BUILDING A LOW-COST AND IOT-BASED WEATHER STATION

European Projects Semester Autumn 2022

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I. ABSTRACT

University of Applied Science Novia has had several weather stations throughout the years. Since additive manufacturing and data transfer is getting better and more popular each year, Hans Lindén provided a project to create a new weather station. The goal of this project is to build a low-cost IoT weather station at Novia UAS that is solar-powered and has wireless data transfer to the MQTT broker. Besides that, minimal power should be consumed. The final weather station should be able to measure wind speed, wind direction, temperature, relative humidity and rainfall. As an extra feature, the snow depth and light should be measurable. First, research should be done to reach the goal. After the research, a start will be made on designing and coding. This will lead to the assembling of the weather station. All the relevant information will be documented in a report. Eventually, a look will be given on the final weather station, which will lead to suggested improvements and conclusions.

II. ACKNOWLEDGEMENT

We would like to express our great appreciation to thank Hans Lindén for his support in this project as a group counsellor. His help really got us on a good starting path and helped us continue this project. Furthermore, we would like to thank Novia University of Applied Sciences for housing the EPS project here in Vaasa and we want to thank all the teachers for teaching us new things and helping us out. At last, our grateful thanks are extended to each other for being a good team member and giving the support needed.

III. PREFACE

This report is about building a moveable weather station that is connected via a 5G mobile network. The first version is a prototype weather station that is built with purchased modules. For example, the Davis wind speed/direction sensor, the Davis rain sensor and the Wal-front temperature sensor. The sensors will be connected to an Arduino.

The second version will be an improvement of the first version. The second one will have self-designed modules. This will keep the total cost of the weather station low. Also, there will be some design improvements.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
EPS	European Semester Project
UAS	University of Applied Sciences
IoT	Internet of Things
NB-IoT	Narrowband Internet of Things
LTE-M	Long Term Evolution for Machines
MQTT	MQ Telemetry Transport
DIY	Do it yourself
3D	Three-dimensional
V1	Version 1
V2	Version 2
PLA	Polylactic acid
ASA	Acrylic styrene acrylonitrile
PETG	Polyethylene terephthalate glycol
UV	Ultraviolet
CNC	Computer Numerical Control
AWS	Amazon Web Services
I^2C	Inter-Integrated Circuit

LIST OF SYMBOLS

Symbol (Unit)	Definition	SI
mm	One thousandth of a metre	millimetre
V	Electrical potential and electrical voltage	voltage

1. INTRODUCTION

In this chapter information about the EPS, the members and the project can be found. Moreover, the stakeholders, risks and the Gantt chart will be shown.

1.1 European Project Semester

'European Project Semester (EPS) is a programme offered by several European universities to students who have completed at least two years of study. EPS is created with engineering students in mind, but other students who can participate in an engineering project are also welcome.

EPS is a mixture of "Project Related Courses" and project organized/problem-based learning. It is crafted to address the design requirements of the degree and prepare engineering students with all the necessary skills to face the challenges of today's world economy. Students work in international and interdisciplinary teams of 3–6 students on their projects. Projects are done in cooperation with commercial businesses and industries or with research centres. There are minor differences between EPS-projects and the various EPS-providers, but all providers have agreed about the following key elements (European Project Semester, 2022).'

This project takes place in Vaasa, Finland. The hosting university is Novia University of Applied Sciences (UAS). This semester, autumn 2022, 5 projects are divided over a group of eighteen students from all over Europe. Mostly Dutch, German, French and Spanish students are partaking. The participating students, plus a few extra Erasmus students, can be seen in Figure 1.

Figure 1 Picture of all the Erasmus students of Novia

1.2 Meet the projectteam

1.2.1 BRYAN ARENTS – THE HAGUE, THE NETHERLANDS

Hello everyone, my name is Bryan Arents. I am from the political capital of The Netherlands, called 'The Hague' or in Dutch 'Den Haag'. My study is also in this city at the 'The Hague', University of applied sciences. I studied one year of mechanical engineering and two years of Industrial product design. I am planning to get my bachelor's in industrial product design, because I really like the broadness of it and I also like the technical creativity combination.

I am 21 years old and my hobbies are fitness, all kinds of extreme sports and gaming. I also like to travel, so that's also one of the reasons I choose to do this European project semester. For example, I also spend the winter in Bonaire during my gap year, so I lived longer by myself outside the country than actually in my own country.

Figure 2 Bryan Arents

I wanted to do something outside of the country for my Minor, so I looked up my possibilities. Then I found the European Project Semester. Immediately I knew I wanted to do this. I also wanted a project which would be a little bit more on the technical side. That is where Finland came into the picture. I always wanted to go to the Nordic countries, so this was a good opportunity. Also, I am a big fan of nature and snow, so that also suits my pickings. That's why I choose to do the EPS in Vaasa.

I think this project fits me well, because my study is literally designing products. So, designing a weather station fits that nice. Also, I have always been interested in following the weather. For example, checking Windfinder for predicting if the surf will be good. Also, I have a bit of experience working with electronics.

