129 million hectares of land have suffered deforestation. This was responsible for around 30% of CO2 emissions between the years 1861 and 2000. Another area that's affected is evapotranspiration. The process describes the cycle of water through the earth's landmasses and the atmosphere. When trees store water, they disperse some into the air. This natural process cools the air, though there is no mention of the extend of the effect.

18. *Freshwater and climate change*.
    Source [20],[21],[22]
    Due to the connection of freshwater availability and quality to climate change, the ongoing process of climate change can seriously affect whole freshwater ecosystems. Few species can adapt to changes in freshwater ecosystems. This problem also puts access to fresh water for humans and agriculture at risk, which is crucial to many areas of the water crisis. For instance, around 450 million children are living in such areas, and by 2040 almost 1 in 4 children will live in such conditions. This also makes areas of traditional and non-tech powered agriculture vulnerable, as well as contributing to risks of freshwater contamination and increasing water-spread diseases risks.

19. *Effects of plastic on climate change*. [23],[24]
    Firstly, most of the plastic is made of fossil fuels, retrieving which from the underground and producing in general hugely contributes to greenhouse emissions. The same goes for plastic production, transportation, recycling. The plastics industry produces harmful emissions from the beginning to the end. Moreover, recent studies have shown that even "environmentally friendly" plastic releases greenhouse gases when degrading, especially when heated, even by the sun. This creates potential risks regarding plastic, which is stored in dumps, buried underground, or thrown out into the oceans. The increasing amount of it and degradation timespan are big enough to worry about its CO2 emissions.

20. *Climate change and health*. [25], [26]
    Climate change causes serious risks for people with cardiovascular health issues as well as Chronic respiratory diseases and allergies. This is due to fluctuations of temperature, which can lead, for example, to unusually elevated temperatures in summer seasons, increasing mortalities from heart-related diseases, high blood pressure. It also contributes to pollution, striking people with weak lungs, increasing allergens distribution in air above highly populated areas. The link between temperature fluctuations and mortality as well as air pollution and respiratory health issues is proven, and it is a serious threat to our healthcare.

Chapter 2: Identification of General Problems and Challenges

1) Decline of bumble bees is dangerous for the environment, because their pollination is necessary for many flowering plants to reproduce. (biodiversity loss).

2) Because of climate change, the amount of insects on earth are increasing. How do we prevent crop damage by these insects, or design adaptations strategies to prevent crop losses.

3) The fast shift of ***plankton*** from the tropical to the arctic can also have a big impact on the ecosystem and the fish stock (because of climate change). With nearly half of humanity reliant on fish for some 20 percent of their animal protein, this could be devastating. How could we prevent the decreasing fish stock?

4) The need to curb energy consumption (design a device that regulates electricity output depending on the devices charge?)

5) The CO2 levels are rising, by CO2 from fossil fuels. This will bring more carbon dioxide into the carbon cycle. This is a problem, because you can't just get rid of it. How can we suck CO2 out of the air, to get rid of this problem?

6) Deforestation is a major contributor to climate change since the trees that convert CO2 into oxygen are cut down and the carbon dioxide is mostly released back into the atmosphere. It's mainly a problem in less wealthy countries because trees are a valuable resource. How can we slow deforestation down by either preventing it or combating it with measures to increase the number of trees?

7) Cows push unnecessarily much greenhouse gases into the atmosphere. How can we reduce this?

8) Rising sea levels, due to melting ice caps and thermo expansion because of the rising temperature of earth.

9) Possible serious risks of health for people affected by elevated temperatures, such as those with cardiovascular issues. At the same time, air conditioning which "saves" these people from strokes in summer is a great contributor to greenhouse emissions as it consumes an abnormal amount of electricity. This is an interesting and destructive cycle.
What else can we do to protect these people from climate change effects, without making it worse (air conditioning). (Series of temperature tolerant/adaptive clothing, new types of facemasks or face wear? sustainable cooling home plaid?

Chapter 3: Identification of Relevant Problems

- Decline of bumble bees is dangerous for the environment because their pollination is necessary for many flowering plants to reproduce. (Biodiversity loss).

- Because of climate change, the amount of insects on earth are increasing. How do we prevent crop damage by these insects, or design adaptations strategies to prevent crop losses.

- Deforestation is a major contributor to climate change since the trees that convert CO2 into oxygen are cut down and the carbon dioxide is mostly released back into the atmosphere. It's mainly a problem in less wealthy countries because trees are a valuable resource. How can we slow deforestation down by either preventing it or combating it with measures to increase the number of trees?

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- Possible serious risks of health for people affected by elevated temperatures, such as those with cardiovascular issues. At the same time, air conditioning which "saves" these people from strokes in summer is a great contributor to greenhouse emissions as it consumes an abnormal amount of electricity. This is an interesting and destructive cycle. What else can we do to protect these people from climate change effects, without making it worse (air conditioning). (Series of temperature tolerant/adaptive clothing, new types of facemasks or face wear? sustainable cooling home plaid?

