TREEBORG

FINAL REPORT

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TECNOLÒGICAMENT MEDITERRANIS

Project Treeborg

The development of an electronical device, which is implemented into a tree and is powered by energy obtained from the tree.

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Team Treeborg Group 6
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Abstract

The aim of this report is to present the work of the Treeborg team over the time of the European Project Semester (EPS), on the project of analysing the possibility of implementing the electrical device in the tree that would be powered by the energy coming from the nature.

Firstly, the report begins with an introduction where the aim and purpose of the report are stated. The main companies involved in the project are introduced and their main goals.

Secondly, it describes the method of harvesting the energy from the process of photosynthesis. BIOO's technology is explained and their solution for a natural source of energy is investigated.

Next, the advantages and disadvantages of implementing the device inside and outside the tree are pointed out and the comparison between them is conducted. The final conclusion is that in the further part of the report only the internal implementation is considered.

The electronical part of the project is presented as following. Each part of the electronic module is developed and explained. All components of the device are described and depicted. Also, the final code of the device is shown.

In the further part of the report, the implementation into the tree is described and the methodology. The least harmful way had to be chosen to guarantee that the tree will survive the operation. The possible impact on the tree is also considered.

As the main part of the report, the design of the device is elaborated. Starting with the initial concepts that were created at the beginning of the semester, to the final selection that is thoroughly described and depicted. Both internal and external parts are presented. At the end, possible improvements and the material to be used are described.

The problems faced with time limitation and technical aspects are mentioned. Also, the possibilities for the future are described. The possibility of using the device in a smart city is justified and the other uses of the idea are presented. Moreover, the improved electronic system is described.

As one of the last points, the marketing strategy is considered. The basic profile of the customer is created and the market analysis is conducted. The basic cost calculation is made and displayed in a form of a table. The afterlife of the device and possible business partners are also considered.

Lastly, the discussion on the project itself is made and finishes with final conclusions.

Key words: Tree, Nature, Electronics, Energy, Engineering, Design, Methodology, Smart-City

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Furthermore, the Neàpolis Company should be thanked for giving such an innovative and demanding project. Also, the UPC and home universities of the team members deserve a gratitude for allowing European Project Semester (EPS) 2017 to happen.

Was it not for the BIOO company, we would face some serious problems. Therefore, the team is indebted to them for supporting us with their technology without which the whole project would be endangered.

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Finally, we would like to thank each other for an amiable semester and hard work on the project. We all have put our hearts to the project and fully devoted ourselves to it.

Thank you.

Team

Declaration

We hereby declare that this submission is entirely our own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of our work.

Signatures: ______________________________

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Date: 13 June 2017

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1. Introduction

1.1 Aim

The aim of the Treeborg Project is to create a device that would collect data about air pollution and surrounding environment, while providing a Wi-Fi hotspot, which would be powered by the energy coming from the tree.

1.2 Project Purpose

This project is a cooperation between Neàpolis, 'Team Treeborg' and the Universitat Politècnica de Catalunya (UPC) in Vilanova i la Geltrú. The Treeborg team, consisting of four individuals from different countries, were asked by the Neàpolis Company to investigate during their time on the European Project Semester (EPS) in Vilanova i la Geltrú, the possibility of harvesting energy from nature to power a small electronic device that could be inserted into the tree. Moreover, this device should be able to provide a Wi-Fi hotspot and collect the data from the environment. The existence of such a device is needed to increase the awareness for citizens about the pollution in their surroundings. Also, it will make city centres more people-friendly by providing a Wi-Fi hotspot. The purpose of the project was to conduct the research and create a prototype of such a solution.

With the progress of work, the project was divided into three main parts: electronics, design and impact on the tree. During the semester, all parts were tackled and developed.

The main interest for the team during this semester was to create the electronical system with sensors that would detect humidity, temperature and harmful gases, like CO (Carbon Monoxide). Furthermore, the design of a special housing for that system and developing the methodology of implementing it into the tree was to be created. The designed device should not harm the tree permanently. It is also needed to have a relatively long lifetime and should be powered fully by the energy coming from the tree.

2. Basic Information

2.1 Company

2.1.1 Arkyne Technologies

Arkyne Technologies is a company which is based in Barcelona (Catalonia) and is a pioneering clean-tech company, that develops and commercialises a unique system (BIOO technology), which can generate energy from photosynthesis waste products, in a sustainable, green way. [1]

Figure 1: BIOO Logo

2.1.2 Neàpolis

Created in 2006, Neàpolis is promoting innovation in technology, design and entrepreneurship. The company's goal is to make Vilanova i la Geltrú a competitive, green, creative and smart city. Neàpolis' aim is to support local innovation and competitiveness, including the promotion of regional, national and international cooperation.

Neàpolis has been working with UPC (Universitat Politècnica de Catalunya) and EPS (European Semester Project) program since 2013. This collaboration aims to improve in many aspects within Vilanova. [2]

Neàpolis' director of technology, Josep Farré is involved in the Treeborg project. He was a supervisor of this project.

Figure 2: Neàpolis Logo

2.2 Energy

The BIOO plant pot (see Figure 3) is invented by the Barcelona-based company, Arkyne Technologies. The developers claim that the technology is able to deliver up to three smartphone charges (~ 2500mAh) a day with a 5V and 1A charging port, while using the biological battery placed in the plant pot. The energy harvested from this pot is already enough to use it for the Treeborg device, because the Arduino device only needs between 4.8 and 5.0V, with a current of +/- 50 mA. Arkyne claims that their technology will work for at least five years straight and the user only needs to water the pot and keep the plant in it growing, this will maintain the production of energy at night and day without providing any damage to the plant itself.

Figure 3: BIOO Lite

One of the newest inventions of the company is the scaled-up version of the plant pot, the BIOO Panel (see Figure 4), which is a 1x1m device and will be able to generate up to 40 W and nearly a maximum of 280 kWh, while using the same technology as the plant pot. The advantage of the panel is that it can be connected with other panels and provide a larger current and also generate a larger amount of energy.

In comparison to a normal solar panel, it will be more cost efficient and greener. The price will be around 200 to 270€, which would be much cheaper in comparison to the solar panel, which is around 1,500€. Ideally, a normal 10x10m garden could be utilised for this device according to the company, Arkyne technologies. The other option can be the usage of smaller bushes and trees like in this project. The connection with a tree is right now in development and will be the perfect addition to the Treeborg device. But in consonance with the Arkyne Company, there will be different options to solve the energy solution for the Treeborg device. The first solution would be powering the device with a direct connection to the roots of the tree. The second solution can be the utilisation of the energy provided by an external panel or a smaller bush in the direct surroundings of the tree. The second option would be more suitable for the prototype as the smaller pot or panel would be easier to control. Using an independent planting pot might be in the beginning, more suitable for this project in comparison to the direct connection with the tree, because that would cause more problems in terms of installation and maintenance.

Figure 4: BIOO Panel

The BIOO Lite system (see Figure 4) is a normal plant, which has an included system that uses the waste products from the plant's photosynthesis processes to generate electricity. The general explanation is that the whole system is based on a special species of bacteria which are living in the plant pot and break up the chemical bonds of the photosynthesis waste products, while releasing electrons during the digestion process. Then, a nanocable collects the electrons and captures them to transmit them through a battery. Finally, a normal USB (2.0/3.0) cable is attached which can be used to charge any device with the green energy.

BIOO Lite is a system which is based on a biological engine called PMFC (plant-microbial fuel cell) that generates energy from the decomposition of carbon-based organic substances, the waste products of photosynthetic processes by bacteria in the soil. The plant pot is divided into different parts. At the bottom, there is an electrode anaerobic structure, in there, is a solid layer of biomass which contains the bacteria. Those microorganisms can be activated by just adding water as a biological activator. Between those layers, an internal electrical circuit is placed with a battery to store the energy and create an oxygenated cavity. Then, there is a semi-permeable layer added which purifies and filters the water and will not let soil through. On top of it is the growing plant surrounded by soil, like a plant in a normal plant pot.

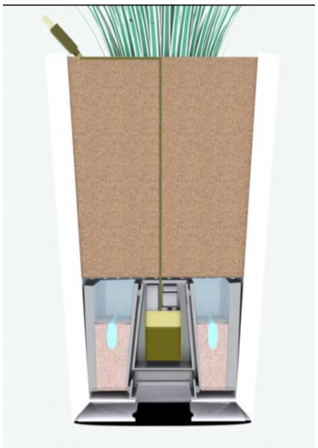


Figure 5: Cross-section of the BIOO Lite system

When the plant is growing while performing the normal photosynthetic processes, the organic substances or products of the chemical and biological processes are transported downside to the bacteria sitting in the bottom of the pot. Those products function as a nutrition for the microorganism, which are previously isolated by a patented secluding process. The bacteria digest the organic substances and cause electrons during the digestion to set free. The electrons are getting directly obtained by the rhizosphere (directly influenced area in the soil, near the roots). As a result, the electrons travel through the nanowires created by the bacteria from one electrode to the other and create a current between the soil and the electrodes in the system. At the same time, Water (H_2O) is generated due to an access of hydrogen. The current is driven to the accumulator or battery and supplying the wire to the actual device. So, the products of this process are just water (H_2O) and electricity which is a really green solution to generate energy. [1]

3. Electronic Parts

Electronic components are very important in this device as these components act as a bridge between humans and the surrounding environment. With this technology, people can read or can gather the data they need from the surrounding environment with the help of this device. To be more specific, here are the functions of the Treeborg device:

1. Gather the information about:
    a. The humidity and temperature of the air.
    b. The concentration of carbon monoxide (CO) in the air.
2. Deliver the data to the people through display on the web server.
3. Wi-Fi hotspot.

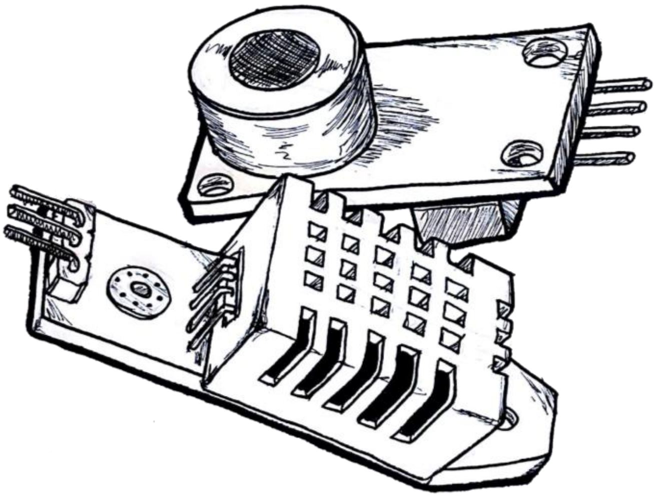


Figure 6: Sensors for humidity and carbon monoxide

As electronic parts are necessary for this device, this section will explain how the electronic parts work in the device. The electronic components in the device can be divided into three different modules. Each module has its own different role in the device and function, which causes the device to work like it was predetermined.

1. The first part is the power module, which stores the energy from the tree and powers up the device.
2. The second part is the data module, which collects the data from the surrounding environment and delivers it to the users.
3. The third part is the communication module, which is about how the device will interact with people and how this device will communicate with other devices such as computers to transfer the data.

3.1 Power Module

The main idea of this module is to explain how the energy from the tree will be stored and used so the device can work normally.

Firstly, energy obtained from the tree will pass through the power shield. The power shield will act as a recharge platform for the battery, so that it can be used to store energy. Then, the energy will be used to power up the device. And again, the power shield will act as a filter which controls the energy that flows into the device. For example, if the level of energy is too small, this shield will boost up the energy, so it can be used by the device.

Below is a flowchart of how this power module will work on this device:

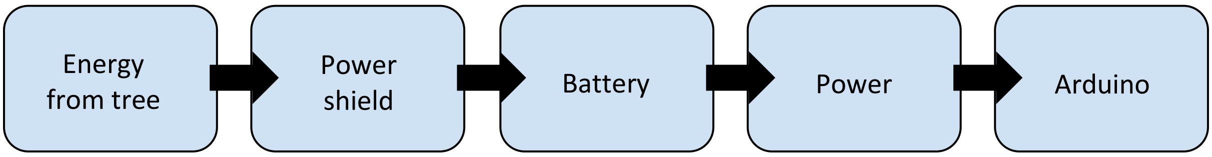


Figure 7: Power Module Flow

The components that are installed in this device for power module are:

3.1.1 Adafruit Lithium Polymer Battery

Lithium polymer battery which is also known as a LiPo battery, will be used to store energy for the device. LiPo battery is a rechargeable battery of lithium ion technology using a polymer electrolyte. Compared to other types of batteries, this battery was chosen because it is advantageous on high energy density, it is small in size, thin, highly safe, cost efficient and mostly, it is compatible with the Arduino and Power Shield.

The output range of this battery is 4.2V to 3.7V. This battery also has a capability to deliver about 1200mAh. With this configuration, this battery is suitable to power up the device as it is using Arduino as its processor and just needs 5V of power to operate. To boost the output voltage of the battery, a Power Shield will be used. [3]

This battery also includes a protection circuit which keeps the voltage of the battery from getting too high due to overcharging or very low, due to overuse. It will cut down the supply of energy when the conditions are met. In addition, this circuit will also protect the battery against output shorts.

Figure 8: LiPo Battery

3.1.2 Adafruit Power Boost Shield

Power Shield is a stackable shield that can be connected to Arduino and provides a slim, rechargeable power pack, with a built-in battery charger, as well as an AC/DC booster. The on-board boost converter can provide at least 500mA of current, and can peak at 1A. There is an on-board fuse to protect against higher current draws which could damage the boost converter or battery. It is also used to control the power going inside and outside the battery. [4]

This Shield was chosen because it is compatible with all other types of processors such as Arduino Uno, Duemilanove, Mega, Leonardo and Due. This Shield also is very suitable for charging the lithium polymer battery.

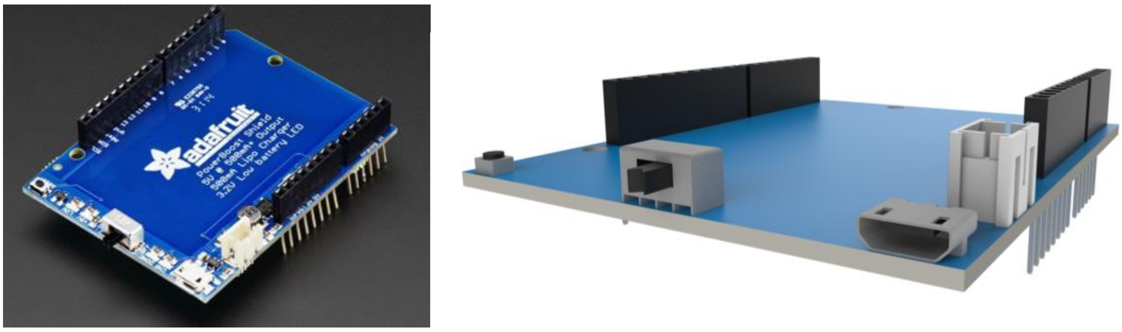


Figure 9: Power boost Shield

3.2 Power Consumption

Below is a table of the power/energy provided or consumed by each part of the device.

Table 1: Power consumption

Energy/Device	BIOO system (energy source)	Battery	Power boost Shield	Device (Arduino)
Voltage	5V	3.7 to 4.8V max	Boost voltage to 5V	4.8 to 5V needed
Current	1A	1200mAh	500mA to 1A	+- 50mA needed

From the value obtained, there will be no problem to power up the device as long as the BIOO system provides a constant source of energy. Moreover, the battery can last more or less about one and a half day while not being in charge mode. Although the maximum voltage for the battery is 4.8V, the Power Shield will boost it up to the value needed.

3.3 Data Module

This section will explain how the data obtained will be processed and how it will be displayed as a warning sign to the people. To clarify Figure 10 was made. Firstly, the sensor that is installed in the device will get the data needed from air surrounding the tree. The data and information will be processed through Arduino with a specific programming code. The data will be monitored and displayed through the web server created.

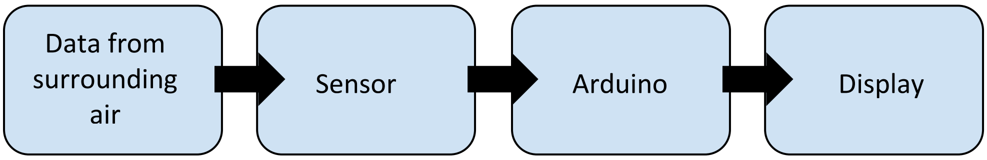


Figure 10: Data Module Flow

The components that are used in this device for the power module are:

3.3.1 Arduino

It is an open-source electronics platform based on easy-to-use hardware and software. Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators. All of the data obtained from sensors will be processed here through coding. You can tell your Arduino what to do by writing code in the Arduino programming language. [5]

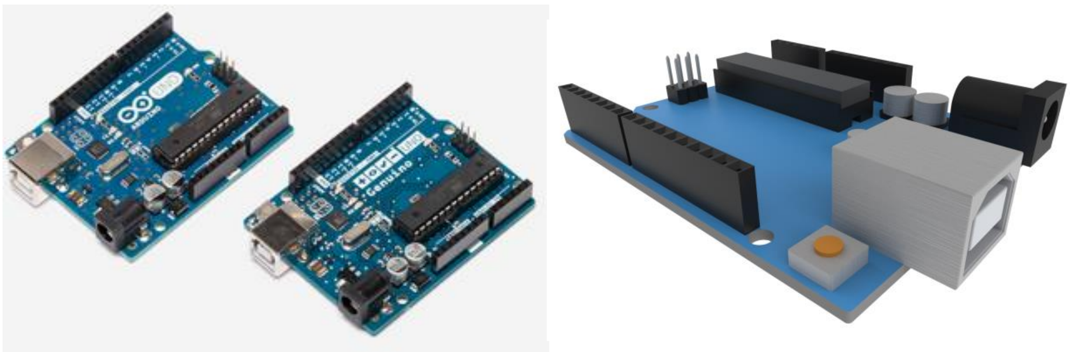


Figure 11: Arduino Uno

3.3.2 DHT22 (Humidity and Temperature Sensor)

This sensor is a basic digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and gives out a digital signal to the data pin on the Arduino.