My goals with this project are to broaden my knowledge by working with students from different fields. Also, I would like to extend my English communication skills. Furthermore, I would like to develop even more as a product designer.

1.2.2 JOB VAN KOEVERINGE - 'S-HERTOGENBOSCH, THE NETHERLANDS

Hi, my name is Job van Koeveringe. I'm studying at Avans University of Applied Sciences in ''s-Hertogenbosch', colloquially known as 'Den Bosch'. Currently I'm in my third year of the study Computer Science. The study covers the objects: Applies the principles of mathematics, engineering, and logic to a plethora of functions, including algorithm formulation, software and hardware development, and artificial intelligence.

Figure 3 Job van Koeveringe

I am 21 years old, and my hobbies are: Scouting, travelling, home automation and watching Formula 1. Weekly I accompany a group at my own scouting and several times a year for national events of Scouting Nederland. During the holidays, I love to travel with friends and explore the world. In my free time, I love to expand my home automation with open-source software called Home Assistant. On Formula 1 weekends, I am always watching, and I try to visit at least one race a year.

For my Minor, I wanted to do something abroad. I had no interest in just taking classes. My interest was to do something study-oriented in a kind of group assignment. The advisor at my home university recommended me to do a European Project Semester. The question now was where am I going to attend the EPS? My preference was for a northern country. The EPS was offered in Norway and Finland. I had already been on holiday to Norway several times. On the other hand, I had never visited Finland. In Norway, the university was in the middle of Oslo; in Finland, the university was in a student town called Vaasa. After some more comparisons, I finally decided to choose Vaasa Finland.

There were six projects to choose from this semester at the EPS. However, among these, there were only two that fell in my study direction. The submarine and the weather station. The submarine would use a Raspberry Pi and the weather station would use Arduino. Since I already had knowledge of Raspberry Pi, I preferred to do something with Arduino. I also would like to have a physical product at the end of the project and with a submarine there was less chance of that. That's why I went for the IoT weather station.

My goals for this project are to learn to work with foreign students on a joint project, each with their own cultural background, to improve my English communication skills and learn the Swedish language. Also, broaden my knowledge of IoT using AWS.

1.2.3 CHANTAL TIJHUIS – ENSCHEDE, THE NETHERLANDS

Hi! I'm Chantal and I am 21 years old. I'm currently in my third year of the study Applied Physics. I am following this study at Saxion, which is located in Enschede. Applied Physics is a broad study. I learned a bit of thermodynamics, fluid mechanics and heat transfer, mechanics, optics, statistics and more. In this team I may not be able to show a lot of study skills, but I will get the chance to learn a bit more about programming and designing.

Figure 4 Chantal Tijhuis

The hobbies I have outside of school are listening to music, baking, hiking, rollerblading and meeting my friends.

I chose to do the EPS in Vaasa, because I've always wanted to go to a Scandinavian country, which I thought Finland was which is not true, mostly for the differences in seasons. Furthermore, it was a fantastic opportunity. The other option I had is to do the same kind of thing, so a project in a multidisciplinary group, at Saxion or in a different country. Vaasa looked like a nice and not too crowded city, which I really like at the moment. Doing this project outside of my home country can make me learn more about myself, because it is my first time being on my own for a longer period. Furthermore, it is a great opportunity to learn skills from others, not only knowledge, but also social skills.

1.2.4 ANTONIN SILVESTRE – MANOSQUE, FRANCE

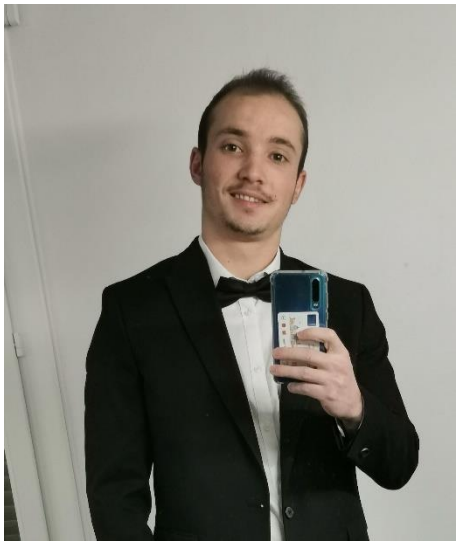


Figure 5 Antonin Silvestre

Hi! My name is Antonin Silvestre. I am 21 years old. I am from Manosque, a small town near Marseille in the south of France. I study at National Engineering school, Tarbes. Currently, I am doing my fourth year of study. My field of study is based on general engineering. I learn mechanical, material science and building engineering.

I applied for the EPS because I really like to work as a team. To me it's very enriching and it enables me to improve my English. My life is based on challenges and the EPS is a challenge that pushes me out of my comfort zone.

Moreover, EPS is a mix of courses and a project with people from all over Europe. That is perfect to discover new cultures or different way of lives. During my free time I usually do sports, mostly rugby. Furthermore, I like different types of activities that are sport-related, like CrossFit and mountain bike.