- The CO_2 levels are rising, by CO_2 from fossil fuels. This will bring more carbon dioxide into the carbon cycle. This is a problem, because you can't just get rid of it. How can we suck CO_2 out of the air, to get rid of this problem?

Chapter 4: Problem Selection and Motivation

The issue we selected was the rapidly declining bee population, the rapidly increasing insect population. As of right now, one major threat we face due to climate change is the rapid decay of plant life and ecosystems globally.

That is why we find this issue broad and interconnected in terms of many climates change issues, still not being too broad to work on. It is a great spot to concentrate on for our team.
Operating with one main issue subject such as bee's population in the context of climate change gives more room for working on efficient and creative solutions in terms of project timing and criteria. It also gives possibilities for great collaboration with students or professionals from the biology/environment related fields.

The main problem is that because the bee population is dying out the maintaining of plant life has gotten harder, resulting in plants not receiving pollination quickly enough and dying out, resulting in damage done to the ecosystem. Whereas climate change has benefitted other insects in causing their populations to rapidly grow, this has resulted in more damage being done to crops and plants globally making it harder to sustain life on this planet. As insignificant as insects may seem their role in maintaining and supporting ecosystems on a global scale is anything but that.

Bees have a huge influence on our food production. Over threequarters of plants depend on them and 90% of the world's food production depends on bees. Besides, the bees have a huge impact on the preservation of the ecological balance in nature as well as an indicator on how well the environment is doing [29].

Our group hoped that by choosing this issue we would have a chance to put our best foot forward, in solving this problem and combatting climate change, the best way we knew how. Additionally, many members of the group were already found of the idea of helping insects and due to the abundance of sources on the issues of insects and bees, and the myriad of issues caused by growing insect populations and lack of bees, we believed that this was the most optimal choice we could make when selecting our issue.

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Chapter 5: Potential Solutions

5 Potential solutions

Auditory Population Monitoring:
Setting up a microphone near the hive and recording the noise made by the bees inside in the hive and taking a normal of the noise made by the hive each day. The solution could aid in the survival of beehives by recording the sound made by the hive over a period of time. This would allow for a trend to be extrapolated, charting the hive's growth. If the noise decreases with time, it could suggest that the hive is dying off and is under threat, allowing us to inspect the hive and alleviate it from the threat. Also, by taking the normal of the sound made by the hive each day it would also lower the risk of the experiment being ruined by something like an acorn hitting the hive or a bee landing on the mic, as the data would appear as outliers and could be removed from the data, allowing for more accurate tracking of the colony's population and health. Also, if the general trend is the sound decreasing over time, with a consistent increase in decibels during specific parts of the day, this could also be an indicator of the fact that (for example) a creature is feeding on the hive and is diminishing its food supply and the number of living bees. Providing more insight into the issue and allowing for the potential of a solution to be made during the bees' time of crisis.

Pesticide spraying drone:
Since the use of pesticides is (as of right now) unavoidable, spraying them more selectively would prevent a lot of bees and flowers from being sprayed. For this solution, a drone would fly over the crops systematically. Attached to the bottom of the drone is our device. The device is made up of mainly two parts: A spray gun and a sensor (camera) attached to a microcontroller. Using image analysis, the microcontroller would differentiate between extreme changes in coloration and avoid spraying those areas. The idea is that those areas are likely to be either bees (other similarly sized insects) or flowers. If this works, it could prevent a lot of bees (and their food source) from being sprayed with pesticides, which would reduce the damage pesticides to bee colonies substantially.

Monitoring Bee Behavior and Bee Populations: Flower Pollination:
In a podcast: Dr. Katie Turo and Dr. Mary Gardiner talk, among other things, about monitoring bees, specifically urban bees. "We care about bees for pollinating rural farms and rural crops and the farms care about the quality/quantity of the crops too" [30].
According to this news article [31], bees are an overall indicator of the health of the environment. By for example monitoring pollination of flowers, we could identify the behavior/health of the bees. One way of monitoring bees is applying a light sensor (or better optical sensor) on a pole, as a bird-eye view. This system can identify bees with this sensor through a bee recognition algorithm. The system also knows where the flowers and plants are located and keeps track of how many bees has passed within a certain time frame. To know if a bee pollinates a flower, the system could identify for how long the bee has been seen at a flower and, how many bees has been seen. If the system thinks a certain flower has been pollinated, then the system could verify this by looking at the flower itself (e.g.: tomato plant: center will go from white to dark [32]). A database of the appearance of certain pollinated flowers could be necessary for this to identify.
Another way of monitoring flower pollination might be chemical analysis of flowers. But we think this solution is too complex and beyond the scope of this project.
This solution is little bit ambitious, because of the complexity of the recognition of pollination and bees, but it can work out with the right optical sensors.