Figure 12: Humidity and Temperature Sensor (DHT22)

3.3.3 MQ-9 (Carbon Monoxide Gas Sensor)

The gas sensor (MQ9) module is useful for gas leakage detection. It is suitable for detecting LPG (Liquified Petroleum Gas), CO (Carbon Monoxide), and CH4 (Methane). Due to its high sensitivity and fast response time, measurements can be taken as soon as possible. The sensitivity of the sensor can be adjusted by using the potentiometer (device that forms an adjustable voltage divider). The sensor could be used to detect different gases containing CO and combustible gases. It has a low-cost price and is suitable for different applications.

Figure 13: MQ-9 Sensor

3.4 Communication Module

This module was created to give an easy way for people to read the data through their own phone or computer. Through the code shown before, the device can connect to the surrounding Wi-Fi and create their own server. The value of each data will be displayed on this server. For future reference, this communication module maybe can serve as a Wi-Fi hotspot to the people nearby.

For the Wi-Fi connection service, Arduino Wi-Fi shield will be used. The Arduino Wi-Fi Shield can connect the Arduino to the internet wirelessly. With a few lines of coding, people can control their own Arduino through the internet with this Wi-Fi Shield. There is an onboard micro-SD card slot, which can be used to store files for serving over the network. It is compatible with the Arduino Uno and Mega. [8]

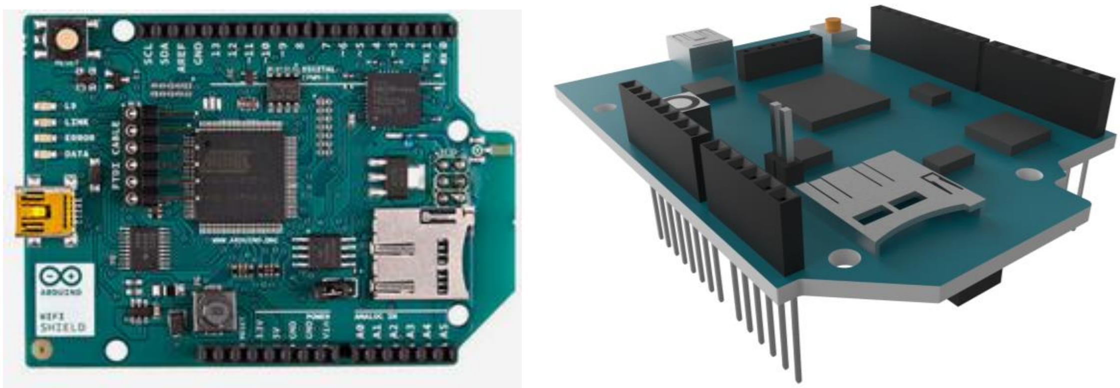


Figure 14: Arduino Wi-Fi Shield

3.5 Code

The programming code is very important for this project. The code (see appendix B.) will act to command the device to do actions through the Arduino. There are two general ideas that were built in this programming code, the first for the data collection and the second one for the web server.

For the data collection.

1. Arduino will command sensors to collect data.
2. Arduino will process the data and determine if it in the range safe or not.
3. Display the data with a warning sign in the Arduino monitor and a graph in an Arduino plotter.

For the Web server.

1. Arduino will try to connect to the network ID provided.
2. After successfully connected, it will create a web server with a specific address.
3. Will display the data with the warning sign.

The table below show the limit value of each sensors that was program in the code. If the value exceeds this limit, a danger sign will appear on the output display.

Table 2: Range and Limit Value of the Sensors

Sensors	Range	Limit
DHT22 (Temperature)	0 to 100°C	28°C
DHT22 (Humidity)	0 to 100 %	100%
MQ-9 (CO gas)	0 to 500	150

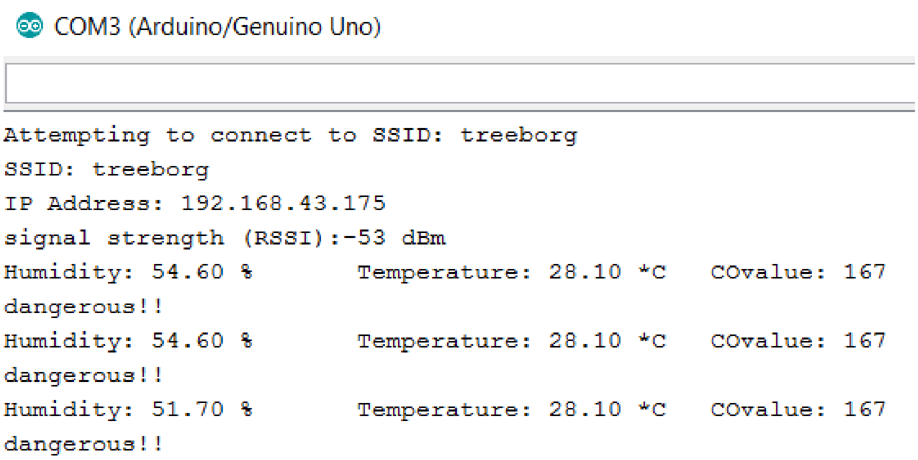
The programming code is available at the appendix (Part B) of this report for more references.

3.6 Output Display

This device will show three output displays to deliver the information obtained to the surrounding people. Two of the options will need a computer from users. Users need to connect to the device using USB and have Arduino IDE install on their computer. And the last one is through the web server that Arduino created. Users can go to the web address provided from Arduino and simply read the data displayed on the server

3.6.1 Arduino Serial Monitor

This display will show the value of the gas and the details of the server created by Arduino.


COM3 (Arduino/Genuino Uno)

```
Attempting to connect to SSID: treeborg
SSID: treeborg
IP Address: 192.168.43.175
signal strength (RSSI):-53 dBm
Humidity: 54.60 %       Temperature: 28.10 *C   COvalue: 167
dangerous!!
Humidity: 54.60 %       Temperature: 28.10 *C   COvalue: 167
dangerous!!
Humidity: 51.70 %       Temperature: 28.10 *C   COvalue: 167
dangerous!!
```

Figure 15: Arduino Serial Monitor

3.6.2 Arduino Serial Plotter

Similar with the serial monitor, but this type of display will show the value of the gas in graphic format so that the data will be easily visualised.

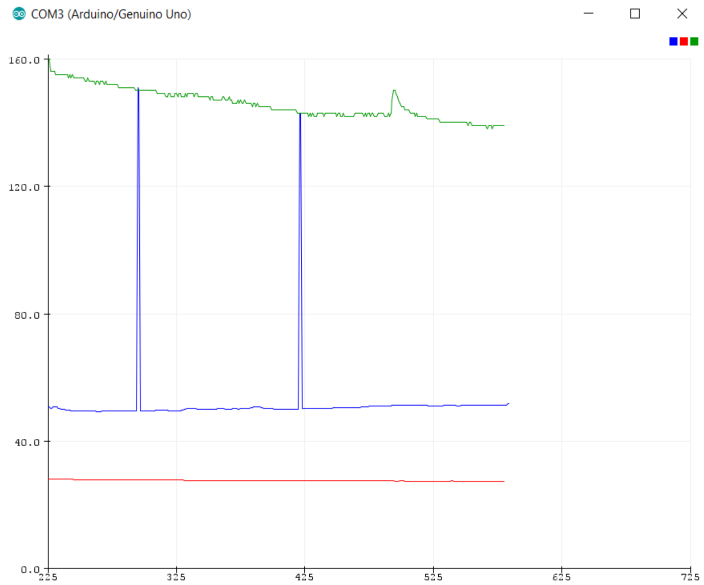


Figure 16: Arduino Serial Plotter

3.6.3 Web Server

All of the information will be delivered through the web server created by the device.

Figure 17: Web Server Display

4. Implementation of the Device into the Tree

4.1 Pros and Cons of Implementation into the Tree

As with many promising ideas, it is always beneficial to look at the pros and cons, as this will clear or bring up prominent issues that arises when it comes to implementing a device into the tree:

PROS:

- Unexplored idea.
- Possibly innovative.
- New method to store/hide devices or products.
- Could prevent further activities such as vandalism and theft.
- The shape and appearance of the tree will not change.
- The natural structure of the tree can be used without an external installation like poles or pylons.
- With the usage of the BIOO technology, the tree stays together with the device independent from external energy sources.
- 'Green' ideas mostly experience more support by the population.
- Through the invisibility of the device, people would not be frightened or distracted by the device.
- Neàpolis Company wanted an internal device.
- The idea of improving the nature by adding features to plants is really future oriented.
- Wealthy corporation partners can be easily attracted by this idea.
- Many cities already have many trees which could be used.
- The appearance of cities will not be changed in a negative way, or could even improve by allowing cities to plant more trees without 'wasting' space.
- The Treeborg can be placed in spots where there is no electrical connection.
- With an implemented Wi-Fi adapter, the Treeborg can be used as a hotspot in areas where no internet wires exist.

CONS:

- The implementation could possibly harm the tree's health.
- If further changes are needed for the device, it could lead to more harm to the tree.
- Unexplored idea, but there are also no experiences and comparable projects.
- Device would probably perform better when placed outside of the tree.
- Tree's growth could damage the device.
- After the life cycle of the device is expired, there is no possibility to get the device out of the tree without damaging the trunk again.
- More work is needed for the installation, like drilling and camouflaging (use of veneer) into the tree.
- Not every tree is suitable to be a host for this device because the trunk has to have a specific thickness and height.
- Not in every city or street are suitable trees at strategic points.

- The usage of living organism as a carrier always take the risk that the plant gets harmed by environmental influences which can lead to a malfunction of the system.

4.2 Pros and Cons of an External Installation of the Device

PROS:

- The installation would be easier because there are less factors to be taken into account.
- The placement would be less dependent on given circumstances because other structures, like houses or lantern poles could be possibly used.
- With an external device, it would be easier to change parts of the device.
- For maintenance, the device can be reached really quickly.
- It would probably work better, as the Wi-Fi signal would not be disturbed by the trunk.

CONS:

- The BIOO technology could not be used without a plant or tree.
- The aesthetic aspect is not satisfied because an exterior pole with the device will not be as appealing as a green tree.
- The device that is not hidden can attract the attention for possible theft or vandalism.
- It is not innovative because a solution with installing a pole with sensors does already exist.
- Infrastructural aspects are needed as the device needs an external energy source.
- Those kinds of devices would not be accepted as a part of an innovative Smart City.
- The project aim would not be reached because it is not a 'Treeborg'.
- It would be less attractive for possible companies/partners to buy the device because it is not innovative and is not 'green'.
- People tend to have a more negative attitude against innovative things when they are actually visible to them, while they are not understanding what it is about, or if it can harm their privacy.
- Needs connection to electrical sources or infrastructures.

4.3 Comparison between Pros and Cons

In summary, there are plenty of arguments for the installation of the device into a tree, but also for an external solution of the Treeborg. The pros and cons have to be compared with each other, but at the same time, the project scope should be taken into account.

On the one hand, the arguments for the external installation of the device are mostly offering an easier handling of the technical parts. Using a pole as a substitution for a tree as a carrier, would exclude the problems which can occur while using living organisms. Those problems can be environmental forces like pests, droughts, or even physical damages to the tree which can harm or influence the health of the tree negatively. All of them will not happen if a pole was used as an 'artificial tree', and also would make the maintenance or future modifications simpler because all of the parts can be reached without complications. But then, the connection with the BIOO technology would not make sense and would be hard to realise without a plant, furthermore, there would be no innovative aspect which would lead to a downgrade for the project and also, there would be no attraction of possible future partners and customers. Without the implementation into a tree and thus hiding the device, it might be really vulnerable and susceptible to vandalism and theft because the hardware parts are actually valuable and would catch the attraction of thieves, like shown in Figure 18.

Figure 18: An external installation might catch the attention of thieves

On the other hand, an internal solution would be more interesting in terms of aesthetic reason and moreover, a support of ‘green’ thinking which perfectly fits to the idea of a future Smart City. By a solution of the project with an implementation of a technical device into the tree, the actual given project scope would be fulfilled. It is a really innovative and future-oriented idea to connect a living organism with a technical device, and in additional use, the photosynthetic products to generate electricity. This creates an independent ‘Treeborg’, which provides great opportunities to improve and simplify the living situation in a Smart City. The downsides of the internal solution are mostly co-relating to the advantages of the external installation of the device. When it comes to maintenance or modifications, the placement into the trunk will disallow those actions and would hinder any steps in terms of access to the device. However, the option of putting the device into the tree will not change the appearance of the city or even improve the city's landscape by enabling governments to plant more trees in cities. And, in addition, the tree would keep its appearance and shape, so people who are often sensitive in a negative way against changes to their environment will not recognise it and will not get distracted by it. Due to its independence to electrical sources or internet cables, the Treeborg could be used as a hotspot in regions where no electricity or internet is available. One of the best arguments for the connection between the tree and the technical part might be the usage of the BIOO technology, because it is an innovative idea and could be attractive for possible future customers or partner companies. Having the connection between machines and plants to create a ‘Treeborg’ could be the first step into the future, making usage of nature instead of fighting against it.

4.4 Biological aspects

When it comes to the implementation into the tree, it should be considered that trees are living organisms and can be harmed through an implementation of an electronical device. Therefore, a methodology where the least damage to the tree is provided should be used. Important at this point is the connection between the roots, where the BIOO module is placed and the device inside the tree. The wires should be hidden under the bark or at least camouflaged and not that visible to prevent them from getting damaged by vandalism or environmental influences.

4.5. The different parts of a tree

When thinking about a tree the first two things which comes to the mind are the leaves and the trunk of a tree because those are the most significant and visible things of a tree. There are more parts of a tree which are important for the life and existence of a tree, those parts are going to be described in the following part of the report.

4.5.1 Leaves

The tree crown consists mostly out of leaves. They are the lungs of a tree, carry out photosynthesis and making the food for a tree, and their main task is the exchange of gases with the air like oxygen and carbon dioxide. The shapes of leaves can differ greatly depending on the species of the tree and the degree of latitude where the tree is growing. For example, trees in colder regions of the world mostly have needle-shaped leaves to minimize the loss of water in the winter and be able to carry them in the winter to avoid growing them anew in the spring to maximize the usage of sun in the short summers. Meanwhile, the crowns of trees in hot regions consist of leaves which can be turned to avoid getting burned by the sunlight and having reflecting surfaces to reflect the excess sunlight.

4.5.2 Branches and Twigs

Branches and twigs are the connection between the trunk and the leaves, while growing out of the trunk. Branches support the structure of the tree crown while transporting materials such as nutrients and liquids to the leaves, fruits and flowers. Especially in cities the branches must be controlled regularly to prevent them from falling down or blocking streets for high vehicles. That is why some trees are more suitable as 'city trees' than others, because their growth can be better controlled. A good example in Spain and the region of Vilanova i la Geltrú are the platane trees. Those trees get often trimmed very hard but can resist this human intervention and stay alive.

4.5.3 Trunk

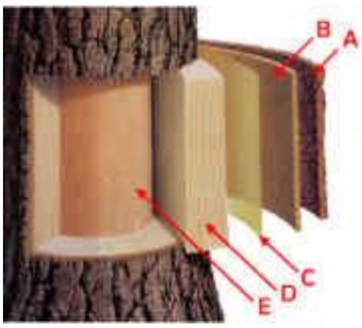


Figure 19 The five layers of a tree

A trunk of a tree consists five different layers, which all fulfil different tasks for the tree. In figure 19. The five layers from A-E are marked to make it more visible.

A. The outer layer is 'the outer bark', its main purpose is the protection of the tree from environmental circumstances, like UV-light, weather, temperature differences, parasites and from losing moisture when the air is dry. It continuously grows and gets renewed.

B. The second layer is 'the inner bark' it consists mainly of bast, it lives only for a short time, then turns into the outer bark and when it dies it becomes the layer of cork. In this layer, the transport of nutrition takes place in the tree.

C. The third layer is 'the cambium', this is the growing part of the trunk. Every year it grows new wood and bark in combination with the hormone cycles which is described later. In spring those hormones get stimulated and causes the tree to grow. This is also a reason why the age of a tree can be measured by it rings in the trunk. If this layer gets damaged this part of the tree will not grow anymore so this is important especially for this project to harm this layer as little as possible.

D. The forth layer is called 'sapwood' because it has the function to transport water from the roots sitting in the ground to the leaves up in the tree crown. Sapwood consists relatively new and young wood, it loses it vitality when newer layers of sapwood are grown out and it, then it turns into the next layer described at E.

E. The 'heartwood' is the last layer of the trunk. It is placed in the middle of the tree and is the 'heart' of the tree. It has supporting and stabilising task and although it contains dead wood cells it will not decay while the other layers around are not damaged or hurt. It is really stable because it consists of cellulose fibres which are glued together with a chemical called lignin and can support heavy weights.

This knowledge about the different layers of the trunk is important for the project because the main part of the device will be placed into the 'heartwood'. One part of the implementation is to close the wound of the tree properly to avoid the decay of the heartwood. Managing to repair the tree as much as possible will be one of the main challenges of the implementation.

4.5.4 Roots

The roots of the tree are mostly hidden in the ground but they are as important for the growth of the tree as the leaves because their function is to stabilise the tree, store food reserves and absorb water, minerals and nutrients from the soil. The roots of the tree are mostly twice as big as the crown of a tree and consists of two different types. At first, the large perennial roots which anchor the tree in the ground and the smaller feeder roots.

The device from BIOO will be placed here to produce electricity and power the device up in the trunk. It is also important for the project to figure out where the BIOO element will be places as the feeder roots are outside at the root bundle, which is mostly placed far away from the core trunk and hidden under asphalt or a street. As an alternative, an extra brush might be planted as later on described in 4.7.3.