Finally, I choose to do my Erasmus in Finland, because I always wanted to travel to a Nordic country for the snow and its landscapes.

1.3 Team role assessment and allocation

1.3.1 BELBIN TEST

Researcher Meredith Belbin has identified nine types of behaviours within a work environment. Table 1 shows the different kind of behaviours. Most of the time people will identify to more than one profile. For a team to be most successful, a diverse combination of people's behaviour is needed (Belbin, 2022).

Table 1 Belbin team roles with description

	TEAM ROLES	CONTRIBUTION	ALLOWABLE WEAKNESSES
THINKING	Plant	Creative, imaginative, free-thinking. Generates ideas and solves difficult problems.	Ignores incidentals. Too preoccupied to communicate effectively.
	Specialist	Single-minded, self-starting, dedicated. Provides knowledge and skills in rare supply.	Contributes only on a narrow front. Dwells on technicalities.
	Monitor Evaluator	Sober, strategic and discerning. Sees all options and judges accurately.	Lacks drive and ability to inspire others. Can be overly critical.
ACTION	Shaper	Challenging, dynamic, thrives on pressure. Has the drive and courage to overcome obstacles.	Prone to provocation. Offends people's feelings.
	Implementer	Practical, reliable, efficient. Turns ideas into actions and organises work that needs to be done.	Somewhat inflexible. Slow to respond to new possibilities.
	Complete Finisher	Painstaking, conscientious, anxious. Searches out errors. Polishes and perfects.	Inclined to worry unduly. Reluctant to delegate.
PEOPLE	Resource Investigator	Outgoing, enthusiastic, communicative. Explores opportunities and develops contacts.	Over-optimistic. Loses interest once initial enthusiasm has passed.
	Coordinator	Mature, confident, identifies talent. Clarifies goals. Delegates effectively.	Can be seen as manipulative. Offloads own share of the work.
	Team worker	Co-operative, perceptive and diplomatic. Listens and averts friction.	Indecisive in crunch situations. Avoids confrontation.

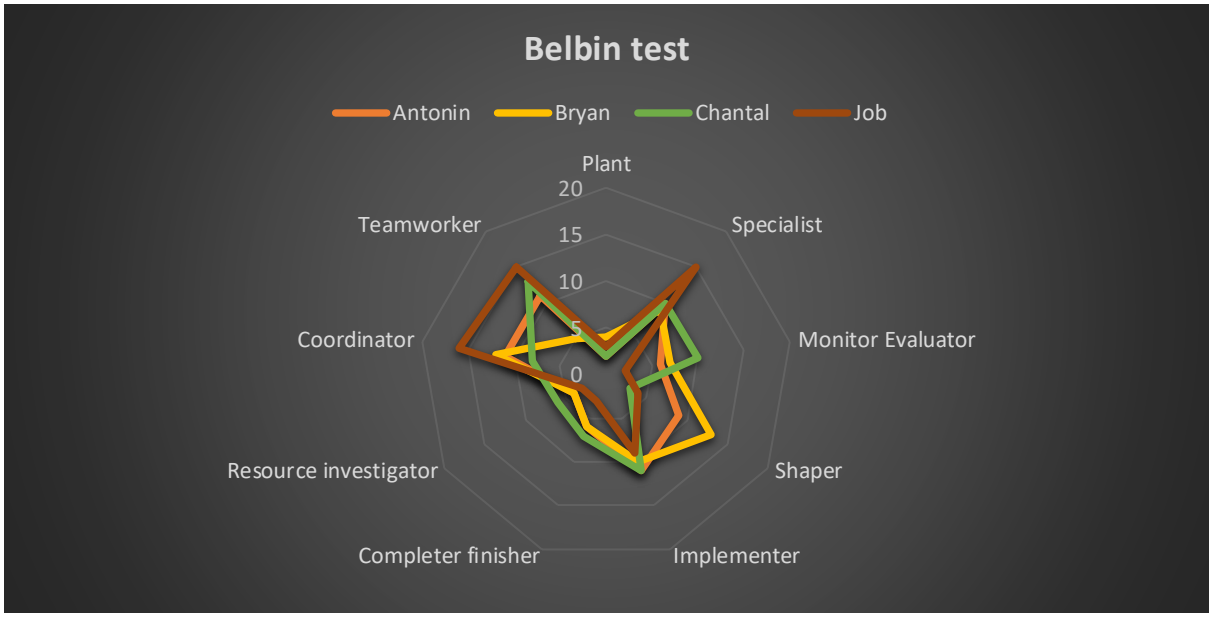


Figure 6 Belbin test scores of the members. Orange is Antonin, yellow is Bryan, green is Chantal and brown is Job.