Monitoring hive weight:

Weighing the hives could give us an insight in the average growth (in honey as well as the amount of bees) per timespan. For instance, after each time emptying the hive, we can weigh the empty “honeyless” hive. Subtracting the weight of the hive and dividing the result with the average "bee weight", will give us an estimate of the amount of bees. Of course, weighing the honey and charting the results over a period of time will also give us a useful chart. Comparing different hives in the same kind of environment could tell us which hive to look out for, and which hives are doing well in a specific region. Comparing results from a large base of different environments, however, will show us what plants and what conditions are ideal for the bees.
Not only will this provide us with immediate insight into the conditions of our hives, but it will also give us a large database which we can use to effectively and efficiently improve the living conditions for bee colonies.

Secure Beehive:
Especially for wild bees, a secure place to stay is not guaranteed. What we want to build is an ecologically friendly, cheap beehive. That is also trustworthy and can protect them from external factors like: predators, extreme temperatures, and changes in climate. These will likely accelerate with climate change. By making the beehive more resistant against cold temperatures, and keeping it cool in the summer/warm in the winter, we can optimize the ideal work sphere for our bee workers. This would work by having sensors inside and outside the beehive, so that the micro controller can optimize the temperature for the bee workers and have a more productive beehive. In this way we secure the beehive from termination over a longer time period.
What can also be helpful for beehives is having humidity sensors to watch out for too dry of a climate. Bees will not procreate if there is too much of it. With this sensor we can help the population, especially in countries with a lot of droughts.

Chapter 6: Solution Selection

The solution we ended up selecting was the use of auditory/thermal sensors in order to track and create a trajectory for the population of bees within the hive. The solution was selected due to its numerous benefits and its larger utility over the other solutions. The first major appeal over the other solutions, is the ability to monitor and sense the bees' behavior and mood. While the bees' aggression towards human's is minimal, in case bees were aggravated/distressed or calm the beekeeper could receive a notification allowing them to monitor and act on the health and mood of the colony without having to do so manually. There is also a commercial opportunity, as novelty attraction for children to increase interest in bees and science. Also, unlike a weight sensor which can have its data easily invalidated through factors like miscellaneous leaves falling on the hive, the movement of the bees inside the hive constantly offsetting the weight sensor and invalidating the data. A thermal sensor could also compliment the auditory sensor by providing a better insight into the colony's health, especially during the winter. This is because the temperature inside the beehive has to be kept very stable for the bees to be able to procreate and function. All in all, this solution also seemed the most feasible with our current skill level and is could be the most optimal contribution we could make to helping combat the declining bee population.

Calculation of the total time we have to complete the project:
Week 5(13th December) - Week 10 (24th January)
5 Effective weeks – 2 weeks buffer = 3 weeks to establish the main functionality and test it

Nick: Team leading [weeks 5-10], management, coordination, interaction with clients (, helps wherever it's needed)
Bart: Product Design [weeks 5-6] Building the exterior, purchasing and installing hardware
John: Documentation [weeks 5-10], (Presentations), feedback, support with installing and purchasing of hardware
Casper (and John): programming [weeks 5-7], (user interface,) data analysis
Suzanne/Arne: Data analysis [weeks 5-10], (preparation of final demo)
Denis: Implementation/ Research [weeks 5-10] [weeks 8-10] in the field, preparation of final demo, validation

Johnny: **Documentation**, presentation, and planning (helps wherever it is needed). Documents the results of different tests, also writes the documentation, and can help when needed.
S2: contacts beekeeper, research (**networking**). Is responsible for everything from finding a test site to contacting people outside of this project like beekeepers.
S3: builds physical device to be placed into the hive (**product design**). Also has to make sure that the electronics are suitable for the expected conditions.
S4: **Programming** of the micro controller. Programs the Arduino to collect the data in reasonable time intervals. Potentially must outsource processing power to other devices.
S5/S6: **Data** collection, **analysis**, and processing. "Gets" the raw data from Casper and needs to process it into usable statistics. This is the area of least expertise, so it will need a lot of our resources.
S6: team leader, research and development/ **implementation; Presentation** (helps wherever it is needed). Besides coordinating the team, has to test the different iterations of our product and provide feedback on possibilities for improvement.

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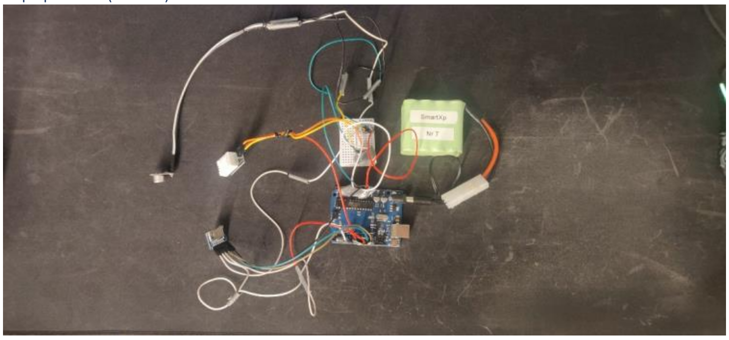
Chapter 7: Methodology

Equipment (FINAL)



Final Arduino with sensors used on the beehive.