4.6. Important facts for the recovery of the tree bark

For the reparation of a damaged tree, at first clean circumstances are needed to minimize the risk of pests and germs further damaging the tree. If the missing piece of bark is still available it can be attached back to tree, but there must be taken care of the right position and direction of the piece of bark. In the methodology of the Treeborg implementation a way was figured out to provide the smallest possible damage to the tree, while using tree hormones to boost the health of the tree.

4.6.1 Auxin

Plant hormones are common signal transducers, which can convert an environmental stimulus into a physiological or anatomical response of the plant. In spring when more sunlight shines on the plants, auxin has an important role in the growth of the roots, using a simple pathway with the plant hormone auxin. The hormone auxin can thus be used to stimulate the growth of the root of tree which is a helpful considering that BIOO uses the chemical processes in the roots of a plant. This kind of growth hormones are often used in the process of refining of fruit trees when branches from other trees get transplanted to other tree or in the fruit industry to stimulate the plants to grow more fruits.

4.6.2 Auxin-Cytokine pathway

As long as trees have an adequate nitrogen supply through the soil which surrounds the roots, the roots will produce the hormone cytokine to establish the auxin pathway. However, when there is not enough nitrogen available, the stress level of the tree raises and the production of cytokine will stop. This causes auxin to be the most dominant hormone in the tree with the result of a root growth and the possibility to reach a bigger area of soil and a greater chance to acquire new nitrogen sources. If the concentration of auxin and cytokinin are equal, then normal cell division will take place. If the concentration of auxin is greater than cytokinin, then roots will form. If the concentration of auxin is less than cytokinin then shoots will form. As a result, this hormone can also be used to support the tree to grow more roots after the installation of the BIOO technologies to make the system work more efficient.

4.6.3 The natural reaction of a tree to damage

The loss of a branch or a piece of bark will disrupt the auxin-cytokinin pathway. It is because of the missing piece of the tree the auxin production will be stopped and the production of cytokine will be continued, also at the point where the tree got damaged an increased level of water will occur because the cytokine-destroying genes which are produced in the missing tissues are also missing. As a result, the pathways are disrupted and an increased growth in the roots and branches occur. In relation to the implementation of the device the addition of auxin as a growing hormone can increase the growth and ability to repair the damage to the tree. In the fruit industry those hormones also are used to boost the growth of fruits and their associated plants.

4.6.4 Platane tree

Platane trees also plane trees form an own family with around 10 different species of plane trees. Their maximal age differs between 100 and 300 years. The wood of this trees is very hard and stable and the need of the tree is only sunny place. Those species are really undemanding.

Platane tree are quite common in cities because they are pretty resistant against different levels of humidity they can resist wet grounds in wetland habitat but also are they tolerant against droughts. The trees are often used in cities because they seem to be tolerant against urban conditions like air pollution and damaging of their trunk and branches. The branches of the plane trees are vulnerable to wind that is why they have to be trimmed regularly. Due to the facts that this is the most common tree in Vilanova i la Geltrú, there was considered to use this tree for the prototype implementation.

4.7 Methodology

Firstly, there should be taken in account which trees are capable to carry such a device. Therefore, there some characteristics the trees should possess and important notes that have to be remembered:

- A sufficient diameter of the trunk to support a hole with those dimensions.
- A sufficient height of the tree because the devices are to be put into at the height which will make it easier to hide the device and to prevent the Treeborg device from being stolen.
- A good position of the tree; the tree should be central in terms of position to guarantee the biggest coverage for the sensors and the potential Wi-Fi signal.
- The species of the tree is also an important factor because not every species of a tree is suitable for this device and even for being a city tree.
- Health of the tree: the tree must be in a good state of health to support such an intervention into its organism. Only healthy organisms are capable to recover from operations in their trunks.
- Age of the tree: the tree should be middle aged with potential to grow but there should be remembered that the growth of the tree can cause problems with the position of the device. Young trees will not have the sufficient diameter to support the drill hole and too old trees will be incapable to withstand the changes.
- The bark should be healthy and mainly undamaged to make sure that the operation can be accomplished properly.

- It should be also take in account that tree pests can use the drilled hole as entrance for their lifecycles if the holes are not sealed properly.
- Sealing of the wounds is an important step to prevent moisture to move into the tree and cause the heartwood to rot which could cause a total collapse of the trunk.

4.7.1 Implementation of the technical device into the tree

The implementation of the technical device into the tree might be one of the biggest challenges of the project, this is caused by the fact that there are almost no similar projects or ideas to compare with. Nevertheless, there are a few methods how the implantation or attachment of the device in or to the tree could be realised.

One of the first considerations was an external installation of the device on the outside of the tree or even on an artificial pole (See 4.3 for more pieces of information) but those ideas would not fit into the project scope and were quickly discarded. The external attachment to a pole or the tree would be simpler to handle but would also entail negative things.

Figure 20: Natural holes in Platane trees in Vilanova i la Geltrú (Cat)

The second option was a utilisation of natural holes in the trees, this would be easy to realise, as long only natural resources would be used and no additional harm to tree were provided. This would be a really simple solution as some of the tree holes are really big (see figure above) and the openings are common as well. On the other side, the usage of those natural pinholes would be dependent on random factors which makes it hard to plan and realise. Furthermore, the project scope was to find a methodology which can be applied to almost every tree in cities.

As third option, a drill hole was considered. This is one of the most logical solutions as wood is a material which is relatively easy to pierce with the help of a drill. The biggest obstacles here were the fact that the drill hole must be placed into a living organism and that it must be taken into account that the damage should be as small as possible. The first thoughts were a normal big drill, but after the making first prototypes, it turned out that the actual device would be too big (diameter

7,5cm) for a normal drill hole with a maximal diameter of 1cm. After a conversation with a wood specialist, it became clear that for the drilling a special drill would be needed. A utilisation of a crown drill bit was considered to drill a bigger hole with the right diameter. (See figure)

Figure 21: Special crown drill bit to drill bigger holes

For practise routine, there was a piece of a dead tree trunk ordered to figure out the best methodology to pierce a suited opening into the wood. The simulation is a good way to discover the weaknesses and strength of the method, however, the factors of the living tree cannot be practised. It might be difficult without the official permission to practise on a living tree.

On a living tree, there are more factors which should be taken into account: the age, health, height, diameter, position, species and the condition of the bark; after the selection considering those characteristics the implementation can start. If the suitable tree is found a right place for the device is needed, it should be in an adequate height to prevent the device of theft and on a hidden spot or at least not that conspicuous. Then, the bark has to be opened with three cuts: one horizontal and two verticals, to create a rectangular opening in the bark to gently drag down the three important outer layers of the bark. The next step would be the drilling of the canal for the device therefore the drill with the appropriate crown bit can be used. The device will be stored in the heartwood, which consists only of dead cells, so it will not hurt the tree. The drill is only able to drill a hole for 7cm with the crown so this step is divided into two parts. In the beginning a 7cm deep hole is going to be drilled, then the inner wood has to be removed with a hammer and chisel and then the same working step has to be performed to create a canal with the length of approximately 13-14 cm into the tree.

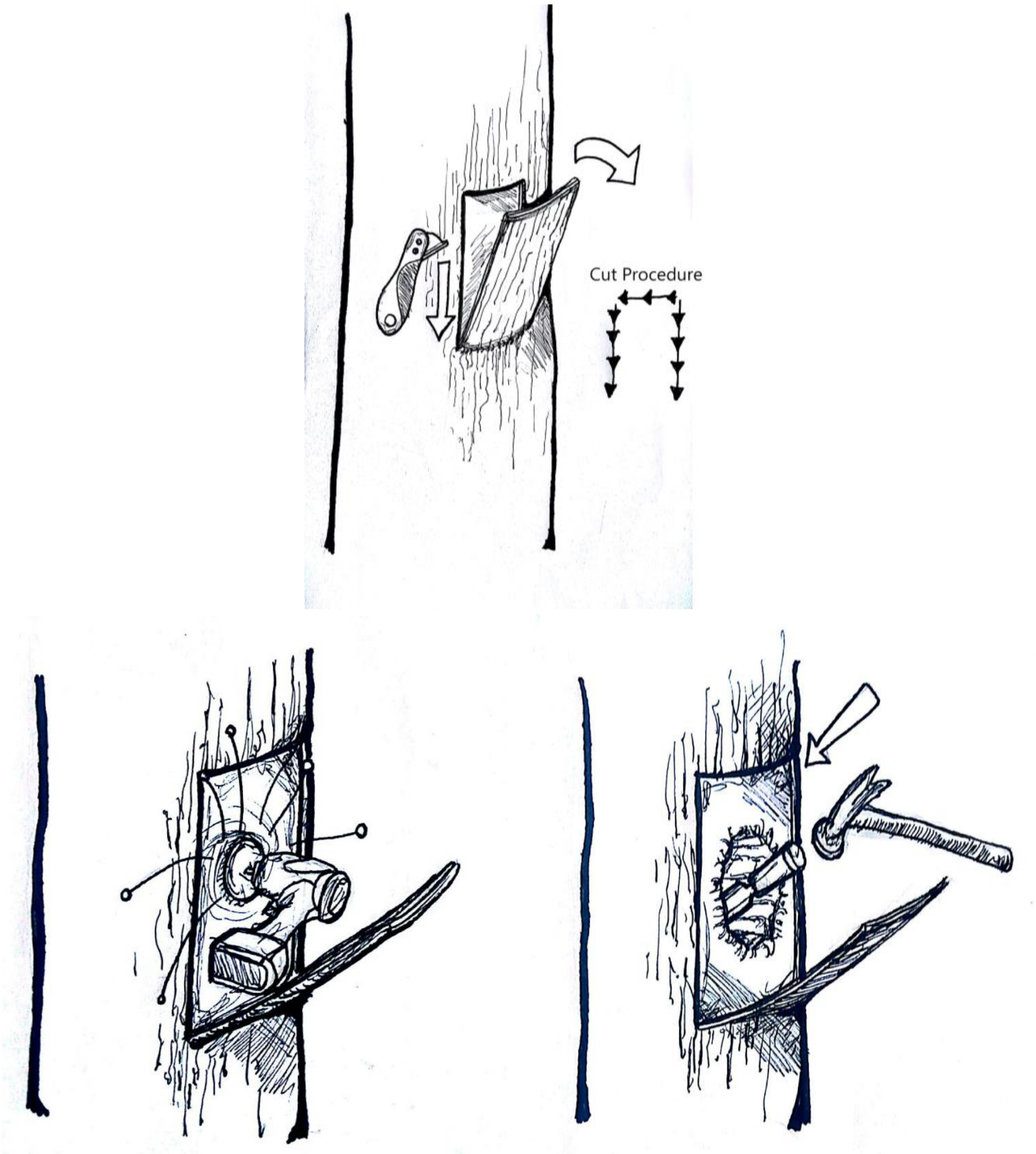


Figure 22: Method of making the hole

After drilling the hole, the device can be placed into the tree and the hole must be sealed properly to prevent fungi spores and other tree pests to enter the canal. There would be an option to apply tree compatible fungicides and pesticides to secure the health of the tree. As a next step the bark can be put back to its original spot and fixed to the wood to ensure that the important cambium layer, which controls the growth and nutrition transport is undamaged. As one of the last steps the Kevlar canal for the cables can be drilled to connect the device and the sensors. The attachment of the sensors is explained in 4.7.2.

Finally, a treatment with tree growth hormones can be considered to give the tree a small boost for its recovery from the implementation and attachment of the device. The utilisation of hormones would consist of the medication with auxine and cytokinines. Those are hormones, especially auxine, has a 'cell stretching effect' which stimulates the growth of cells and in this case the growth of roots and buds of the tree. This would be actually handy, because the roots will get probably damaged through the installation of the BIOO parts and more new roots will provide more growth overall, which can have a positive effect on the recovery process. [9]

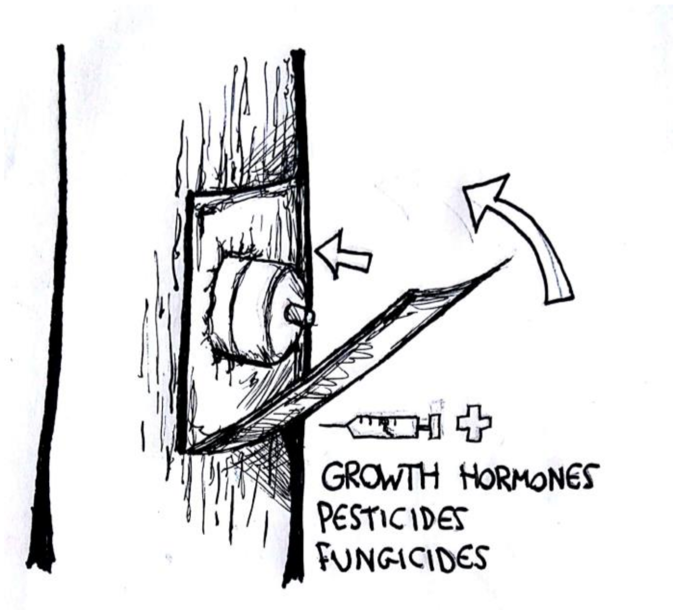


Figure 23: Hormones treatment to repair the bark

The methodology which is described above was used for practise purposes and might be possible for a dead trunk or for a really big tree which has a big diameter. There was a different method investigated to provide possibly less damage to the tree by using the uncut section of a cut branch as a hideout for the device without hurting the main trunk. This might be also a good option for the platane trees as they get trimmed every year they offer a lot of uncut sections to hide the device in it.

For this method, is it necessary that there is a suited tree with a multi-branch crown, where a branch might get cut for installation purposes. Then the branch would get cut leaving a ~20 cm long uncut section at the trunk. Therefore, it should be made sure that only the branch which gets cut, gets damaged and no other part of the tree. As the following step, the uncut section would get drilled and thus, eroded to create space for the device in it. After sealing the inner surface with fungicides and Bacteroides, the device can be deployed by putting it into the new opening. After closing the opening, it should be taken in account that there will be no moisture left in the new wound, because moisture causes fungi to grow and harming the healthy wood of the tree. An optional method to combat this is install a drainage pipe to make sure that all accumulated moisture will get out of the hole. This is a common method for clipped fruit trees, which form sometimes knotholes. [11]

When it comes to the tree operation, the moment should be chosen wisely there are seasons where the trees can react better to eventual damages than during other seasons. For example, during the summer months is the chance of a higher infection than during winter, but on the other side is the tree during the colder months, which is less active and cannot react on the damage. But taken in to account that a platane tree would be used, it is well known that especially platanes need their trim during winter which would enable also the implementation of the device at the same time.

It should be taken in to account the developed device is only a prototype and future devices might be much smaller. The decreased size would enable more ways to implement the device without harming the tree that much. While considering that possible sizes of drill holes might be around 3cm diameter, which would allow a 18x45mm Arduino Nano to fit in. Basically, a rule can be applied: the smaller the device gets, the less damage will get applied to the tree, which makes a further development necessary.

4.7.2 Attachment of the sensor housing on the tree

For the attachment of the sensor housing on the tree, the same conditions should apply to provide the smallest possible damage or harm to the tree, especially the outer two layers of the tree: the outer bark and the cambium, to not hinder the growth of the tree.

Five different options were considered to attach the sensor housing on the tree. The first and probably easiest way would be an installation with the help of a nail. It is really important that the nail is made from the soft metal, aluminium. This material is the best option because it can be cut by chainsaws. However, more stable materials can be dangerous for chainsaws and the saws in sawmills because the possible sparks can cause a fire. Furthermore, aluminium forms an oxide layer quickly, which prevents the metal from corrosion, for example: corrosive iron nails would cause a poisoning effect on the tree and might be very harmful in the long run. In addition, it would be important to make sure that the nail is not completely lodged in the wood and to leave the tree some space to grow, 2cm should be enough, taking into account that the device would be attached around 5 years to the tree. Most suitable are special forestry nails made from aluminium which are also used by forestry industries to attach trail signs to trees.

Figure 25: Example for the use of nails for signs

Figure 24: Metal wire to attach birdhouses

Figure 26: Attachment of the sensor housing with utilization of aluminium nails

The second option might be an attachment with the help of a leash made from a metal wire wrapped around the trunk. In this way, the bark would not be harmed at all and a removal would be really simple. The most important things which should be taken into account are that the leash is not too tight to prevent the growing tree to get choked by its own growth. There is also an additional thing to add which would prevent the metal wire to choke and cut into the bark, a rubber tube wrapped around the wire to expand its diameter. Another important subject is the material of the metal wire, the material should be comparable to the nail in the first paragraph, made from metal which is not corrosive or has a rubber cover to prevent metal ions from poisoning the tree. This method is often used to hang up bird houses or nesting boxes in trees and is a good option if the attached object will not stay that long in the tree.

The third option is also used by the forestry industry for the attachment of trail signs. It is a small curved, non-corrosive metal plate (adapted to the trunk curvature) glued to the outer bark of a tree with the help of environmentally-friendly silicone. Important for this option is that there is absolutely no free space between the plate and the bark to prevent it from water logging and against frost damage. With this solution, it is important that the species of the tree is analysed, because for example: the platane, which is a pretty common city tree, loses parts of its outer bark frequently. This fact could make the glue attachment a bit difficult, as the outer bark is not that stable in comparison with bark of other trees. Like options one and two, this option also will not damage the outer bark and might be suitable for a short-term solution.

Figure 27: Example of the tree bark used for method 3

A fourth option might be suitable for sensors which are not directly placed at the main trunk and more placed in the crown on branches. For this attachment, a clamp (jubilee clip) would be used with a flexible width to support the growth of the tree. Also for this solution the choice of material is to be considered. A sort of clamp might be the safest possibility because branches mostly move in the wind and eventually bend sometimes. The clamp must be flexible to not strangle the branch in its growth, otherwise the branch would be harmed and could possibly die if the clamp is too tight. A cheaper option would be an attachment with a small bast rope. Those ropes are often used with freshly planted young trees to fix and support them. Those ropes are made from organic material and are therefore, not harmful.