With a quick few on the results in Figure 6 it can be said that the members got a lot of roles in common, such as team worker, implementer and coordinator. In the team the roles plant, completer finisher and resource investigator are not prominent. The equal profiles can ensure that little is thought outside the box and that the project will follow one straight line, because the roles not prominent are more creative. Furthermore, equal profiles can mean that sometimes minor frictions can occur. Lot of the members got a higher score on coordinator. With this profile people will mostly lead when needed, which means that if more than one team member takes the lead, discussion may occur. On the contrary, same profiles can complement the group and is essential to achieve an ideal balance for a smooth progress. Moreover, Bryan and Job got shaper and specialist, this means that the group is diverse and well-balanced enough. To make the team more diverse, a resource investigator, a complete finisher, a plant and a monitor evaluator are needed when adding a new team member.

1.3.2 LEADERSHIP TEST

The leadership skills test helps team members determine a person's ability to manage, lead and guide others. It should answer whether team members have everything they need to become prominent leaders (Lavri, 2022).

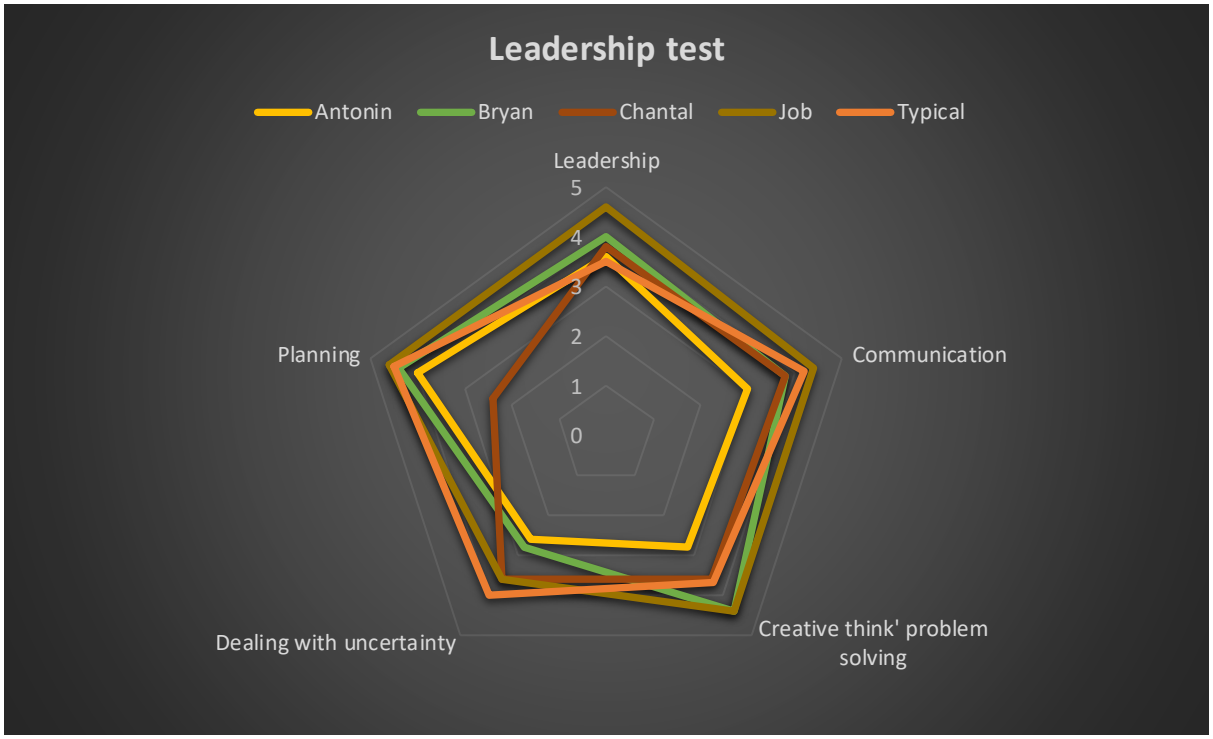


Figure 7 Leadership test scores of the members. Orange is Antonin, yellow is Bryan, green is Chantal, brown is Job and gold is a typical project manager.

From Figure 7 it can be concluded that none of the team members have reached the scores of a typical project manager on every area. Job scored remarkably high on every area though didn't reach the score for a typical manager at the area of dealing with uncertainty. Compared to the other team members Chantal did not score high on planning, which means she needs someone who can make the planning for her. Antonin scored a little lower on communication, dealing with uncertainty and creative think' problem solving. Lastly, Bryan scored the lowest on dealing with uncertainty, which can make him keen on planning everything in detail. The differences in each member's low scores and each member's high score may lead to good teamwork. In different situations different members of the team will show of their lead ability. Furthermore, learning from others is increased.

1.4 Project management

1.4.1 STAKEHOLDERS

A person or group that has an interest in any decision or action of an organization is the definition of a stakeholder (Smith, 2000). In Figure 8 the stakeholder matrix of the project can be seen. The matrix gives a visual overview of each individual stakeholder and their influence and interest. The overview is made more organized by putting in four different quadrants.