We want to measure the temperature, humidity, sound volume and sound frequency.
To do this, we need the following sensors:

- DHT22 [1]
  - Measures both temperature and humidity.
    - 3 to 5V supply
    - 2.5 mA current use during conversion
    - 0-100% humidity reading with 2-5% accuracy
    - Sampling rate of once every 2 seconds
  - MAX4466 [2]
    - Measures both sound volume and sound frequency
    - 3.3V supply
    - 20-20k Hz microphone
    - Adjustable gain, 25-125x (200mVpp-1Vpp)

To store our data and power the board we needed the following parts:

- Micro SD TF Card Module[3]
- SD Card (Personal)
- ESP8266 [4]
- (9v) Batteries (Alfred)

Without the SD Card and the batteries, this costed us €51,28 in total, shipping and tax included.

[1] https://www.conrad.nl/p/joy-it-sen-dht22-temperatuursensor-temperatuurvochtigheidssensor-geschikt-voor-serie-arduino-asus-asus-tinker-board-2159178

- [2] https://www.bitsandparts.nl/Electret-condenser-microfoon-met-MAX4466-instelbare-versterker-p1907045
- https://www.bitsandparts.nl/Electret-condenser-microfoon-met-MAX4466-instelbare-versterker-p118151

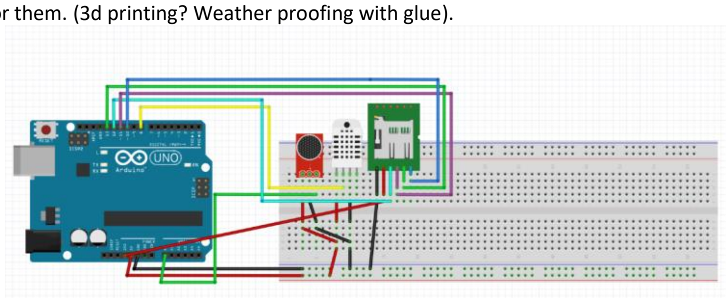
[3] https://www.otronic.nl/a-62566236/communicatie/3-3v-micro-sd-card-module-voor-esp32-esp8266/

[4] https://www.bol.com/nl/nl/p/esp-01-esp8266-module-arduino/9300000043972231/?Referrer=ENTcli_shipment_confirmation_standard2008093611

Apart from the sensors, we will use an Arduino UNO board, a breadboard, wires and resistors, all of which we already have.
None of the components require calibration.

Once the components receive approval, The assertation of said parts will be in order. This will immediately be followed by the development of the prototype, for which a casing will be made.

While waiting for the acquisition of the parts the group will look into a power source for the system, (if needed) weather proofing of the parts, and researching the materials we will use and how to construct a casing for them. (3d printing? Weather proofing with glue).



The schematic of the Arduino including the sensors.

Data collection

Data collection will start soonest the second day after the holidays (optimistically speaking). The data collection will consist of the sensor being on for the entire day, turning on every 2 minutes, to take a reading of the hive at that moment in time and save it for the production of usable data on the hives, and also data on what needs to be fine-tuned and still needs to be done in order to collect sufficiently valid data on the hives.

Data use/ analysis

Data analysis right now consists of pre-data analysis. Pre-data analysis for the coming days will focus on, gathering information/knowledge regarding how to interpret data, as well as, researching what equipment you need for the optimal data collection and how to apply it, as well as, how to obtain the data needed for the product from these sensors.

Following pre data analysis comes post pre data analysis. Post pre data analysis consists of using the data, refining the method of data collection and analysis in order to optimize the results obtained from the experiment, as well as ensuring all data collected is usable and sufficient for the purposes of the project.

Programming and algorithm:

General Idea:

To find out what the health of the hive is, we will use machine learning: random forest algorithm. A public dataset of audio samples is available from various states of the hive.
We can train our Random Forest classifier with the features from the audio data so that it can identify whether the beehive is healthy, or the beehive is endangered.
Because we cannot guarantee whether we can record audio from a beehive at all, we decided to focus first on the online dataset [37].

Database/ Data recording

We have found a data base with bee recordings. Half of it consists of audio where the queen bee was not present in the beehive, while the other half of the recording has the queen bee present. It consists of roughly 50 hours of audio data. The audio can be used for machine learning (Random forest algorithm) [36]. The datasets can be found here [38][43][44].

Feature extraction

Windowing and Frame Blocking:

Beehive sounds are variable. The time period and frequencies are not constant but differ over time. Non-stationary sounds are hard to analyse. Therefore, we cut the audio until small bits, around 20 to 80 ms. These small parts do sound like stationary sounds, called frames. Now we are able to analyse them. The problem with signal framing is that there is a spectral leakage going on. Making the data less accurate. To reduce spectral leakage, we implemented window functions. We used the Von Hann/ Hanning functions [40].