Figure 28: Example of method 4

The last option might be a free hanging sensor case, but this option would be only possible if the sensors would be independent from any energy source, using its own battery and own set of modules to send the data. This option would be combined with mimicry, for example: fruits of the tree or an artificial branch. This option would enable a greater spreading of the sensors and thus, a bigger measuring range. The whole tree could be involved as a measuring area for the sensors.

4.7.3 Installation of the BIOO technologies

For the installation of the BIOO technology, only theoretical solutions are concerned because of the lack of time and because of the fact that the BIOO technology is delivered by an external partner. It was communicated with Arkyne Technologies, that there are probably two possible options to connect the Treeborg with their system. The first possibility would be the direct connection of the tree roots with the bio system. This would cause some problems, because normally city trees, which have a suitable diameter for the device, are mostly surrounded by asphalt and paving stones. As a result, there would be structural construction works necessary and the smaller roots which are relevant for the transport of water, nutrients and the photosynthetic products are most likely far away from the trunk and deep in the ground. Furthermore, is the BIOO technology only optimised for the application of smaller brushes, grass and plants and not yet for trees. But this is definitely an idea for the future and Arkyne is already doing research with trees, figuring out which species are the most suitable for their technologies.

The second possibly used option is the planting of smaller plants/brushes or the grass panels in the direct surrounding of the tree together with the BIOO technology. This would enable a much easier installation and maintenance of the technology. There are possibilities like traffic islands with the BIOO plants and a Treeborg on it. The greatest advantage of this solution might be the fact that it is already achievable with the existing BIOO systems. The only problems of this solution might be the greater risk of theft and/or vandalism. But the aim of this project was to hide everything so with a good camouflaging it might be impossible to locate the device and it would prevent it against those criminal actions.

The final challenge might be the connection between the two systems because there is a cable needed and a long-distance gap has to be closed from the ground up until higher in the air: there is also the fact taken into account that the tree still grows, that is why the cable has to be flexible or must contain a function to extend its range. Another important feature must be the camouflaging or integration into the tree. There could be a small canal drilled under the two outer layers of the trunk to hide the wires. This would provide extra damage to the tree and a small hidden camouflaged cable might be a more elegant solution.

4.8 Potential impact on the tree

The possible impacts on the tree can be a damage to the stability and the health of the tree, it is dependent on the width of the device, how big the drilled hole is going to be. As earlier mentioned it is necessary to do the least damage possible to the trunk and the bark to keep the organism alive and healthy. If the wound is not sealed properly the open wound can cause an easy access for tree pests to enter the tree and damage the different layers of the tree. First of all, there are no comparable installations or inventions made so the problem is that there is no research about what impact a possible installation into a tree can have. But it should be taken into account that trees are really robust organisms, they can withstand many environmental impacts and survive for example bush fires, lightnings, storm damages floods and droughts. Also, there are many examples for trees which still are alive even with big holes drilled into it by animals like woodpeckers. In figure 29, there is an example of a natural hole in a tree which is used as a nesting place for a duck family without harming the tree.

Figure 29: Woodpecker hole used by a duck as brooding place

One important aspect is the species of the tree, because there are many factors which determine the resistance and resistivity of the tree. The actual state of health and position of the tree is important to take into account, because a healthy tree can withstand the implementation probably more easily than an already weakened tree which suffers from diseases, pests or other negative circumstances. So before implementing the device a health check of the tree is obligatory to secure the successful implementation of the Treeborg device.

In terms of species, there are better and worse suited species for example conifers are more protected against damages of their bark, because they produce a huge amount of resin which is a natural sealing of the wounds. Resin consists mostly from terpenes and derivatives and has an antibacterial and fungicide effect which is the trees perfect solution against injuries at the bark to prevent insects and pathogens to invade them. However, conifers are more known for a resin production and are therefore better protected against wounds in their bark than deciduous trees. But, there are also a good number of deciduous trees which are able to resists many negative threats and could support an implementation of the device for example: the common platane trees. Platane trees are known for their resistance and resistivity against many negative environmental and human caused influences. In the picture below a strongly trimmed platane is shown, those trees can resist those great interventions in their physical appearance and would endure also a drilled hole into their trunk.

Figure 30: Platane tree with its winter trim in Germany

An important thing is, besides the maintenance of the device, the tree health care; in regular intervals, someone should check the growth of the tree and the actual health condition of the trunk. In the figure below is an example shown of a sign which was attached to a tree and forgotten for a long time and is now grown into the tree. What is the problem with those long-lasting organisms is that many complications are only visible after a long time and then aid might be too late.

Figure 31: Impact of an ingrown sign on tree

Summarising, a good sense of responsibility can guarantee a coexistence of the technical part and the living organism. A responsible treating of the tree will allow to implement the device into a tree and with future improvements the intervention into the tree will be even smaller as the device will get smaller.

5. Design

5.1 Concepts

To properly design a housing for both the sensors and modules, a brainstorm should be conducted. At the beginning of the semester, a few ideas were randomly generated ranging of multiple concept ideas. Some of them were taking into account the housing being partially located on the exterior of the tree and some fully located in the interior. Since the initial idea was to create a modular system, the exterior designs were more considered as after installing them partially outside of the tree, there is still the possibility for some further adjustments with time.

First proposition, depicted on figure 32, was to make a round capsule with a similar shape to a cocoon that will allow the tree to grow around it easier. It is a very similar concept to the second design as both consider the possibility of opening glass doors installed in the boxes. The advantage of the first design is the fact it does not have any sharp edges. Also, in the most outside part of the capsule there is a place to create the connection between the capsule and the energy source or to hide the cables.

The second idea, presented in figure 33, does not have a special place for the connection with the energy source, however, it has two other advantages. Firstly, it has the sensors indicators, so that if any problem occurs they will inform which sensor does not work. Secondly, on the back of the housing there is an anchor roll ball that helps to properly locate the device in the tree. Both designs were considered as relatively big devices.

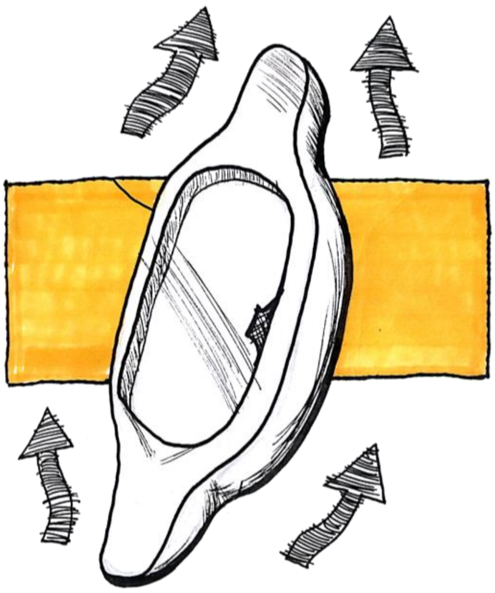


Figure 32: Sketch for device 1

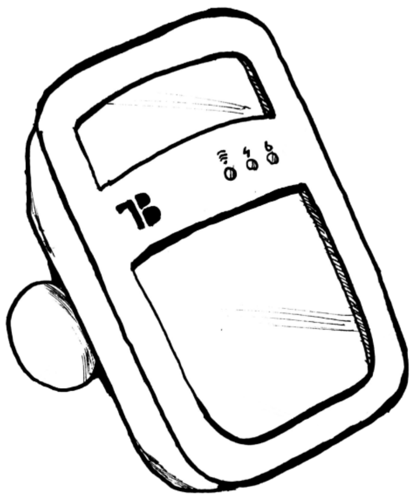


Figure 33: Sketch for device 2

With the progress of the project, it turned out that there is a very limited space in the tree for the device regarding the heartwood, measurements, etc. Therefore, a new concept must have been created. It is presented in figure 34. It has some of the features from the previous designs such as a streamlined and slimmed down shape, the sensor indicators and the glass window. The utility of this idea is, however, more deliberate.

Firstly, in this design it is not just the glass part that could be removed. The whole front can be disconnected from the box to allow the access to the inside system. Also, the sensor indicator will not light up on their own. Only when a special magnetic key is placed in a keyhole the indicator of the broken sensor will light up.

Another aspect worth mentioning is that the box can be positioned in a tree vertically and in doing so, a smaller part of the tree will be hurt. Furthermore, the sensors need to be located partially on the outside of the tree, therefore with such a design there will be a possibility of creating a place for them on the front part of the housing, decreasing the number of used cables and making the whole design more concise. This prototype would also be suitable to house smaller modules such as the Arduino NANO and the ESP8266.

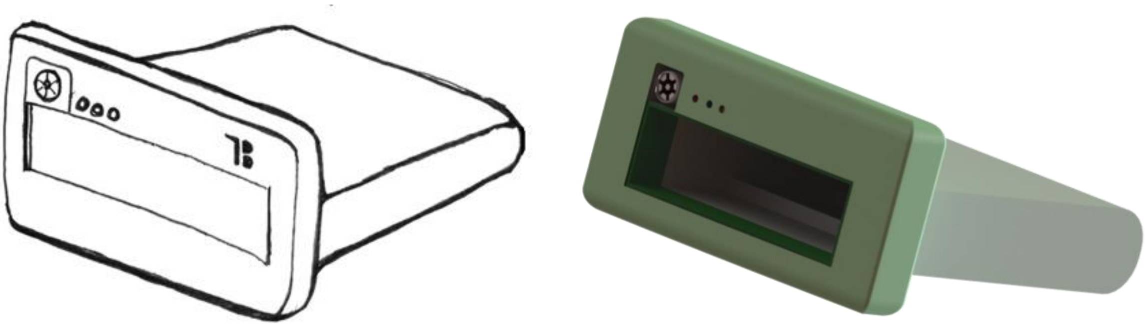


Figure 32: Sketch for device 3

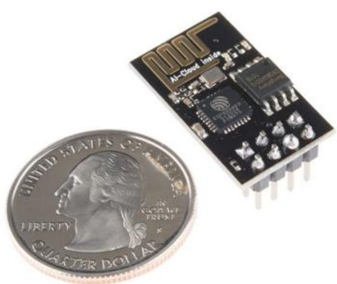


Figure 33: Size comparison between the ESP8266 and a coin

The more research that was conducted, the more real the project was becoming and it occurred the idea of the modular, partially outside box was inapplicable and not what the company initially wanted. To adhere by the brief, the device should be located in the middle of the tree (heartwood section of tree) and place the sensors outside of the tree to ensure the sensors would provide accurate data. The sensors should also be placed in a special housing that can be placed on the outside of the tree whilst connecting to the modules in the tree.

One of the first designs turned out to be the one that was most suitable to be the base for a final shape of the module housing. This design is a full capsule idea depicted on figure 36. It also retains the magnetic lock design and LED indicators from previous designs to ensure security and clarity when a problem arises with one of the components.

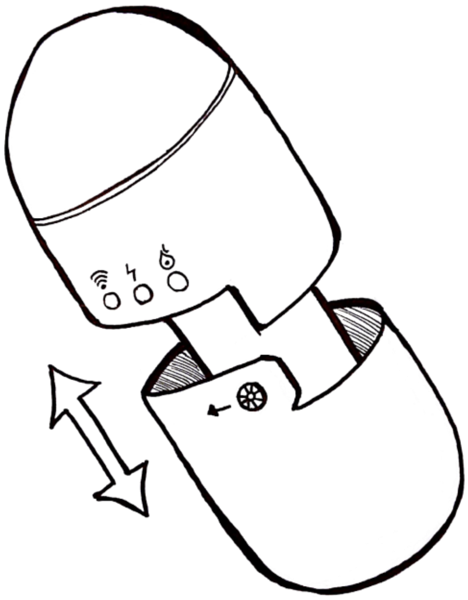


Figure 34: Sketch for device 4

For the sensor housing, a design was drafted up and was made to be small, discreet and simple. A block design was initially used and would be attach to the exterior of the tree. Over time, the design changed subtly in terms of shape and size. To protect the cables connecting both the sensors and modules, they would be encased with a tough cable probably made of Kevlar to ensure that the cables do not get crushed or damaged during installation and use over time.

While discussing the housing for the sensors, two options were considered. First one was to place sensors in line, as depicted in figure 37. The second was to place them one next to another as shown in figure 38. In the first solution, the advantage is that one side is relatively shorter than the other so it will be possible to position it vertically on the site of the tree and reduce the impact. Nevertheless, the second option turned out to be more practical as not only the cables can go out from the same hole but also the shape is squarer alike and the total area is smaller.

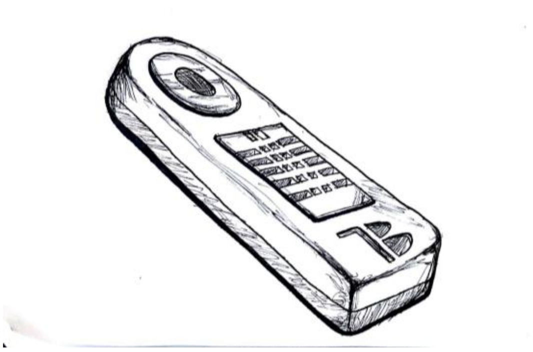


Figure 37: Line positioning of the sensors

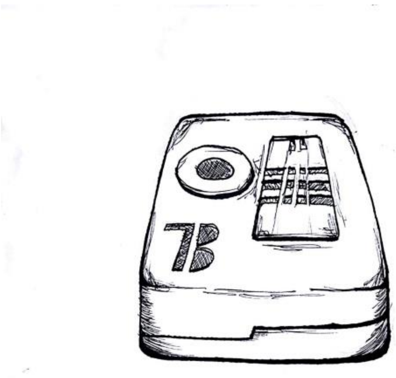


Figure 38: Side-to-side positioning of the sensors

Once the general idea for the housing of the sensors was established, more details had to be defined. Firstly, the sensors needed to at least, stick out from the housing. Secondly, after being placed, they cannot move, they need to be securely locked. The most effective way to do that is to create a special hole for the sensors in one part of the housing and in the second- closing part make special extrusions that would clench the sensors.

The most difficult part was to come up with the appropriate closing for the two parts of the housing. The first idea (figure 39) was to make small pins, however, they would not provide 100% assurance that the box would not open or that it would fully close itself. The second idea was to close the box as the same as an ice-cream box, as shown in figure 40. After few discussions, it turned out this is impossible to be made and therefore the idea was rejected. The third concept was to create the groove on one part and the slide on the other and slide them together. This was a really good idea if not the fact that the wires will not come out on the proper side of the box.

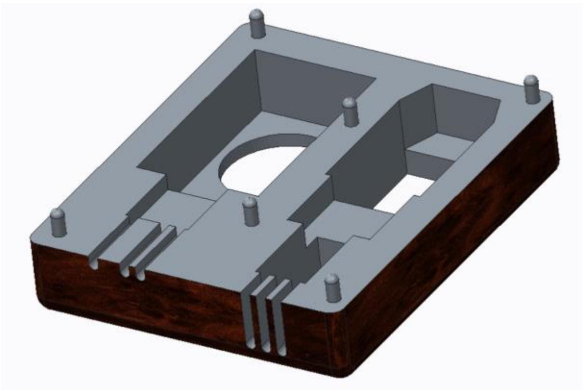


Figure 39: First idea

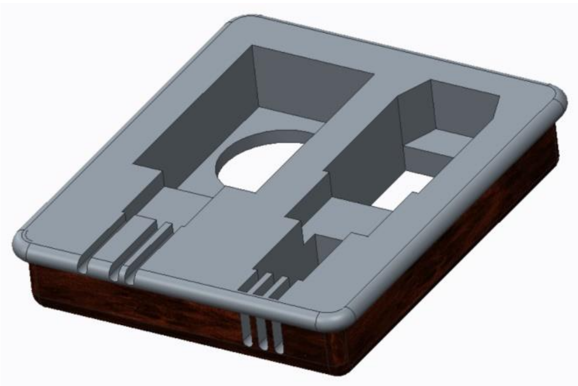


Figure 40: Second idea

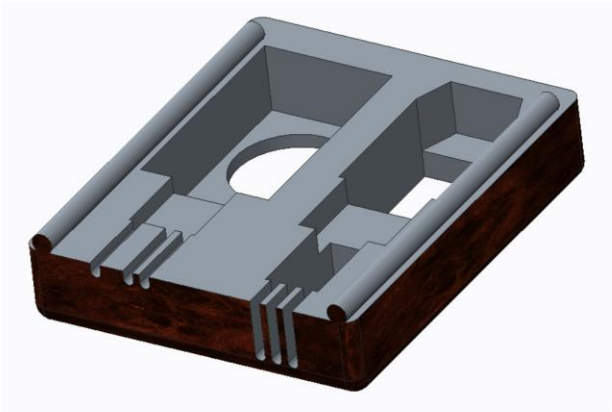


Figure 35: Third idea

As the final closing, the close fit was chosen. It does not require any special adjustments and the cables can go out from the same hole placed on the back of the box. The renders of the final design are shown in figure 41.

5.2 Final design & Housing

For the final selection of concepts to use for our device, we had to make sure that the designs were approved by our supervisors and that they met the brief's guidelines.

For the interior device (containing the electronic modules), a capsule-shaped design is selected. In similarities of previous capsule designs, the design has a more re-defined shape which is similar to a general biscuit tin. The edges have smaller fillets to reduce the size of the overall capsule to ensure no extra space is used. The capsule itself is made of two parts (bottom and top) which have a specially made slot for the combined modules (Arduino UNO, Wi-Fi Shield, Power Shield and battery). For the remaining space inside the capsule, cables are soldered to the modules instead of connectors to allow for minimum space to be used. Both parts close together with a simple slot mechanism that allows the top part to slide onto the bottom. Since the capsule will be placed inside a tree and will stay there, features such as the special magnetic key and LED indicators have been removed. The capsule will be sealed with a strong adhesive such as Gorilla Glue as it will protect the capsule from moisture inside the tree. For cables to connect to the module from the sensors and BIOO's technology, a 10mm diameter hole is placed on the top part. A cable made of tough material such as Kevlar is used to cover the hole and also, protect any wires/cables that are used in transit. The overall dimensions for the assembled capsule is 95mm in height and 74mm in total diameter.