I. Manage Closely: The stakeholder has high influence and high interest
II. Keep Satisfied: The stakeholder has high influence and low interest
III. Keep Informed: The stakeholder has low influence and high interest
IV. Monitor: The stakeholder has low influence and low interest

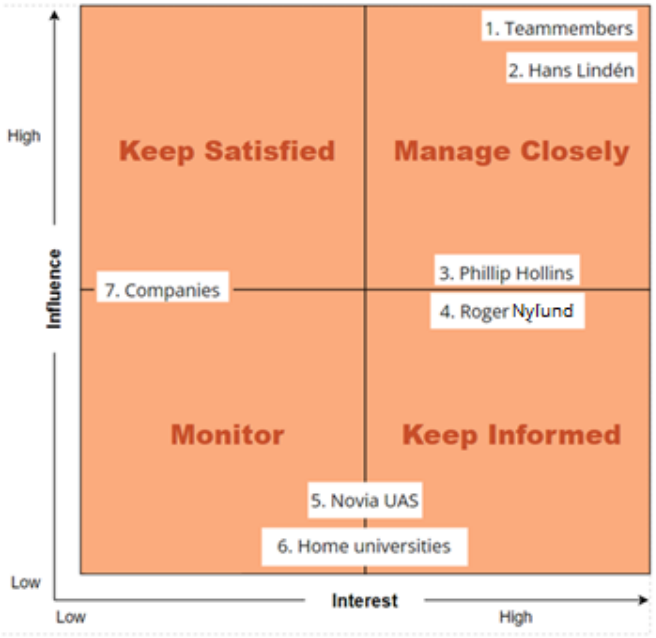


Figure 8 Stakeholders matrix where the stakeholders each have their own number

Established from Figure 8 can be that the group members and Hans Lindén have the most influence and interest in the project. The team members will take care of the project itself and the documentation. Hans Lindén is the supervisor and will provide all the help needed. Philip Hollins and Roger Nylund are placed in the middle of influence and a little bit on the higher side of the interest, because of the influence on the project's time schedule and documentation. The universities don't have influence on the project but have a small interest. Looking at the companies, a medium score is given on influence, when looking at the materials, but the interest is low.

1.4.2 RISK MANAGEMENT

All the project risks are marked in the risk register, Table 2. These risks are divided by internal and external project risks. The risks have an impact in the project, which can be prevented by the prevention-management. These risks are marked with the chance and the earnestness. This gives a threat score. The higher the score, the more impactful the risk can be. The highest scores are ranked in red, followed by orange and yellow.

Table 2 Risk register with information about each individual risk

Risk-assessment						
Internal risk						
Risk				**Threat**		
Nr.	*Type of risk*	*Impact*	*Prevention-management*	*Chance*	*Earnestness*	*Threat score**
1	Not meeting the deadline	No grade	Keep true to the planning and plan in some extra time	M	H	6
2	Different goals	Not the same input in the project	Communicate well	H	M	6
3	Vacation leave	Less project time	Communicate well and plan well	H	M	6
4	Sickness Hans	Less contact	Keep WhatsApp contact	M	M	4
5	Budget is too low	To few money	Focus on cheap solutions	M	M	4
6	Sickness Job	Less hardcore coding knowledge	Antonin might take over/work from home	M	L/M	3
7	Sickness Bryan	Less design knowledge	Teach each other/work from home	M	L	2
8	Sickness Chantal	Less documentation knowledge	Read thru the document regularly/keep documents online	M	L	2
9	Sickness Antonin	Less sensor knowledge	Job can take over	M	L	2
10	Teamwork problems	Bad vibe	Communication and teambuilding	M	L	2
11	Novia stops funding	No more money for the project	Keep Novia friendly towards the EPS	SL	H	1,5
12	Technobothnia doesn't allow us to use the Lab	We can't make our own stuff	Follow the rules of the lab	SL	H	1,5
13	Technobothnia doesn't allow us to work in the EPS room anymore	We have to find a new place	Use the room with respect	SL	L	0,5
14	Lack of specific knowledge	Hard to do some things	Keep talking with Hans, about what is in our capabilities	SL	L	0,5
External risk						
Risk				**Threat**		
Nr.	*Type of risk*	*Impact*	*Prevention-management*	*Chance*	*Earnestness*	*Threat score**
15	Delivery is long	Products are delayed	Buy from good sources	H	M	6
16	Product are not available	New products/design	Keep track of stock	M	M	4
17	Corona rules come back	Work form home	Keep good health and document everything online	L	H	3
18	ETC's don't transfer	Administration problems	Good administration	SL	H	1,5
19	Russia attack's Finland	Project ends	Now where the bomb shelters are	SL	H	1,5

1.4.3 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) is a tool that breaks work into smaller task to make the work more manageable and approachable (WorkBreakdownStructure, 2022). There are two types of WBS: 1) Deliverable-based and 2) Phase-based. In this project the phase-based Work Breakdown Structure is mostly used and can be found in Figure 9.