Mel Spectrogram

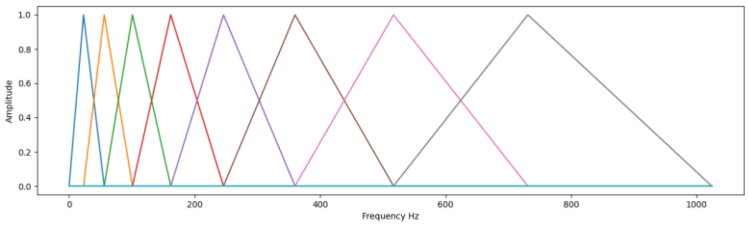
Because we cannot guarantee whether we can record audio from a beehive at all, we decided to focus the implementation first around the online dataset.

According to this paper [45], greenwood function cepstral coefficients (GFCC) features are one of the better ways to distinguish animal sounds from each other. But what is a GFCC feature?
We are not going to explain what a GFCC feature is, because we ended up not using this method because of its complexity. As the paper [45] says:
"GFCCs were introduced as a generalized form of MFCCs: MFCCs are derived from the cepstral representation of an audio clip. MFCCs represents short-time power spectrum of an audio clip based on the discrete cosine transform of log power spectrum on a non-linear mel scale."
That sounds very complex. Let's break it down. The word spectrum is mentioned twice, why? Cepstrum or a cepstral representation is actually **a spectrum of a spectrum** and it turns out that these features are very useful for specific audio identification, such as speech processing [46].

This is done by using the discrete cosine transform (this method will not be further explained). And what about the log power and non-linear mel scale?
People don't perceive sound in a linear way (check it out for yourself). A person can easily distinguish between a tone of 500Hz and 1000Hz, but distinguishing between 10,000Hz and 10,500Hz becomes very difficult (despite the fact that the difference is 500Hz). Humans perceive sound in a logarithmic manner. [47]
Wikipedia [42] explains the Mel scale well: The Mel scale is a perceptual scale of pitches judged by listeners to be equal in distance from one another. The formula, going from frequency scale to Mel scale, is as follows (the Mel function)
$m = 2595\log10(1 + f/700)$
GFCC, as mentioned earlier, is the general form of MFCC. Greenwood came up with a formula: the greenwood function: related to the position of hair cells in the inner ear with frequencies that stimulate the corresponding auditory nerves. He came up with the following formula: $f = A(10ax – K)$. The unknown have to do with characteristics of the cochlea, etc.
When applying for $A = 700$, $a = 0.0003853565$; $K = 1$, we get the formula of the mel function [48][49].

Mel Spectrogram:
According to the video [46], Features which are closer to the original audio are used more and more often for machine learning. Because of the lower complexity and because the Mel spectrogram is closer to the original data than a cepstrum, it was decided to use the Mel Spectrogram from the original audio data.
To convert audio data to a Mel spectro gram, the following operations are performed:

First, windowing and framing is applied. This has been explained before. Then the Fourier transform is applied to this (so that the signal goes from time domain to the frequency domain). Then the Mel Filter Bank is applied (dot product) to the spectrogram.[51] [52]
The Mel Filter bank is a triangular filter function that gives a higher resolution of lower frequencies and a low resolution at high frequencies. This is actually very useful, because bees make sound at low frequencies [50].
This is an example of Mel filter bank



This was made by the script PlotFiguresSound.py. This plot was made with the help of [51] and [52]
After applying this to our spectrogram, a Mel spectrogram is made.

Random forest algorithm

With all the said features talked about in Chapter 7, we can apply the Random Forest Algorithm. It is an algorithm that builds a said ''forest'', it ensembles decision trees. Which is commonly trained with by the "bagging" method. This method combines different learning models to have a higher accuracy and better results [41].

Primary research

For primary research, the group will be contacting beekeepers starting December 18th. The beekeepers will be contacted over email and will be sent the following: An explanation of the project, the benefit for them to join (incentive), our exact requirements and desires for their hives (what will we do to them; how will we experiment on them), and persuasion (the invalidation of any reasons to oppose declining our offer).
If the response from the beekeepers is positive, the group will begin the construction of a concrete time plan. This will consist of asking for their schedule, as well as providing them with an insight into ours. The beekeepers will also receive insight into the specifics of our project (e.g., the idea for the prototype and its purpose), a request to schedule a meeting to discuss the idea further either over the phone or in person, and a “p.s.” asking them to ask any questions of us.
If the response is negative, we will respond by telling them we understand, and we thank them for their time, as well as asking them for any potential leads to somewhere else (any other primary sources have information).
Additionally, regardless of the response some form of contact will be attempted to be maintained with any beekeeper unless asked or made clear that their intention is to end contact in which case contact will cease otherwise contact with sub keeper will continue.