Technical drawings are available in the appendix under part A for more visibility of the design process.

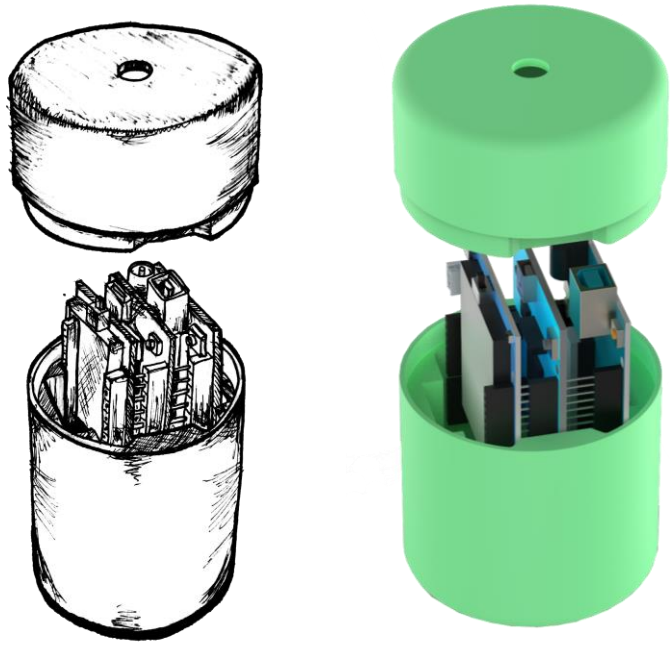


Figure 36: Final design for Interior Case

For the exterior device (containing the sensors), a simple box shape design is chosen. Like the capsule, the sensor housing will also be two parts that can close onto each other. The cavity of the sensor is specially made to house both the DHT22 and MQ-9 sensor and secure them in place. Since the sensors are placed outside of the tree, they will provide accurate data for the modules. To ensure that the sensors do not get destroyed by outdoor elements, a mesh should be used or that sensors should be covered with a waterproof coating. The cables of the sensor will travel through an 8mm diameter hole on the back of the housing which will also use the same Kevlar cable from the capsule. A wood based glue or epoxy can be used to secure the housing to the tree as using screws/nuts/bolts against a tree could lead to further harm and damage. However, aluminium nails can be used as aluminium does not corrode and is a soft metal. If the sensor housing is attached near a branch, a special type of jubilee clip can be used to secure the housing and allow the tree/branch to still grow with affecting the sensor. The way of securing the sensor box is described more in details in point 4.7.2. The overall dimensions of the housing are 50mm in height, 60mm in width and 22mm in depth. To tackle vandalism and the weather, the housing will be coated in a wood veneer that replicates the current tree and sprayed with a waterproof coating.

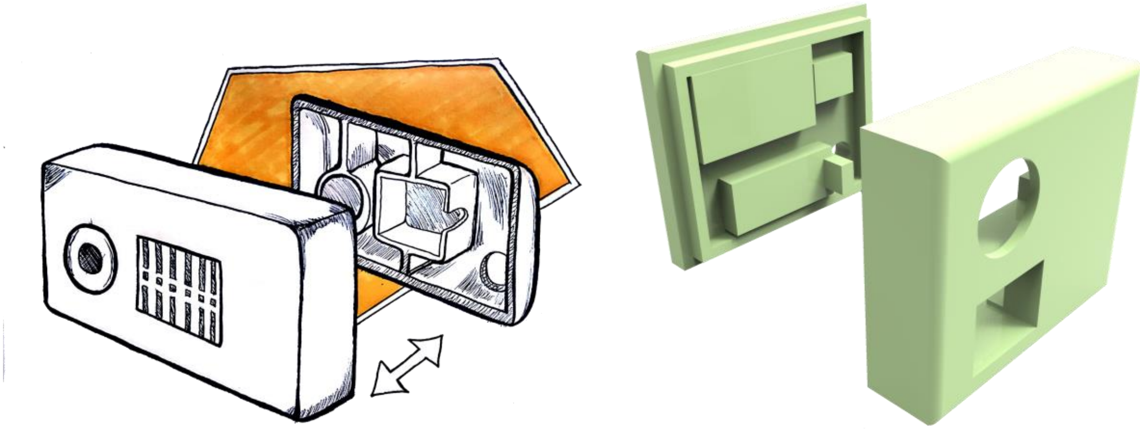


Figure 37: Final design for the sensor case

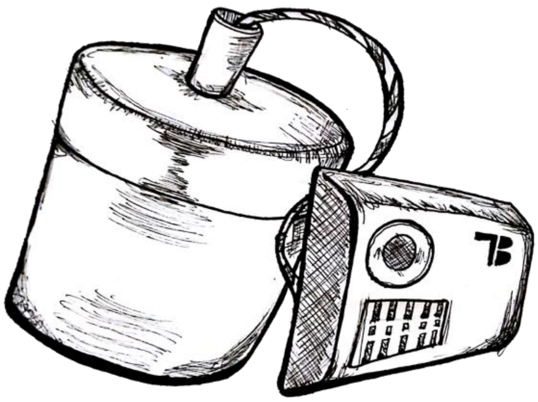


Figure 38: Sketch for the whole device, hardware housing and sensor housing

5.3 Prototype

For the prototype of our product and to test its usability, it was needed to make a working model as it is one of the brief's main guidelines. Since there are not a lot of parts used for the capsule and sensor housing, they could be easily made using a 3D printer.

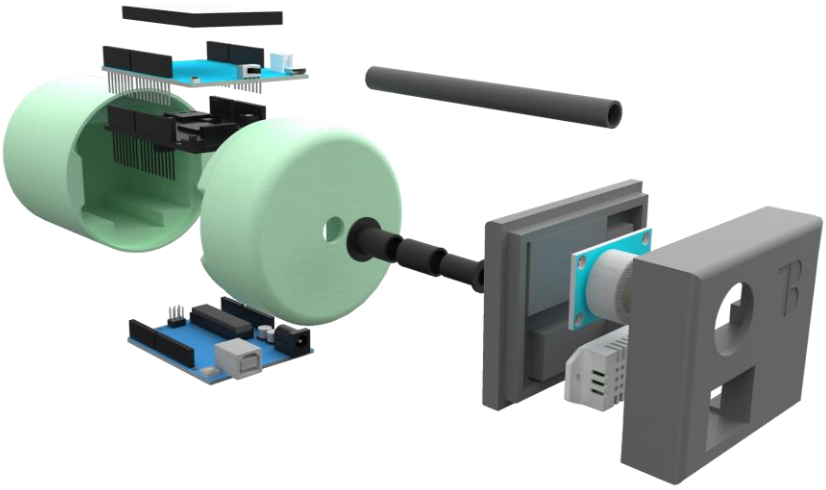


Figure 39: The whole exploded view on the device

To start with the capsule, a look at suitable methods had to been made that could be used to close and seal the capsule. Initially, a solution using a threaded capsule which would lock by revolving. Since this was going to be a prototype and also be used to demonstrate in presentations, it was changed from threaded to chamfered slots, so that the capsule would be able use a close fit. Once, the CAD model of the capsule was ready, it was ready to print. The printing took at least 24 hours and was a lengthy process. The dimensions of the capsule were 125mm in height and 90mm in diameter. A 16mm diameter hole was used on the top capsule for cables to pass through. Due to tolerance errors and misprints with the machine, the capsule could not close properly and needed force to open. Fine sandpaper was used to shorten the diameter so that the capsule could close properly. Another problem with the capsule was that is was too big and would probably not fit in the tree's heartwood.

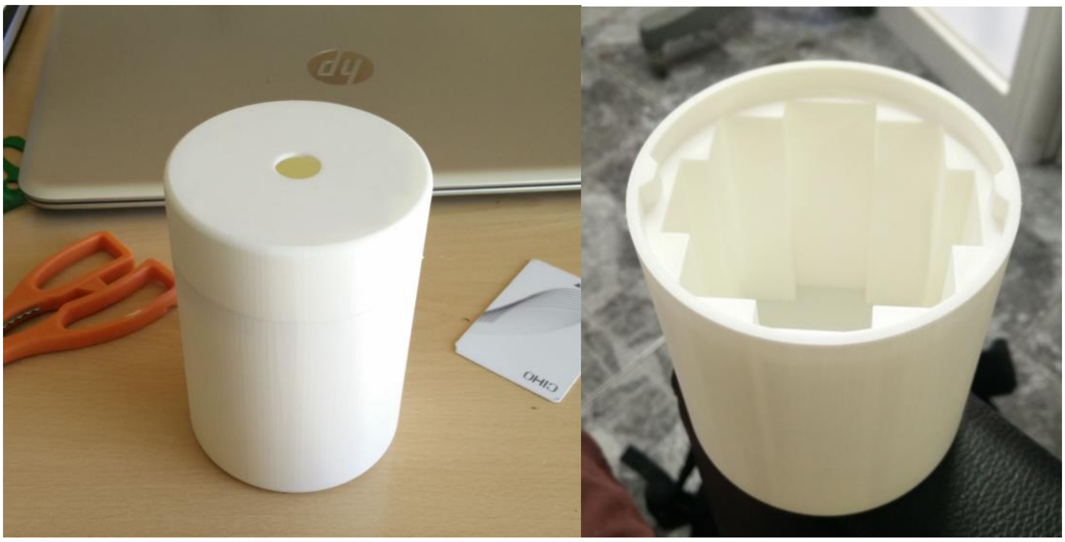


Figure 40: Interior Case Prototype

The capsule prototype was redesigned with the capsule itself being completely smaller than its counterpart. Space saving was used in areas that were deemed a waste and made to good use. The overall height of the capsule is now 95mm which was the height of the previous bottom part of the capsule. The diameter of the capsule is now 74mm. The hole in the top part of the capsule was now 10mm in diameter. The inside housing has been changed to adjust to the changed measurements of the combined modules. Since the goal was to make the capsule as small as possible for an easy fit in the tree, extra space inside of the capsule had to be lost. For instance, wires will have to be soldered to the module as there was no space for wire connectors as they took up too much vertical space. The capsule needed a bit of sanding to tighten the diameter to ensure an easy close. A test fitted the modules and figured out that an extra hole was needed for the micro-USB cable as the head of the cable did not fit inside the top part of the capsule properly. Removing the head could also be an option and would make the cable fit without the use of an extra hole, but could leave the cable vulnerable to stressed bending and possible intrusions. The slots have also widened for extra stability once closed and will make it harder to shear.

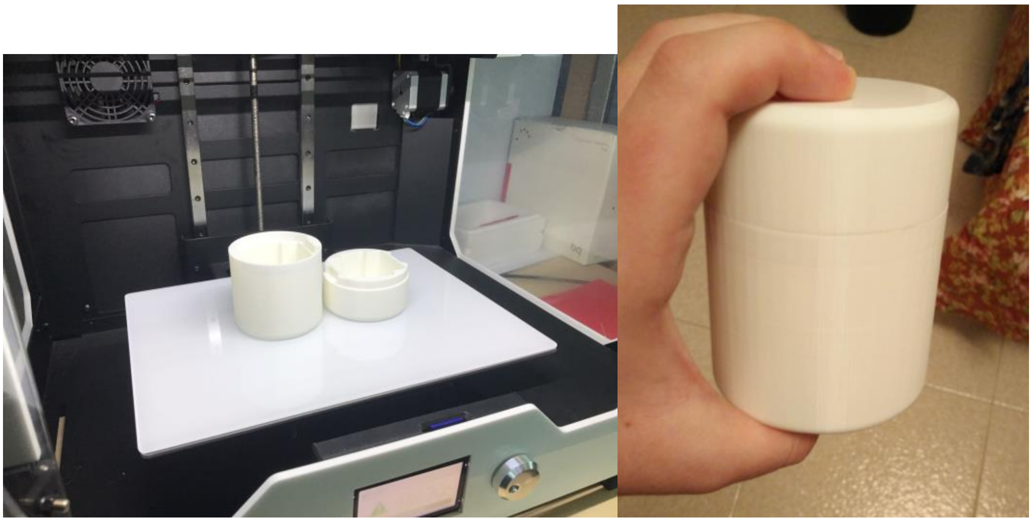


Figure 41: 3D printing process for the new case

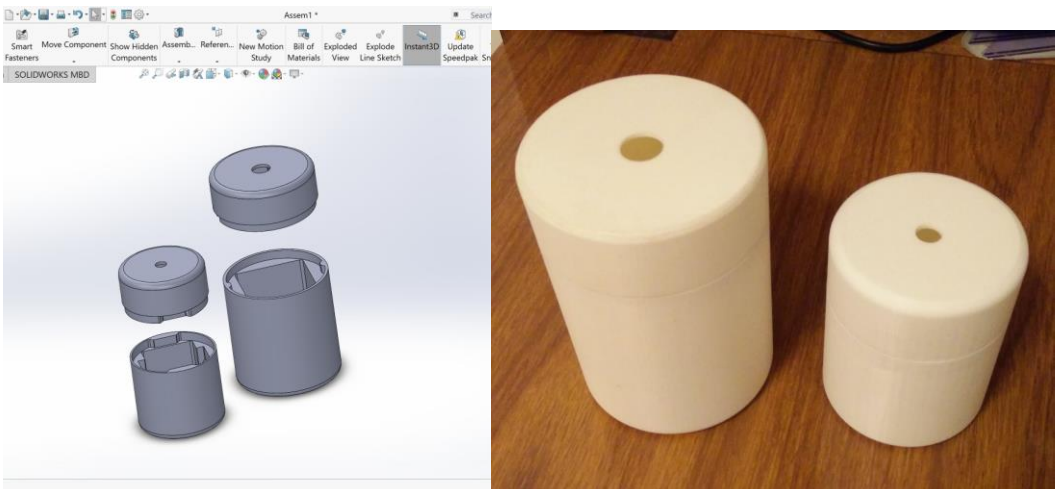


Figure 42: Comparison between the new (small) and the old (bigger) case

The sensor housing prototype was made of two parts and also needed to be printed. The dimensions of the housing are 50mm in height, 60mm in width and 22mm in depth. The housing has a unique cavity that allowed it to secure both the MQ-9 and DHT22 sensors in place. After the parts were printed, problems arose with positioning and printing error which made the sensors difficult to fit. These problems could be changed with the use of a Dremel to remove parts and to sanded down edges to ensure the sensors can fit with ease. A second prototype had to be made with repositioned parts in the cavity and the incorporation of the group logo in the front of the sensor housing.

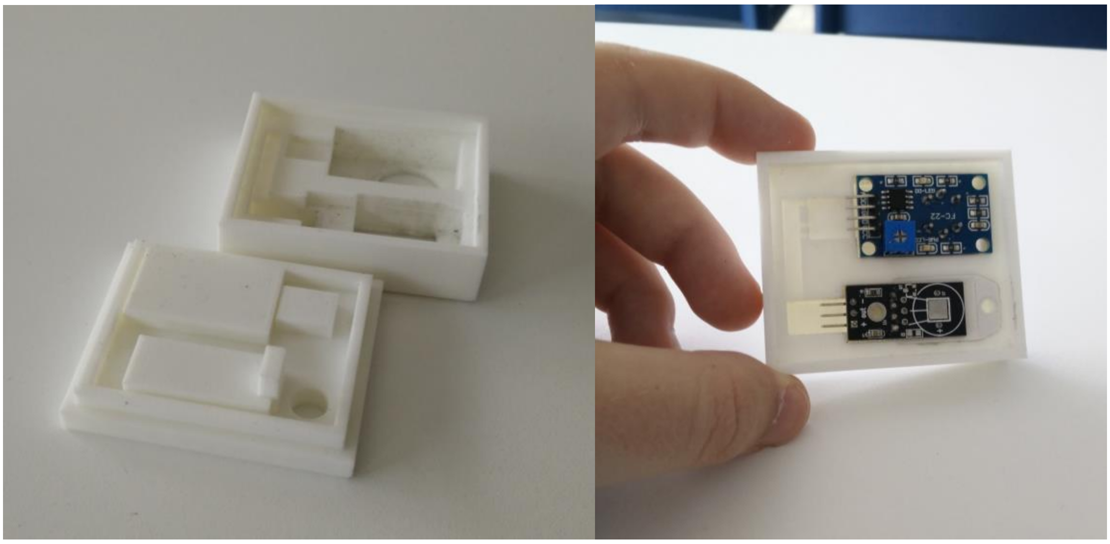


Figure 43: The prototype for exterior case

For demonstrating the methodology of implementing the device into a tree, the team was able to get a section of a tree trunk of ~250mm diameter. The tree trunk consists mostly of heartwood and is dead which means multiple types of methods can be used to implement both devices. The tree trunk will have a section drilled out for the capsule and will have the sensor housing placed on the exterior of the tree trunk. Firstly, the bark will be scored with three cuts (one horizontal & two vertical) and will open to reveal the heartwood. Secondly, a 7cm crown drill is used to drill out a section of the heartwood 7cm deep. Afterwards, another 7cm is hammered and chiselled out to make room for the capsule and allow some space for the Kevlar pipe. The capsule itself will be sealed with a rubber seal or a strong adhesive that does not harm the tree. Extra sealing will be used cover other nooks and crannies that are in the tree cavity. Once the sealing is finished, the bark will be closed back up. An extra hole is drilled out for the cables coming from the capsule which will connect to the sensor housing.

Figure 44: Drill

Figure 45: Drilling process

The sensor housing will be attached to a bracket using an adhesive. The housing will be placed just above the closed cavity and will be attached using aluminium nails. Thought and care has to be shown during this part as using a hammer against a tree could lead to further damage. Additional cracks and openings can be sealed up to prevent moisture build up in the cavity or other used parts of the tree trunk.