WORK BREAKDOWN STRUCTURE TREE DIAGRAM TEMPLATE

PROJECT TITLE	Weather station	PROJECT MANAGER	Hans Lindén
PROJECT MEMBERS	Antonin Silvestre, Bryan Arents, Chantal Tijhuis & Job van Koeveringe	DATE	maandag 26 september 2022

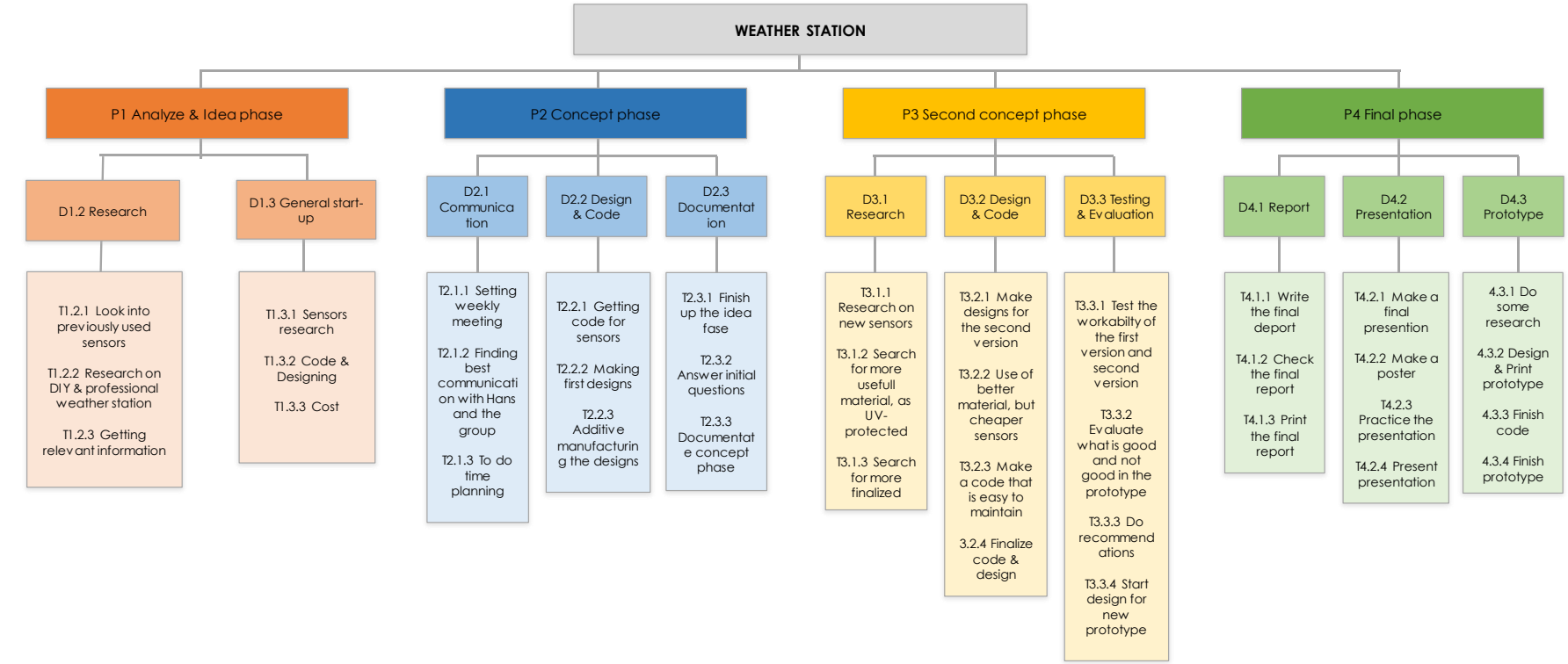


Figure 9 Work Breakdown Structure (WBS) with the phase, each delivery and the tasks

1.4.4 GANTT CHART

The task list, Table 3, holds all the tasks in the project with the responsible persons, start date, deadline and completion. The tasks are divided into the phases of the project. These phases describe the intricate design phases and help the designer to come to a well-functioning product.