Secondary research

For secondary research, the group will investigate previous attempts made at similar projects. specifically, their designs, weatherproofing, how to create simulated beehives, how to deal with winter and data collection, and research any prototype needed for testing alternatives.

Validation

For validation the group will research different conditions bees are under and how that relates to the expected bee data. Ideally, the group will use the data from the hives to determine the health status of the hive and compare that to the conclusions and observations made by the beekeeper on the hive at the same time. If both health statuses line up from the beekeeper and the group's data then that is 1 step closer to the final conclusion. As of right now this approach to the validation still requires some research but this will be the current approach to the validation requirement.

If this is not possible, we check whether the model works with the sounds from the database. We divide the data into two groups: train data and test data. The train data is used to train the random forest classifier. After we have trained the classifier, we can validate whether the model actually works with the test data. The test data contains (just like the train data) features of an audio file, corresponding to a state; Either “active” or “No queen bee”.
The model receives the test data (the features), without the state. The model predicts whether the beehive is in an “Active” or “No Queen Bee” state. The random forest Classifier must ensure that the prediction matches the state that corresponds to the features of the audio. The more the classifier predicts correctly, the better we can conclude that the random forest classifier functions well.

Chapter 8: Validation


The implementation of the Arduino with sensors in one of the beehives.

The data collected by the prototype to figure out how healthy a beehive is, was temperature (°C), humidity, and volume (arbitrary units) over time.

Validating data with research

Temperature Data (based only on single hive):
According to the research done prior the temperature of a beehive during winter should not drop below 10°C otherwise that would be an indicator that the beehive was either dead or doing extremely poorly, according to the data collected from the first beehive the temperature would range from 18-22°C which is a healthy range for a beehive to be showing during winter [33]. The primary issue with the temperature data is the time of year we decided to collect it. According to our measurements, continuously taken 2 times to avoid false values, the temperature of a beehive is most relevant during the summer as then is when the beehive needs to maintain an average temperature of (34 C —36C) to produce healthy offspring, were the temperature to drop below this - bees born during this period would be born with neural deficiencies and overall maturation process will be affected [34]. Due to the time at which this data was collected, and the poorer conditions of winter it is harder to derive any meaningful conclusions from the data gathered and inhibits its usefulness outside of saying that the beehive is alive.

Audio Data (based only on single hive):
Recording the volume of a beehive with time should help track the activity of the hive, especially predicting the swarming of the bees. In theory, specific and monotonous sounds in the beehive indicate the beginning of swarming with surprisingly high accuracy.[35] The audio data collected on the first beehive was only able to show us the bee's activity which can simply be correlated to the active/healthy state of the beehive (with following research on correlation between colony's health and audio data). The algorithm in the source used to predict swarming, unfortunately, could not be tested as bees usually swarm from April to May. The main issue with the data collected is that the sample rate of the audio data was far too low, roughly 68 samples per second, which was the product of Arduino's baud rate of 9600bps. The wintertime we worked at has also influenced the usefulness of audio monitoring, as well as the necessity longer prior/following up research on audio monitoring in Winter. This effectively bottlenecked the data we collected and made it difficult to do anything with the audio data collected from the first beehive.

Audio Data (based on online dataset):
The validation process has already been explained to a considerable extent in the methodology. As mentioned before, all data is split into two groups "Test data" and "Train data". Train data contains 70% of all audio data (and the test data contains 30%). It has not been decided to divide the data fifty-fifty. The more data is given to the model to train the classifier, the better the model can distinguish between the two states "Active" and "No Queen bee". Of course, the group also wanted to have any data left for validation. Otherwise, it is not possible to check whether the model really works properly. Therefore, this ratio was thought to be reasonable.
The unfortunate thing about this is that it is not possible to test whether the classifier works well on other measurements. Each microphone is different and may pick up sound differently than the microphone used in the dataset. The accuracy of the classifier's prediction could influence this.

Humidity Data (based only on single hive):
According to [36] bees try to maintain average humidity of 60%, were this value to increase it would mean that there is a leak in the beehive letting in more water and were this value to decrease it would mean that there is either a leak letting water out of the hive or fungal disease going on. [37]. The humidity in a beehive can be checked just once per day or the inspection can be just triggered by detected rapid changes in humidity itself. Checking the humidity can also be prioritized during the moments of swarming, and active honey production in summer – as humidity changes can correlated with loss of moisture from honey – which signals of threat to the colony, destabilizes the inner environment, and, of course, is affecting the honey quality. According to our sensors, the humidity of the beehive was checked every 8 minutes and displayed a range of about 47-51%. On its own, and taking the winter season into account, the data already can show that the humidity of the beehive is healthy. However, the key issue with the data collected is that monitoring humidity during winter will not reveal much about a bee's state of health, (but is useful as an overall safety measure in case of leakages or other accidents involving moisture)

Validation of the data

The key issues with trying to validate the data currently are that there is sampled data to work with. Ideally, we would have collected data over several weeks/months before determining whether our system works in tracking the health of the hive. We would ideally compare data with not just data from the internet but also with data collected by the keepers on the hives themselves. However, since this is not possible - drawing any conclusions on the validity of our data is quite tough. Additionally, we are unable to compare the data with the data from other hives, as the data from the other hive was lost. This would make it impossible to confirm the validity of our data in relation to another beehive and is another issue with the validation of the data collected. Currently, our only way to validate the data is through online sources, and by checking whether our data was able to answer our hypothesis (which does not guarantee that the data collected is valid). Unless the data collection period could be extended over a longer period, over a larger sample size (more hives), the question concerning the validity of our data is mostly inconclusive.