All parts used for the prototype and also, the final design, have technical drawings which include measurements are shown in the appendix of this report.

5.4 Theoretical Improvements

While designing the capsule and the whole device itself, it became obvious that the obtained prototype is in fact too big to be ever implementable. That is why a few possible improvements had to be considered.

Firstly, to decrease the overall size of the device other Arduino could be used. The one in the prototype is a normal, most common version. However, there exists a Nano version. it is described more in point 7.3. Using such a mini computer would highly decrease the required space for the device. Nevertheless, there are also drawbacks of using such a minimised version. In the prototype, apart from the Arduino Uno there are two other shields that are crucial for the proper work of the system. If Arduino Uno was substituted with Arduino Nano, the Shields also would have to change. For example, the Wi-Fi Shield would be changed for a Wi-Fi transmitter. However, there would be a problem with finding a substitution for a power shield.

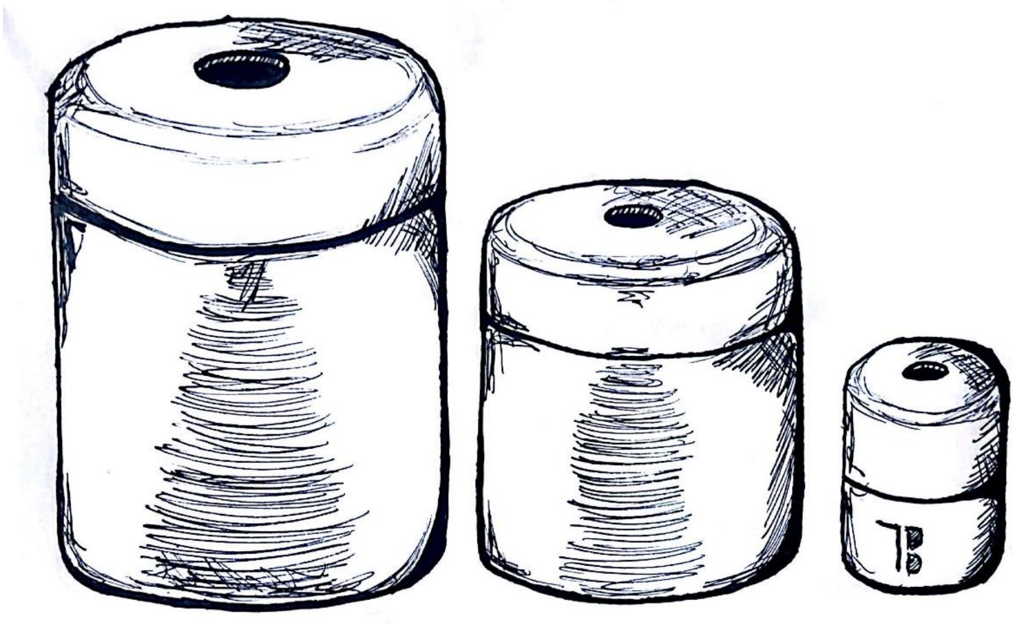


Figure 46: First and second generation of prototype. Future prototype? (in the right)

Apart from the electronic shields, there is also a battery hidden in the main capsule. When the electrical components are minimised, also, the battery can be smaller. However, the size is not the only thing that can be improved with this element. The battery could be substituted with a one of a better quality that would guarantee a stable energy supply. The battery should be able to work and power the device on its own for a relatively long period of time.

The housing for the sensors cannot be minimised. The sensors are already small and there are no "mini" versions. Therefore, the only improvement in this case can be adding other types of sensors and creating new hiding-boxes for them. There is no point in making a housing for each sensor separately, it is more efficient to make one at least for two because all the sensors have to be connected with the device inside the tree and therefore more capillary tube for cables and more hole would have to be created. That would not only hurt the tree otiosely but also it would create an unneeded spiral of wires. Therefore, the housing for the sensors should stay the same or be slightly redesigned for different types of sensors.

5.5 Materials

As the Treeborg Team has no member with a material engineering study background, there was not enough expertise which materials are suitable for the case of the device. The most important thing is that the chosen material does not harm the tree.

As the solution, Enric Martin Fuentes, a material professor from Universitat Politecnica de Catalunya (UPC) was invited to give some advice and finally propose some suitable materials for the case. High-density polyethylene (HDPE) was suggested as this material since it is more suitable than others due to its characteristic. Material with polyvinyl chloride (PVC), CVC (combination of polyester and cotton) and Polytetrafluoroethylene (PTFE) must be excluded as this type of material would harm the tree.

High-density polyethylene (HDPE) is one of the most commonly used polymers in the world, it is made from petroleum. Below are some advantages and disadvantages listed of materials which could affect the project. [10]

Advantages:

- Low costs
- Impact resistant from -40°C to 90°C
- Moisture resistance
- Good chemical resistance
- Antioxidant
- Low and high density
- Good impact resistance
- Toughness
- High thermal expansion

Disadvantages:

- High thermal expansion
- Poor weathering resistance
- Subject to stress cracking
- Difficult to bond
- Flammable
- Poor temperature capability

Another suitable polymer that could be used for the capsule and sensor housing, would be ABS due to its many properties that makes it advantageous compared to other polymers. ABS is a tough, rigid material that can be easily coated and also has a high impact strength. ABS is also readily available and can be used as a filament for 3D printing. Being a type of polymer, ABS also comes with disadvantages. ABS is made of oil which can lead to damage and harm to the environment, this can be an issue as we are placing parts into a tree which is a living organism. ABS also has poor weatherability, but this problem can be resolved by using a weather/vapour coating. [12]

To combat issues regarding the visibility of the sensor housing, a wooden veneer can be used as a skin/wrap for the housing. Veneer covering has a wide range of selection to choose from and can also be very cheap. Both the sensor housing and the capsule will also be covered with a hydrophobic spray such as NeverWet to make sure that both parts are protected from the tree's moisture and changing weather conditions. [12]

6. Problems

6.1 Technical Problems

Firstly, the installation of an energy source which uses inconsistent sources is a risky step and can cause different problems. As an example, the natural life cycle in terms of the seasons is a big factor as plants have smaller growing activities in the winter, than during summer and spring. Even the changes between day and night can cause a difference of energy income because the photosynthetic activities are dependent on the interaction of chlorophyll cells in the leaves and the solar radiation.

Secondly, another technical problem is the battery. It is the weakest point of the electronic box as its capacity can only decrease. If during winter the temperature is low enough the tree trunk might not be going to be strong enough in terms of isolation to prevent the battery from malfunctioning. Moreover, when the battery undergoes aging, it also loses its capacity. However, the biggest problem might be that the battery has a shorter life cycle then the rest of the device as it wears off quicker.

Thirdly, there are already some smaller hardware parts available for example the Arduino Nano, which will be described later on but the problem with those next generation parts is that they are mostly not compatible to needed hardware parts like the power boost shield or the Wi-Fi shield yet. Furthermore, are those parts like the Power Boost Shield or the Wi-Fi Shield not yet as a smaller version available.

Fourthly, the whole device is constantly endangered by nature, e.g.: moisture, the tree grown itself or a thunderstorm. If the electrical components meet with the moist they are most probably going to get destroyed. Same case happens if lightning hits the tree. If while doing so there is a short circuit that poses a threat of lightning can set the tree on fire. Also, when the tree is growing it can damage the device by squishing it.

Finally, once the device is implemented into the tree there is no possibility of maintaining it or adjusting in any way. If something goes wrong, the device would be left behind while not working in the tree.

6.2 Limited Time

The time given for the work on this project was limited. Only four months to create a new and innovative device might not be enough time to finish a project with that many aspects. The prototype was finished in the last month (May) and only one month is not a suited timespan to measure the impact of the device on the tree. It takes a long time for trees to recover and within one month it would not be possible to estimate how big impact the Treeborg device has on trees.

Moreover, even if the system was to be installed in any way, there would be a need for a permission to use a living tree for an experiment and no one wanted to give one. Maybe, if a tree specialist would say it has chances to work and not have a permanent impact on the tree, people would look at it more favourably, and however, it is really difficult to find a specialist with wide enough knowledge to estimate the influence on the tree.

7. Future

7.1 Smart City

The main future target for this project is to create a smart city which applies the Internet of Things system (IoT). IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. All of the things that humans want can be found with one click on the internet.

The idea is to create or to build a network of trees which can communicate with each other. The device will be installed in a group of trees which have a specific distance between them. This device will perform a mesh networking system to generate some ways to communicate. Mesh is a network topology in which devices are connected with many redundant interconnections between network nodes.

With this type of application, it is impossible to create a modern and smart city. And hopefully this project can make the city more attractive to the people surrounding, even to the foreign people and tourist.

7.2 Uses and Possibilities

The usage of the device was an open case for the Treeborg team as only a general idea was presented to them and it was their task to define what they would like to do within this project. That is why there is more possible applications of this idea. Aside from the chosen idea of collecting data about temperature, humidity, level of CO gas and providing a Wi-Fi hotspot to give passengers access to the internet, there were other options considered. Below are some possibilities and uses that the device can be applied for.

Firstly, it could be used as a warning device. If the level of harmful gases would exceed the acceptable levels the alarm would inform the government of the city. That would allow them to decrease those gases and prevent their further rise.

Another way of using this device as a warning device was to implement it into some trees in the forest and if the humidity level would become dangerously low, it would send a signal of the possibility of the fire in those conditions and was the fire there it would turn on the alarm to allow the firefighters to get there faster.

From the previous idea a new, more user-friendly one rose. If the humidity level near the cities trees was below appropriate one an irrigation system would turn on and water the plants.

Moreover, it could be used by the private householders who wants to have a green way of powering the Wi-Fi connection outside in their backyard as they want to live close to nature.

Another possibility of using this idea is installing the security cameras or light on the tree. They would be powered by the green energy suiting perfectly to the idea of smart city. Also, a power outlet could be installed on the tree so that if someone needs a low voltage energy to for example charge the phone does not need to search for a bar or restaurant that would provide one but could actually use the one from the tree without any extra costs.

Last but not least, the internal sensors to monitor the tree conditions and learn more about the health of the trees could be used. This idea could be connected with others to have also some other, more social aspect.

The possible uses, however, are limitless. Those are just a few options considered by the team at the beginning of the semester while deciding on the project scope. The Wi-Fi was required by the company, but the idea of collecting data about the temperature, humidity and CO was chosen as it seems to be most useful and a proper base for future improvements and development.

7.3 Future Device

In the future, the device will be consisting of new, smaller and more compact components because it is necessary for the device to decrease in size and in price.

The components that can be used for a new version:

7.3.1 ESP8266

This chip can be used as a Wi-Fi transmitter to replace the Wi-Fi shield on the device. Its size dimension is around five times smaller than the actual used Wi-Fi Shield and the price is also pretty low with only around 5€, this chip can be very suitable for the future device. [15]

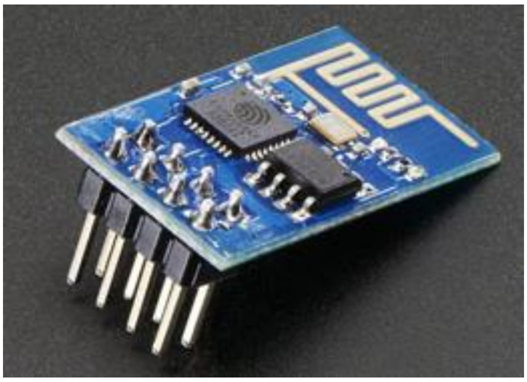


Figure 47: ESP8266

7.3.2 Arduino Nano

The Arduino Nano has more or less, the same functions as the Arduino Uno, but in terms of size it is smaller than the precursor. With the dimensions of 18 x 45 mm it is suitable to reduce the overall size of the device. So, when it comes to installation into the tree a much smaller housing and device would be possible. [14]

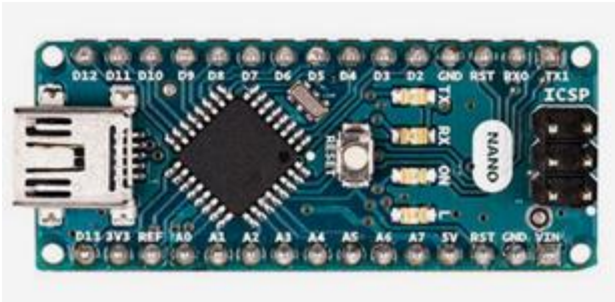


Figure 48: Arduino Nano

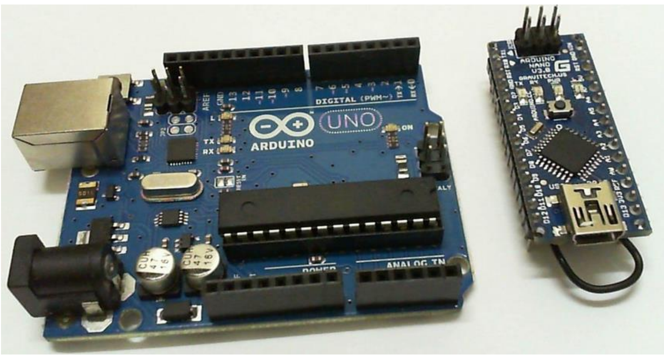


Figure 49: Comparison between Arduino Uno and the new Nano

7.3.3 Addition of a portable Wi-Fi

In the future, there is a possibility that this device can be connected to the Wi-Fi portable to provide internet access to the users via a HotSpot access point. This would allow a commercial utilisation of the Treeborg in cooperation with telecommunication companies.

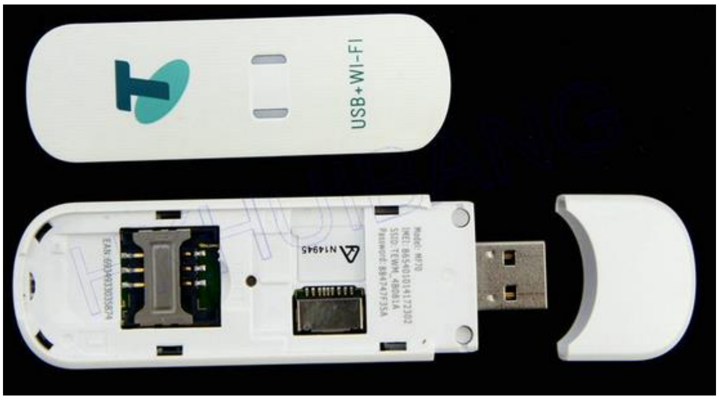


Figure 50: A portable Wi-Fi stick

7.3.4 Utilization of additional sensors

Right now, there are only three different values measured with this device: temperature, humidity and carbon dioxide, but there are plenty of options of gases in the air which could be measured. Following gases and important air constituents can be measured as well as they can endanger the health of a person from a certain value. [20]

- Carbon Dioxide (CO_2)
- Ozone (O_3)
- Nitrate (NO_2)
- Oxygen (O_2)
- Air pressure (kPa)
- Noise (dB)

7.3.5 Utilisation of Sentrilo

Sentrilo is an open source platform which was designed for storing and sharing information of a Smart City. It can be used by cities and companies, which believe that the utilisation of free and open software should be the standard for a smart City where all the information gathered are open for everyone.

Together with an application which is further explained in 7.3.6. Sentrilo can be used to link the sensors and actuators to manage and control urban services. The Internet of Things (IoT) is a wide connection between computers, devices, software and sensors which enables these objects to serve and collect data. [21]

7.3.6 User Interface and Homepage

For the future, there would be a possibility to design a homepage which can inform the users about the features and functions of the Treeborg, and show the data which are gathered by the sensors of the device. There could be also shown a log of all the data and/or a comparison between the values measured by the different Treeborgs distributed over the city, this would allow the user to see which parts of the city are most polluted or support his choice of which place would be more suited to spend their lunch break.

In the age of smartphones, a mobile application it would be probably the best choice to connect the users with the device, because almost everyone uses a smartphone and together with the possible Wi-Fi access point it would be a perfect addition. There are many possible features when the application runs in the background like, push-alerts if a certain value limit of for example carbon monoxide is reached in a given area to warn the user.

7.3.7 Utilisation of other programs

In the future, more possible programs could be used to display the data. With a different graph and chart for the display, it might be easier for users to read the data. There are some compatible programming languages that can be linked to the Arduino program such as:

- C++
- Python
- MATLAB
- Raspberry pi
- Etc.

7.4 Summary

Summarised, in the future, the main target should be to make the Treeborg device much smaller and to ensure that the device can collect all possible data and connect this device with the 'Internet of Things'. There are many possible ways to use this device when it would be able to connect to the internet. The Treeborg could be very useful and could be developed further in the future, so it can fulfil the needs of people. With the energy obtained from the tree, people do not need to be worry for the power supply for this device so it can be installed anywhere and everywhere whenever there is a tree.

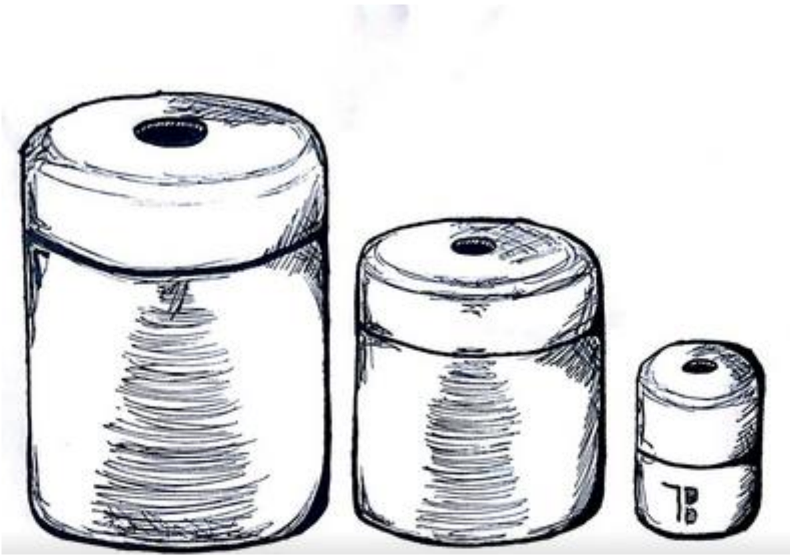


Figure 51: Evolution of the device in terms of size

8. Marketing plan

8.1. Market research

8.1.1 Customer analysis

To define the customer, firstly someone has to establish for what and where the device could be needed. Although defining where the device can be used is quite obvious, to define what for in fact requires some thorough thinking process.