Table 3 List of tasks that needs to be done during the project

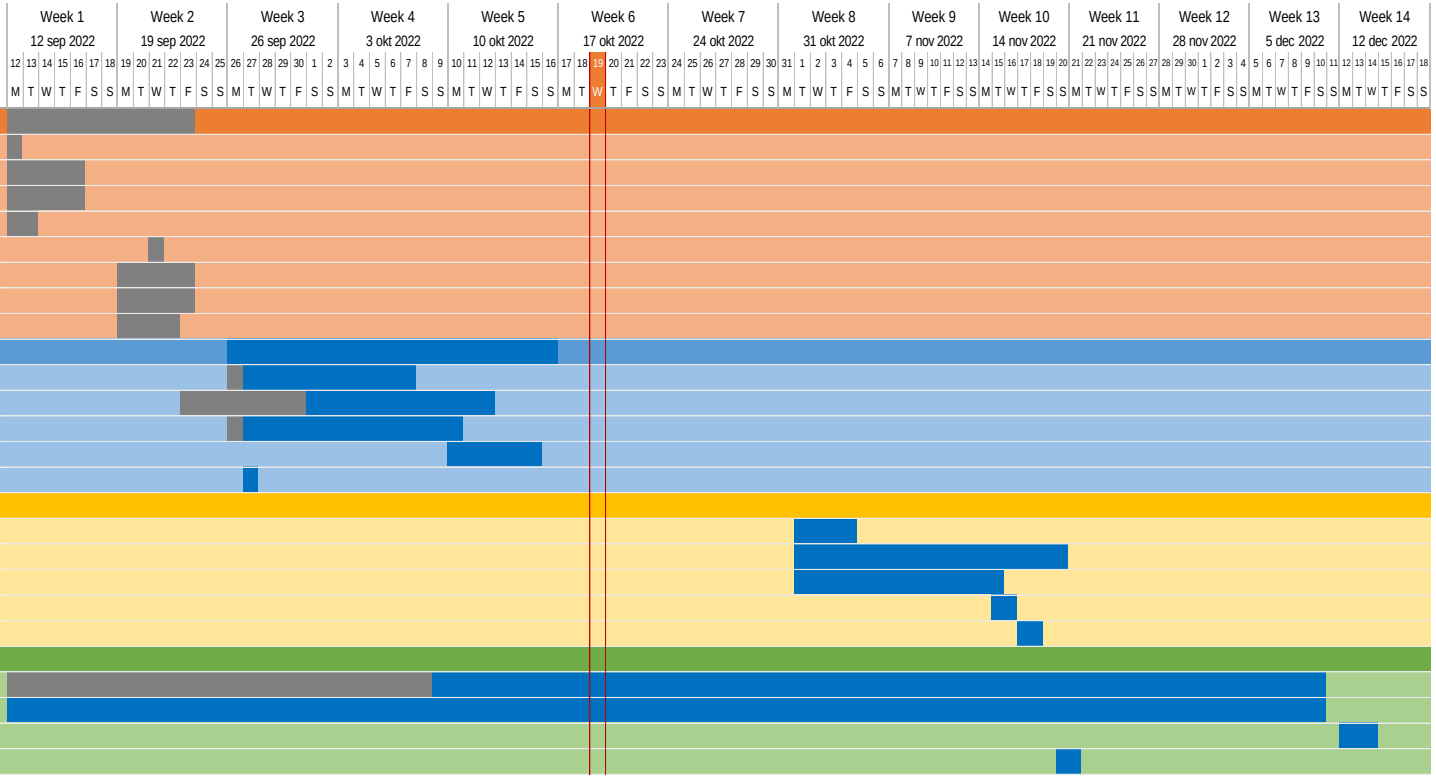
WBS	TASK	NAME	START	END	DAYS	% DONE	WORK DAYS
P1	**Analyse phase & Idea phase**		12-9-2022	23-9-2022	12	100%	10
1.1	Meetings	All	12-9-2022	12-9-2022	1	100%	1
1.2	Research	Bryan and Chantal	12-9-2022	16-9-2022	5	100%	5
1.3	General code	Job and Antonin	12-9-2022	16-9-2022	5	100%	5
1.4	Work document	All	12-9-2022	13-9-2022	2	100%	2
1.5	Meetings	All	21-9-2022	21-9-2022	1	100%	1
1.6	Design	Bryan and Job	19-9-2022	23-9-2022	5	100%	5
1.7	Code	Job and Antonin	19-9-2022	23-9-2022	5	100%	5
1.8	Documentation	Chantal	19-9-2022	22-9-2022	4	100%	4
P2	**Concept phase**		26-9-2022	16-10-2022	21		15
2.1	Design	Bryan	26-9-2022	7-10-2022	12	10%	10
2.2	Production	All	23-9-2022	12-10-2022	20	40%	14
2.3	Code	Job and Antonin	26-9-2022	10-10-2022	15	10%	11
2.4	Assembling	All	10-10-2022	15-10-2022	6	0%	5
2.5	Meetings	All	27-9-2022	27-9-2022	1	0%	1
P3	**Second concept phase**			-			-
3.1	Research	All	1-11-2022	4-11-2022	4	0%	4
3.2	Design	Bryan (all)	1-11-2022	20-11-2022	20	0%	14
3.3	Code	Job and Antonin	1-11-2022	15-11-2022	15	0%	11
3.4	Testing	All	15-11-2022	16-11-2022	2	0%	2
3.5	Evaluation	All	17-11-2022	18-11-2022	2	0%	2
P4	**Final phase**			-			-
4.1	Documentation	All	12-9-2022	10-12-2022	90	30%	65
4.2	Prototype	All	12-9-2022	10-12-2022	90	0%	65
4.3	Presentation	All	12-12-2022	14-12-2022	3	0%	3
4.4	Poster	All	20-11-2022	21-11-2022	2	0%	1

The Gantt gives an overview of the tasks within the timeline of the project. The start and end day of each task can be seen in Table 4.