Chapter 9: Results and Conclusion

As stated, before we collected four types of data: Audio volume, time, temperature and humidity.

Volume:

The volume is measured in an arbitrary unit measured with analogRead on the Arduino which ranges from 0 to 1023. Meaning we can measure if the volume is either higher, lower or somewhere in the middle. With the volume we can see the activity of the bees and if they are going to swarm. If we detect a sound that barely varies in volume, we can call this a monotonous sound. When bees are going to swarm soon, they create such a monotonous sound. Only when bees are unhappy or in danger do they swarm. Thus, when we see monotony in our volume data we can see the bees are not happy.[33]

Commented [RB1]: 13.57 time start

Time

We measured the time in milliseconds, the time is only used to keep track of the other data and make it easier to put data into perspective.

Temperature

The temperature was measured in degrees Celsius.
During summer the temperature of a healthy beehive is somewhere between 34 and 36 degrees Celsius. Anything below that range could lead to offspring with birth defects e.g., neurological issues. [34] If we were to detect temperatures below 34 degrees Celsius in the summertime, we would know the bees were unhealthy.
During the wintertime Typical temperatures for a healthy beehive range from 18-22 degrees but can go as low as 10 degrees. Anything under 10 degrees would mean the bees are doing very poorly or dead. [33] when we took the measurements the temperature outside of the hive was 7 degrees Celsius.

Humidity

The humidity was measured in percentages.
A healthy beehive maintains a humidity of around 60%, anything above this could indicate there was access water getting into the hive and anything below this could indicate a water leak or even a fungus. [37] The ideal humidity percentages for a beehive are between 50%-60% above and below are not ideal and could indicate an unhealthy hive[36].

Data Tables

Please see attached .txt files for our full data cycles. There was too much volume/time data collected for this document to handle thus we have kept it as a separate file. Temperature and humidity however we have added below.

Humidity (in percentages)
50.90
51.50
49.60
47.10
Average: 49.78 %

Temperature (in Celsius)

18.10
18.10
21.10
21.90
Average : 19.80 degrees Celsius

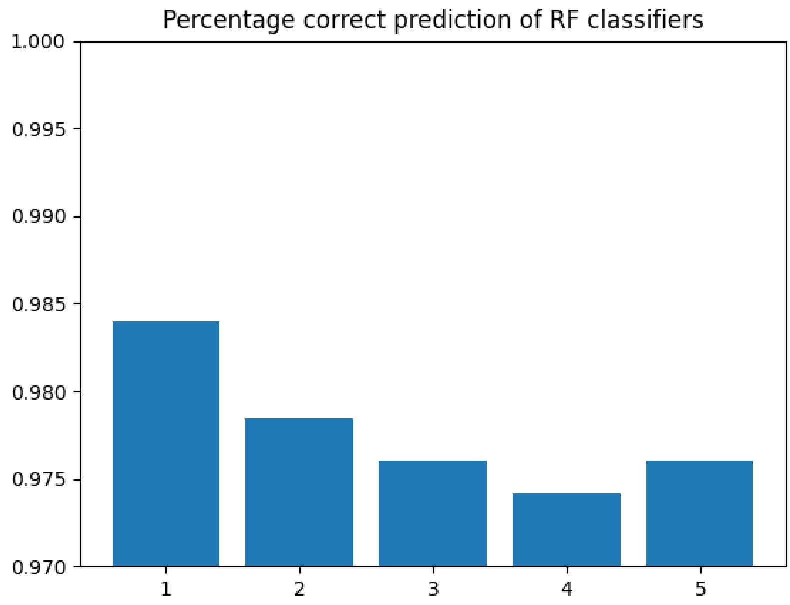
Results Random forest Algorithm :

Feature Extraction: Values used

For the Mel Spectrogram, we used a window size of 2048 and a hop length of 512. These values are also used in this paper [43]. We did not experiment with these values, because we had little other reference material for these values. The librosa library [53] also has the default value 2048, so this seemed like a good decision. According to librosa, using a power of two is beneficial: it improves the speed of the Fast Fourier Transform.
The length of a single sound recording is 30 seconds. There is no specific reason for this length, but it had to be long enough for the classifier to distinguish between a beehive with or without a queen bee.
A mel filter bank with 40 filters was used. This value was also used in both [51] and [54]. According to [54], The mel spaced filterbank as stated formally is a set of 20-40 triangular filters. It was decided to use 40 for higher accuracy.