This device can be used in any city, where trees have the diameter big enough to put the device inside. However, small yet developing villages also may take profit from having the Treeborg product implemented into the trees in a main square of the town.

To specify what for this product can be used one has to define what it does. Firstly, this device can be used not only for collecting the date about the environment but also for showing them in a nice and user-friendly way. Moreover, one of the main aims is to give a Wi-fi hotspot so that the citizens could use it and make use of internet connection outside without buying extra data transfer packets. Therefore, this device can be used as a source of internet for an average person or as a source of information about the environment for people interested in the levels of temperature, humidity or CO.

Now, that this general customer base is defined it is time to specific those people demographically. [16]. The most interested in free city internet are people in age of 15 to 34 as they constitute for over a half of the internet users. [17]

When it comes to the people most willing to obtain the information about the environment those are government workers, meteorologists, companies and individuals considering building in a given city, hobbyist of nature and etc.

However, those are just the indirect customers, main users of our device but not direct buyers of the Treeborg product. The true customers are telecommunication companies and governments of the smart cities which will purchase Treeborg and then further distribute its goods. Those are the people that have to be obtained to successfully release the Treeborg to the market.

8.1.2 Market analysis

To begin the topic of the market analysis, one has to notice that currently there is nothing similar on the market. However, there are companies that provide partially the same goods as the Treeborg. For example, the telecommunication companies provide the access to the internet or meteorological stations provide data about the environment.

To successfully launch the product on the market allying with telecommunication companies is a good idea. They could make a special offer of Wi-Fi internet in the city for a small amount of money. To provide the proper work of such an internet it would have been installed in a sufficient number of trees, therefore the city will not just have one Treeborg device, but at least around twenty. That increases the market potential. To calculate the market volume the market potential has to be multiplied by an average price [18], which will be further described in section 7.2. Therefore, we have:

$$\text{Market volume} = 20*500 = 10{,}000 \text{ per city}$$

When it comes to the displaying the data collected, it has to be done in an attractive and communicative way to rise the interest of possible users. Otherwise people will not choose Treeborg site to check the weather or CO level.

8.1.3 UPS (Unique Selling Point)

The unique selling point of the Treeborg device is the independence of any external source of energy. It is a green idea that does not require a huge amount of maintenance. Also, the internet access and collecting data about the environment are just a few possibilities that come with this idea. It could be used for much more if needed.

8.2 Cost calculation

Below is the table of cost calculation for the hardware of the device. The cost is quite high as the team are using components provided from the company. But for the future, the components of the device will be different, smaller and cheaper.

Table 3: Cost estimation

Cost Calculation		
Area	Items	Prices
Hardware	Arduino Uno	€ 9.99
	Power Shield	€ 17.77
	Wi-Fi Shield	€ 90.00
	MQ-9 sensor	€ 3.95
	DHT22 sensor	€ 4.00
	Wires	€ 5.00
	Battery	€ 8.86

	BIOO	€ 100.00
Housing	Casting	€ 10.00
	Material	€ 20.00
Assembly	Connecting hardware	€ 3.00
	Programming	€ 10.00
	Housing and device assembly	€ 5.00
Installation	Digging the hole for BIOO technology	€ 25.00
	Drilling the hole for the capsule	€ 8.00
	Installing sensors	€ 3.00
	Attaching sensors and wires	€ 3.00
	Hormones after implementation	€ 10.00
Security	Cybersecurity	€ 25.00
	Security from external damage	€ 10.00
	Permission to install an electronic device in a tree	€ 100.00
Maintenance	Technical maintenance	€ 10.00
	Software updates	€ 5.00
	Tree care	€ 5.00
	Replacement of sensors	€ 10.00
	Total:	€ 501.57

8.3 Eco Design/Recycling of our device

What happens to the device when it passes its lifecycle is a very important matter to consider. To talk about the eco-design someone must define what will happen to the device after its usability ends. In this case, it is difficult to talk about a green solution as opening the tree to remove the device is more harmful than just leaving it inside.

If the device is disconnected from the energy source and the sensor box is removed, the box will be left by its own without hurting the tree. The BIOO panel would have to be dug out from the ground as most certainly it could be reused. The sensor box should also be removed and all the remaining wires should be sealed to not corrode or possibly make some short circuit.

Another crucial point is to make a visible note in city papers in which trees the Treeborg was installed. Otherwise, it could possibly jeopardise people who are randomly cutting trees, as not only it could break the cutting tool, but also pose a threat to the life of the person cutting the tree. Therefore, the city government should have the map of some sort with marked trees to not cut the ones that have been used for Treeborg.

8.4 Possible business partners

To talk about business partners, one must understand that those are customers who are going to commercialise the device. Therefore, those people are not only the business partners, but also the customers of the Treeborg device.

The basic idea is to sell the idea to the town halls of the smart cities or telecommunication companies. The former would provide the Treeborg group with all the needed permits to install an electronic device in the tree whiles the latter would create a net to of potential customers that would be interested in buying the access to the city Wi-Fi.

Another group of people that might be interested in the co-operation with the Treeborg team are scientists and environmental agencies. They may want to have the access to the data collected by the sensors for their own usage like controlling the levels of gasses in the surrounding.

Lastly, some other customers may want to co-operate in creation of the Treeborg net such as operators of parks, zoos, amusement parks, museum, etc. They may want to have some shares in the product to decrease the price they would have to pay for a product.

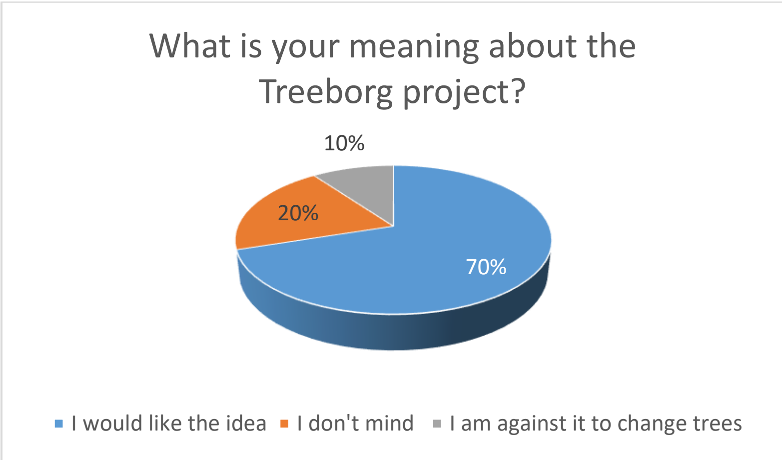
9. Discussion

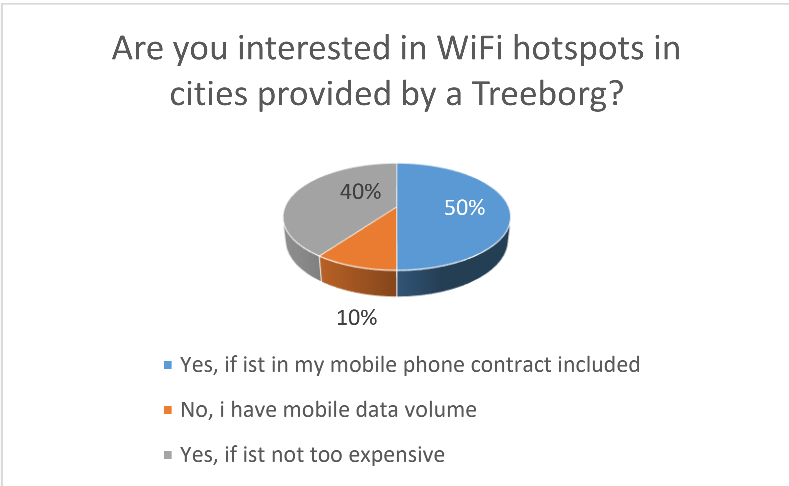
In general, was the project scope reachable, but actually there occurred some problems. Firstly, the possibilities were limited because of the borders made by the tree. It will not be possible to implement a big device into a tree without strongly harming it in terms of health and stability. The hardware right now has also some limitations for example the Arduino chip has a way smaller successor named Arduino Nano it is only 2x2 cm and thus 10x smaller 4x2 cm than its predecessor version. The utilisation of this chip would enable a way smaller device, but the problem right now is that this Arduino Nano is not compatible with the current available Power Shields and Wi-Fi Shields. The size reduction of the technical device would solve many problems, which is hindering the installation right now, there would be less energy needed for the device and the implementation into the tree would be way simpler to do it, because there are drills for drilling holes up to 2.5 cm without the usage of a crown drill bit. [19]

Furthermore, the communication and cooperation with Arkyne Technologies was a bit difficult as they were not that communicative and busy with their own launch of a new project. Most of the time, it was unclear if they would be willing to provide their technology, which made it challenging to plan with. The lack of a tree specialist also hindered the progress of the project, because the treatment plants and trees with a technical device is not explored that much yet. In the end, a prototype placed into a piece of a dead trunk was the solution to practise the implementation and figure out a methodology for the implementation of the device and the attachment of the sensor housing on the outside of the tree.

In total, there are many pros and cons for an installation of the device into the tree and on an external pole as an artificial carrier. (See 4.0) But because the project scope was to find a solution of an internal installation the device was developed to be inside a tree together with the methodology for the implementation and attachment of the tree.

There was made a small survey to figure out the meaning of the people about the idea of placing a technical device into a living tree and converting it into a 'Treeborg'. The people who were asked are widely spreaded in terms of education and demographic distribution. In the pie charts below are the questions and the respective answers graphically illustrated. (see Figure 58)





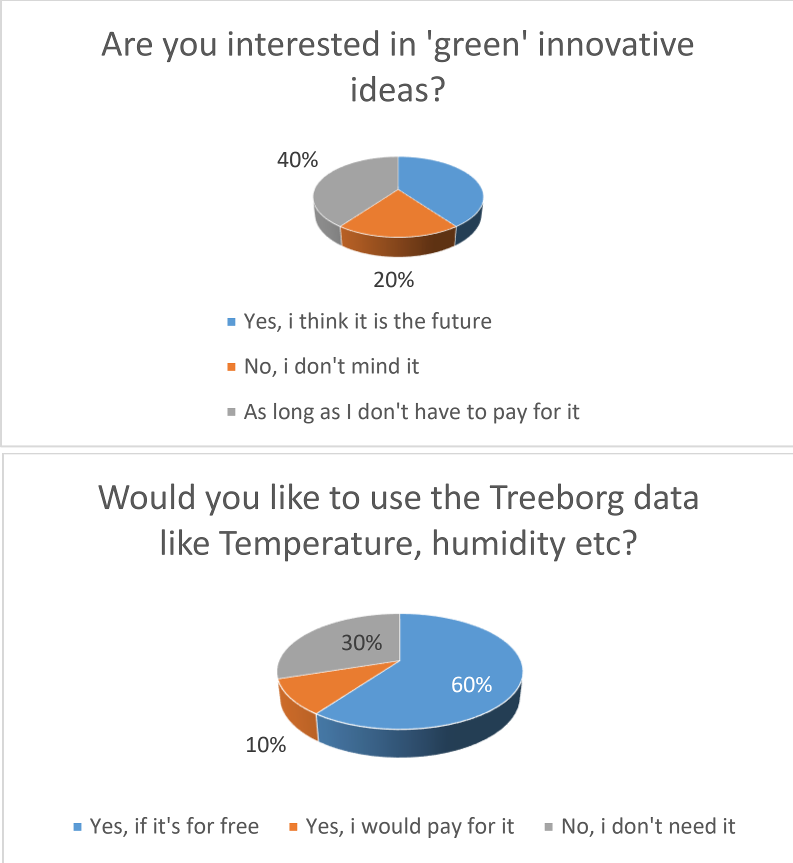


Figure 52: Percentage of surveys

In 7.3, are already possible future improvements mentioned, but it is clear that this project, Treeborg can have a promising future. In the age of mobile phones where almost everyone owns at least one smartphone, the need of Wi-Fi and connectivity increases rapidly. And with the help of the Treeborg would it be possible to provide Internet connection to regions with inferior infrastructure in relation to telecommunication and electricity. As long as the Treeborg can work independent and is based on self-supply it can be theoretically places at any place of their world where suitable trees are growing. In the future when the development of those 'Nano' sized computers progresses the possibilities of those mini devices also increases and the device could be more powerful, smaller and cheaper.

In summary, the project scope was reached more or less and a working prototype could be developed together with a methodology to install the device. Limitations were especially the small amount of time; this project consists of multifaceted parts which couldn't be processed in only 4 months' time in particular with a small team of four students. From time to time a lack of knowledge occurred when it came to material specialists or tree specialists but it could be compensated by asking external persons. But despite all those difficulties, the goal was reached.

10. Conclusion

For the conclusion, the main aim of this project was achieved. All of the research, study and making the prototype proved that it is possible to install this device inside a tree. The team also proved that energy can be harvested and powered up the device with the help of the Arkyne Company. The team also had made a simple prototype to demonstrate how it will be working. This project has a bright future, as this device can do many things. Maybe in the future, this device can be developed more by some company or even another EPS group.