Random Forest:

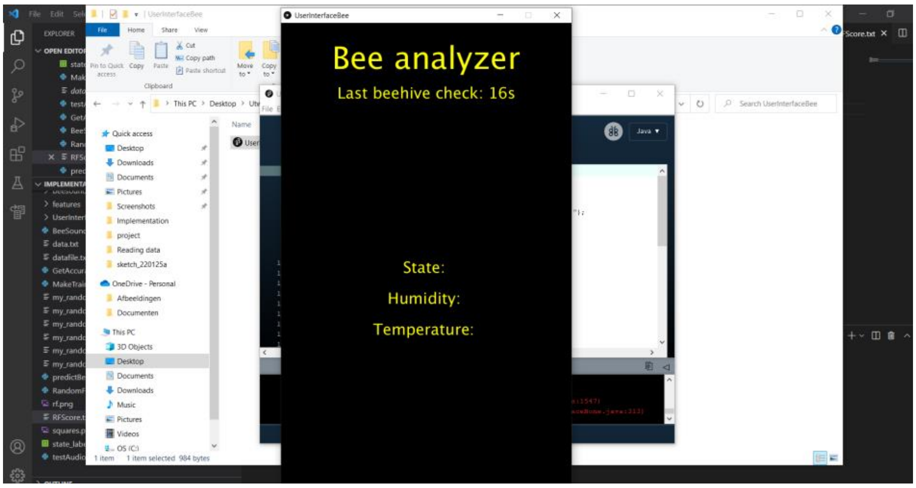
There are 5 random forest classifiers built. Each of these classifiers received 70% train data from all data in the dataset. The choice of train data was random. This means that in the end 5 different classifiers were built, each of which works differently. The remaining data was, of course, used for testing purposes. Below you can see how accurate the classifiers work.



This bin chart was made with GetAccuracyModelDiagram.py

Classifier ID	**Percentage correct predicted**
1	98.4%
2	97.84615384615385%
3	97.6%
4	97.41538461538461%
5	97.6%
(average):	97,77%

Maybe not very relevant for the results, but here is picture of the user interface.



Conclusion

Our data shows the temperature in the hive was about 19.8 degrees. This is within the range of a healthy hive in winter. The humidity was about 49.78% this is on the lower side of the healthy range and on its own would be a reason to check up on the bees. When looking at volume you can see it vary from about 300 to 550, This would not be considered monotonous which indicates the bees are not about to swarm showing a happy hive. Taking this all together we can conclude that these bees are happy and healthy.

The results of the random forest algorithm show that the prediction of the random forest classifier 97.77% of the time correct. However, it should not be forgotten that the selection of the data is quite specific: the audio comes from one kind of beehive. It cannot be validated whether this classifier also predicts well when audio data is received from another sensor and/or from another beehive. In addition, there are many more states in which a beehive can take place than just “active” or “no queen bee”. For example, the classifier could return one of these two states to the user when audio is received, while a beehive is in another state. This could certainly be expanded for further research.

Discussion

Due to the lack of data (being unable to compare it to a second hive, the small time frame in which data collection took place, and the other compromises needed to be made) it is hard to draw any concrete conclusions from this experiment. Since the time frame in which the data was collected was so short saying that the prototype works for different seasons and can accurately send data on the condition of the hive is tenuous at best. Other issues included the Wi-Fi module not being able to connect with the database and the failure of the module to collect data on the second hive.

Furthermore, we used Arduino’s standard bit rate for serial communication of 9600bps. This sampling rate was too slow for our audio-analyzing-software. In turn, this prevented us from comparing the data of both hives and validating the data that way. It also stopped us from maximizing the utility of the audio data gathered from the first hive. Despite these failures, there were still a few upsides to our experiment. Firstly, having data on the first hive that matched what we trying to measure was huge in proving that there is in fact some merit to the prototype built and that with a bit more time and resources it could have been a major success.

Secondly, by separating the temperature and humidity data we ensured that the uncertainty in those two variables would be reduced, while this can't be tested to see if it actually worked the forethought to prevent such a blunder may have potentially saved us from having larger issues with our data. Third, having useable data on the first hive allowed a conclusion to be derived from it further supporting the idea that there is in-fact merit to the idea and prototype we presented. Lastly, all of these factors combined shows that with further testing, over more hives, and a longer period of time, that our idea could in-fact accurately graph the health of beehive with time, and all in all our efforts weren't in vain.

We cannot say this with certainty since we only have 2 cycles of data collection. This is an experiment which is supposed to take place over an extended period of time for us to be able to document the health of the bees. Sadly we had a time frame in which we had to finish the project, which gave us a short time to collect data. Because our second module failed it is even harder to validate our results since we have no other beehive to compare to.

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