11. Bibliography

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Image sources

Figure 1, 3, 4, and 5: https://www.bioo-tech.com/
Figure 2: http://www.neapolis.cat/
Figure 8: https://www.adafruit.com/products/258
Figure 9: https://www.adafruit.com/product/2078
Figure 11: https://www.arduino.cc/en/Main/ArduinoBoardUno
Figure 12: http://www.dx.com/p/arduino-dht11-digital-temperature-humidity-sensor-138531#.WTbIK8ax9PY
Figure 13: http://www.hallroad.org/sensors/717-mq-9-mq9-gas-sensor-lpg-co-ch4.html
Figure 14: https://www.arduino.cc/en/Main/ArduinoWiFiShield
Figure 19: http://www.wald.de/wp-content/uploads/stamm.gif
Figure 24: http://www.dieweltenbummler.de/Forum/gallery/userImages/6d/152-6d1b86db-medium.jpg
Figure 25: https://www.mein-schoener-garten.de/sites/default/files/styles/inline_scaled_s/public/nistkasten-gartenschlauch-schere-2823966-blp-msg-martin-staffler_0.jpg?itok=5B0jKYf7
Figure 27: https://www.baumportal.de/Bilder/styles/midsize_420/public/platane-stamm.jpg?itok=BKVrW5ok
Figure 28: http://www.gartenschlumpf.de/wp-content/uploads/Baeumerichtigabstuetzen.png
Figure 29: https://s-media-cache-ak0.pinimg.com/originals/4a/9e/ab/4a9eab2fe82f0bc08299337271e1f5c0.jpg
Figure 30: http://green-24.de/forum/resources/platanenreihe-am-rhein/thumb/176413
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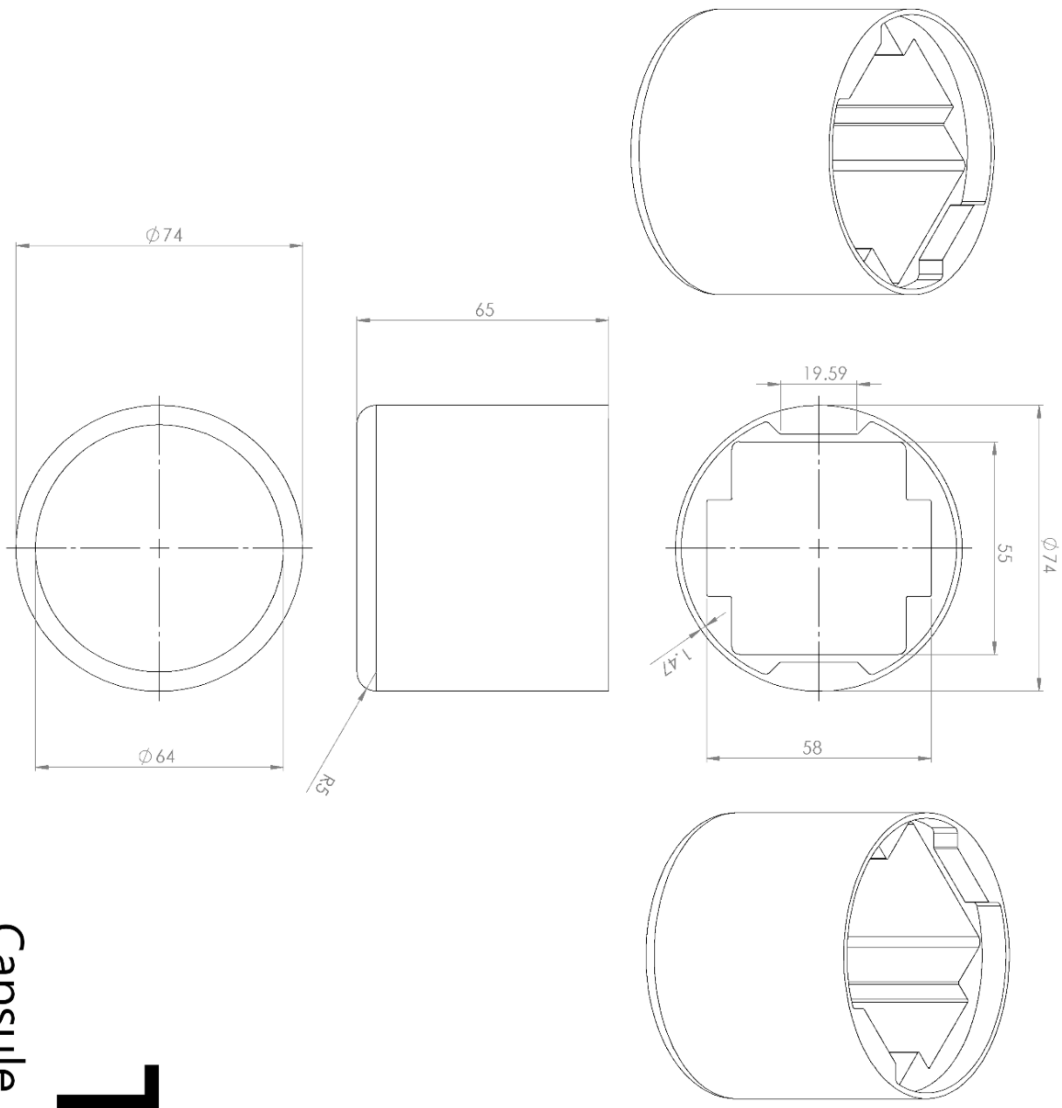
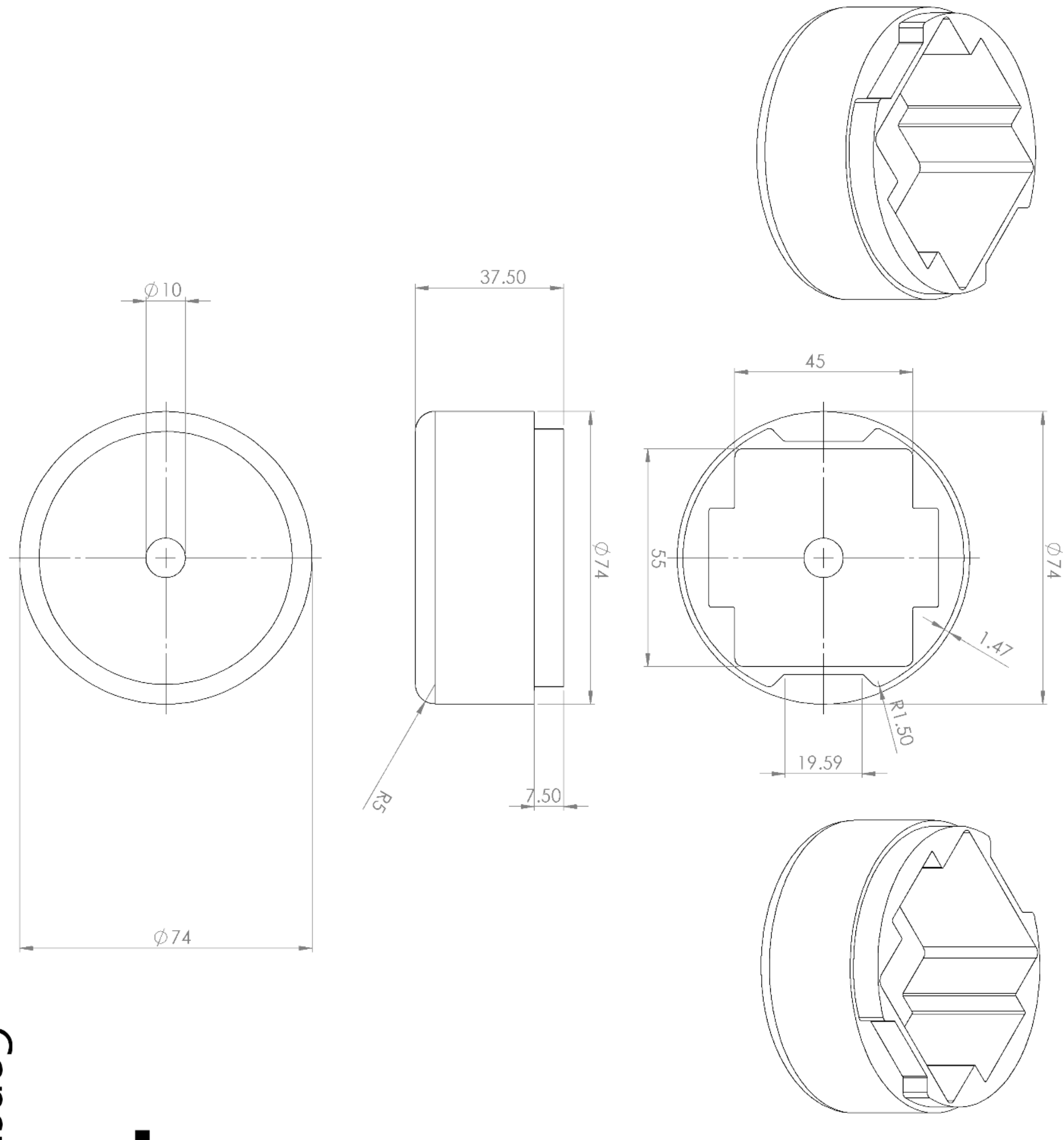
Appendix

A. Technical Drawings

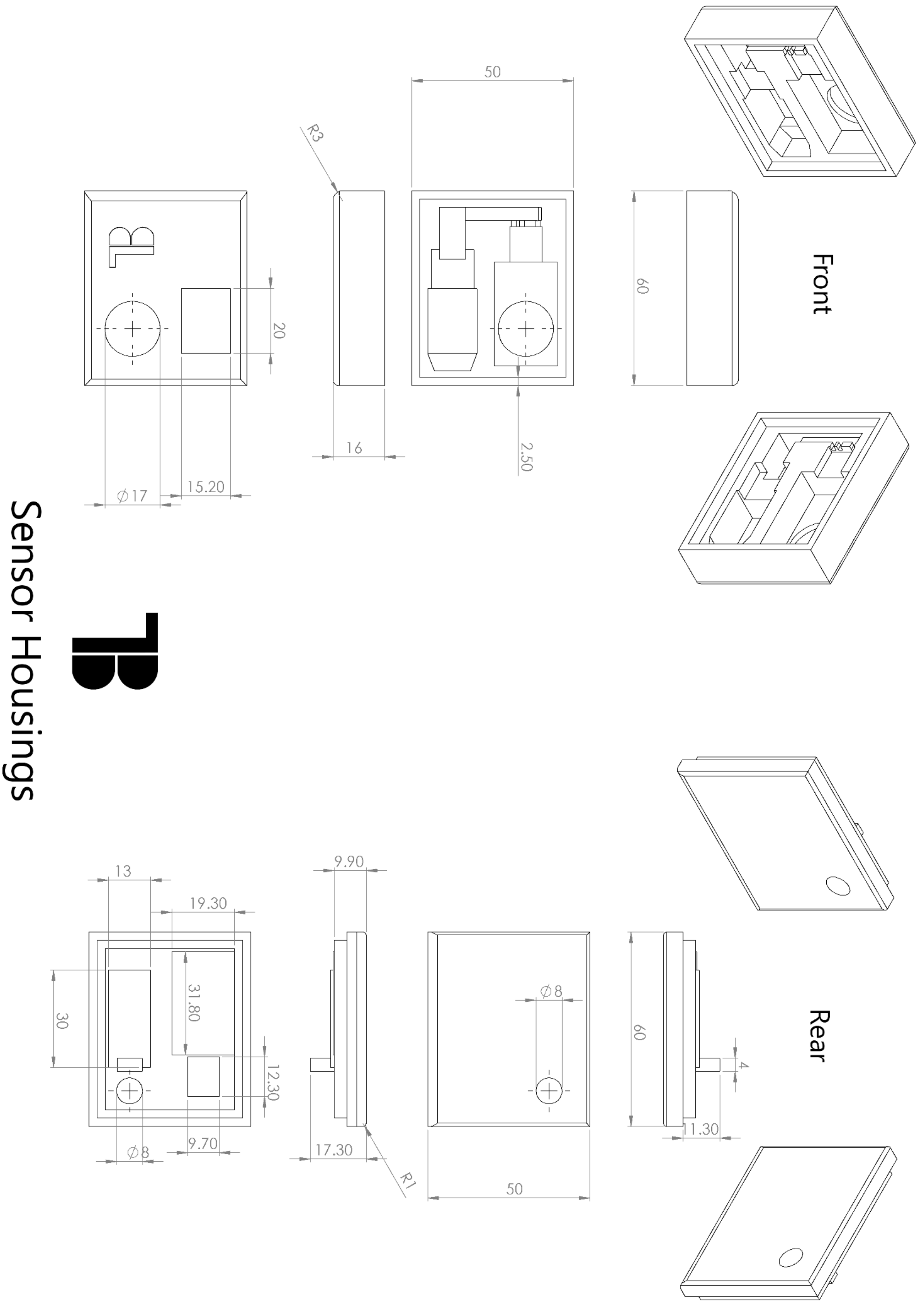
The shown technical drawings of each components that are used for the prototype or final design. All measurements are shown in mm. The use of the kevlar pipe to connect both the capsule and sensor housing can change in size depending on the positioning of both devices and the size of the tree (trunk diameter, length, etc.). Bungs and connectors can come in many sizes and variants. They are also readily available in many hardware shops, so there is no need to print them. The technical drawings depict the desirable dimensions needed for both devices.

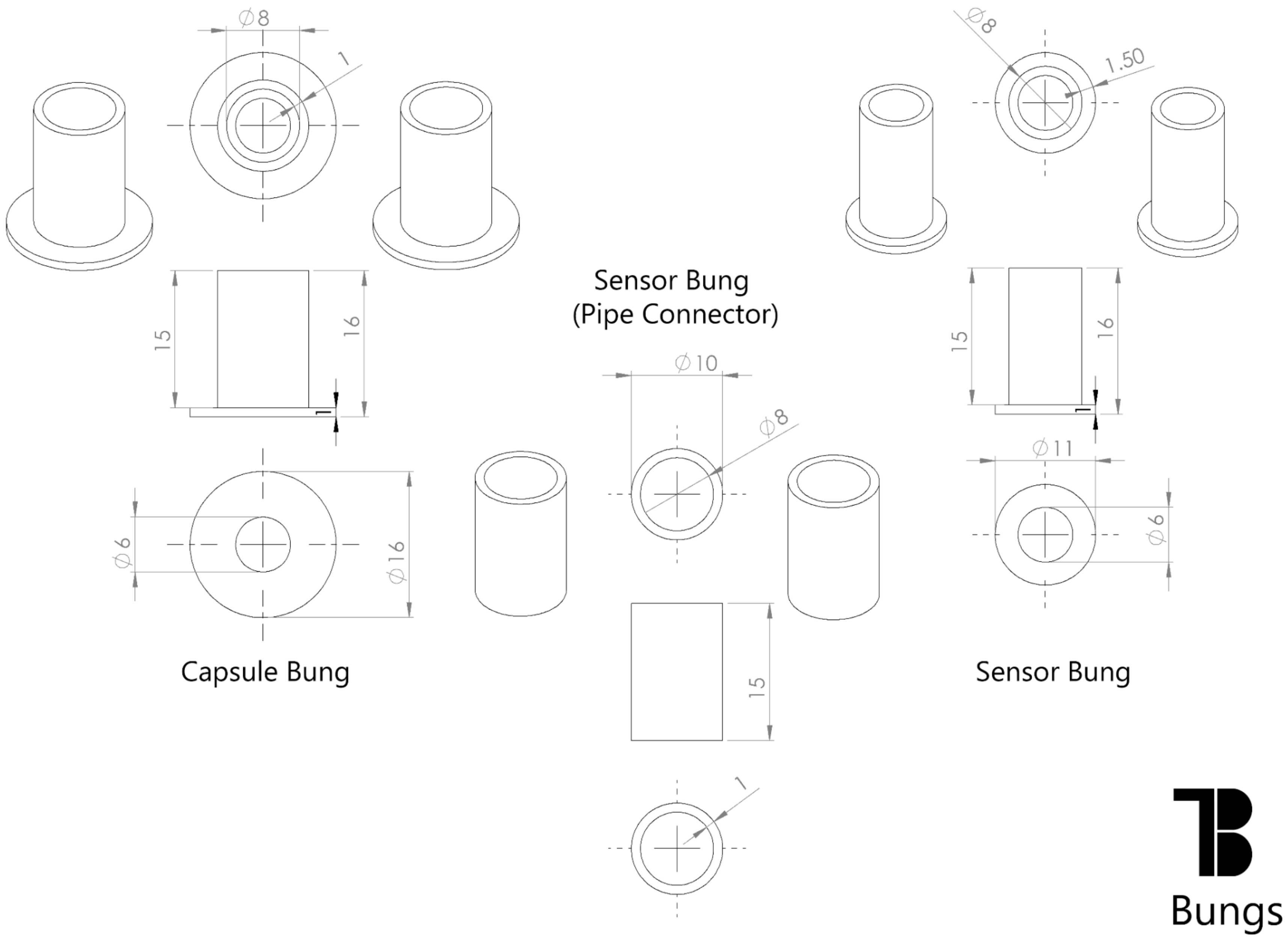


Capsule - Bottom



Capsule - Top


Sensor Housings
Front
Rear
50
R3
60
20
16
2.50
⌀17
15.20
13
19.30
9.90
30
31.80
12.30
⌀8
9.70
17.30
R1
50
⌀8
60
4
11.30


Capsule Bung
Ø8
1
15
16
1
Ø6
Ø16
Sensor Bung
(Pipe Connector)
Ø10
Ø8
15
1
Sensor Bung
Ø8
1.50
15
16
1
Ø11
Ø6
Bungs

B. Arduino Code

Command code is needed to instruct Arduino, so that it can work as we need it to be. Below is how the code program works and a little comment was added after the code ends. This code was made in the IDE Arduino program.

Link to the Arduino program for references:
https://www.dropbox.com/s/p1e6owk1ytiyzog/treeborg.ino?dl=0

```
#include <SPI.h>            //call SPI library
#include <WiFi.h>           //call WiFi library
#include "DHT.h"            //call DHT library
#define DHTPIN 2            //pin connected
#define DHTTYPE DHT22       //define DHT sensor

DHT dht(DHTPIN, DHTTYPE);

char ssid[] = "treeborg";    //network id
char pass[] = "treeborg";    //network password
int keyIndex = 0;

int status = WL_IDLE_STATUS;
int led_pin=9;                      //LED output pin 9
int analog_pin=A0;                  //analog input for MQ9

WiFiServer server(80);


void setup()
     {
     Serial.begin(9600);                    //initialize serial
     dht.begin();
     pinMode(led_pin, OUTPUT);

     if (WiFi.status() == WL_NO_SHIELD)     //check the presence of WiFi shield
          {
          Serial.println("WiFi shield not present");
          while(true);
          }

     while ( status != WL_CONNECTED)       //attempt to connect to network
          {
          Serial.print("Attempting to connect to SSID: ");
          Serial.println(ssid);
          status = WiFi.begin(ssid, pass);
          delay(10000);
          }

     server.begin();
     printWifiStatus();                    //connected and print the status
     }
```

```
void loop()
    {
    WiFiClient client = server.available();           //waiting for incoming client

    float h = dht.readHumidity();                      //read humidity
    float t = dht.readTemperature();                   //read temperature
    int co;
    co=analogRead(analog_pin);                         //read CO gas

    if (client)
       {
       Serial.println("new client");
       boolean currentLineIsBlank = true;
       while (client.connected())
           {
           if (client.available())                     //display data if client available
               {
               char c = client.read();
               Serial.write(c);
               if (c == '\n' && currentLineIsBlank)
                   {
                   client.println("HTTP/1.1 200 OK");
                   client.println("Content-Type: text/html");
                   client.println("Connection: close");
                   client.println("Refresh: 5");
                   client.println();
                   client.println("<!DOCTYPE HTML>");
                   client.println("<html>");

                  client.print("Humidity: ");          //display all information on serial monitor
                  client.print(h);
                  client.print(" %\t");
                  client.print("Temperature: ");
                  client.print(t);
                  client.print(" *C\t");
                  client.print("COvalue: ");
                  client.println(co);

                  if(co >200 || t >28)          //display dangerous if exceed value normal
                      {
                        client.println("dangerous!!");
                      }
                  else
                      {
                        client.println("no dangerous!!");
                      }

                  client.println("</html>");
                  break;
                  }
              if (c == '\n')
                  {
                  currentLineIsBlank = true;
                  }
              else if (c != '\r')
                  {
                  currentLineIsBlank = false;
                  }
              }
          }
```

```
        delay(1);
        client.stop();
        Serial.println("client disonnected");
    }

  Serial.print("Humidity: ");          //display all information on serial monitor
  Serial.print(h);
  Serial.print(" %\t");
  Serial.print("Temperature: ");
  Serial.print(t);
  Serial.print(" *C\t");
  Serial.print("COvalue: ");
  Serial.println(co);

  if(co >200 || t >28)          //display dangerous and turn on LED if exceed value
    {
    Serial.println("dangerous!!");
    digitalWrite(led_pin,HIGH);
    delay(1000);
    }
  else
    {
    Serial.println("No dangerous!");
    digitalWrite(led_pin,LOW);
    delay(1000);
    }
  }
void monitor()
  {
   float h = dht.readHumidity();
   float t = dht.readTemperature();
   int co;
   co=analogRead(analog_pin);

   Serial.print(h);
   Serial.print(" ");
   Serial.println(t);
   Serial.print(" ");
   Serial.println(co);
  }

void printWifiStatus()          //display WiFi status
  {

  Serial.print("SSID: ");
  Serial.println(WiFi.SSID());


  IPAddress ip = WiFi.localIP();
  Serial.print("IP Address: ");
  Serial.println(ip);


  long rssi = WiFi.RSSI();
  Serial.print("signal strength (RSSI):");
  Serial.print(rssi);
  Serial.println(" dBm");

  }
```

Through this program, Arduino will:

- Collect data from the surrounding air through sensors.
- Display the data on the Arduino IDE serial display.
- Display the data with a graph using Arduino's serial plotter.
- Connect to the surrounding Wi-Fi.
- Create a web server.
- Display the value of each gas on the server.