Table 4 Overview of all the task for the project with the responsible people and the deadline

Project Start Date: 9-12-2022 (maandag) | Project Lead: Hans Lindén | Display Week: 1

WBS	TASK	NAME	START	END	DAYS	% DONE	WORK DAYS
1	**Analyse phase & Idea phase**		12-9-2022	23-9-2022	12	100%	10
1.1	Meetings	All	12-9-2022	12-9-2022	1	100%	1
1.2	Research	Bryan and Chantal	12-9-2022	16-9-2022	5	100%	5
1.3	General code	Job and Antonin	12-9-2022	16-9-2022	5	100%	5
1.4	Workdocument	All	12-9-2022	13-9-2022	2	100%	2
1.5	Meetings	All	21-9-2022	21-9-2022	1	100%	1
1.6	Design	Bryan and Job	19-9-2022	23-9-2022	5	100%	5
1.7	Code	Job and Antonin	19-9-2022	23-9-2022	5	100%	5
1.8	Documentation	Chantal	19-9-2022	22-9-2022	4	100%	4
2	**Concept phase**		26-9-2022	16-10-2022	21		15
2.1	Design	Bryan	26-9-2022	7-10-2022	12	10%	10
2.2	Production	All	23-9-2022	12-10-2022	20	40%	14
2.3	Code	Job and Antonin	26-9-2022	10-10-2022	15	10%	11
2.4	Assembling	All	10-10-2022	15-10-2022	6	0%	5
2.5	Meetings	All	27-9-2022	27-9-2022	1	0%	1
3	**Second concept phase**			-			-
3.1	Research	All	1-11-2022	4-11-2022	4	0%	4
3.2	Design	Bryan (all)	1-11-2022	20-11-2022	20	0%	14
3.3	Code	Job and Antonin	1-11-2022	15-11-2022	15	0%	11
3.4	Testing	All	15-11-2022	16-11-2022	2	0%	2
3.5	Evaluation	All	17-11-2022	18-11-2022	2	0%	2
4	**Final phase**			-			-
4.1	Documentation	All	12-9-2022	10-12-2022	90	30%	65
4.2	Prototype	All	12-9-2022	10-12-2022	90	0%	65
4.3	Presentation	All	12-12-2022	14-12-2022	3	0%	3
4.4	Poster	All	20-11-2022	21-11-2022	2	0%	1



2. ANALYSE PHASE V1

In this chapter the first phase, analyse phase, for the first version of the weather station is described. It contains the problem statement, the first question, the answers on the first question and the design of the logo.

2.1 Problem statement

2.1.1 WHAT?

In this project the goal is to build a low-cost IoT weather station at Novia UAS that is solar powered and has wireless data transfer to MQTT broker. Besides that, minimal power should be consumed. Firstly, a working system, prototype, should be made using commercial sensors. The network LTE-M can be used first, but later NB-IoT will be used for more energy efficiency. Furthermore, low-cost sensors should be assessed and with the help of additive manufacturing other sensors the overall cost should be lowered. The code must be made modular so that additional sensors can easily be added and is easy to use.

2.1.2 WHEN?

The duration of the given project will be from the start of September till the middle of December. The midterm presentation will be held at the end of October. For this presentation a prototype should be finished and most information should be gathered. In the middle of December, the final presentation will be held. It should include the final report, the final version of the weather station and all the other relevant information.

2.1.3 WHO?

The people who will work on the project are Antonin Silvestre, Bryan Arents, Chantal Tijhuis and Job van Koeveringe. The group will be supervised by Hans Lindén. For questions about the European Semester Project Roger Nylund can be approached. Furthermore, the information gathered is for the sake of the school, Novia UAS, and especially for the one leading the project, Hans Lindén.

2.2 Questions and actions

2.2.1 GENERAL

a) Where should the weather station be mounded?
   - Field measurements

b) What kinds of production equipment is available?
   - Hans guided tour

c) Which professional examples are already available?
   - Desk research

d) Which amateur examples are already available?
   - Desk research

e) How to present the data?
   - Brainstorming

f) How to advertise our project?
   - Brainstorming

g) What will be the logo?
   - Design

h) What is the future vision?
   - Brainstorming

2.2.2 SENSOR

a) What kinds of sensors will we be mounting on version 1?
   - Hans

b) How to connect all the sensors?
   - Electronic research

c) What voltage do the sensors work on?
   - Electronic research

2.2.3 PROGRAMMING

a) What kind of library's do we need to use?
   - Programming research

b) What is NB-IoT?
   - Desk research

2.2.4 DESIGN

a) How to protect the electronics against the outdoor environment?
   - Desk research and design

b) How to mount the weather station?
   - Desk research, sketching and modelling

c) How to make the station modular interchangeable?
   - Sketching and modelling

2.3 Answers

2.3.1 GENERAL

a) Where should the weather station be mounded?

The first version of the weather station will be mounted on the top of Technobothnia. There are several options to mount the device. The first option is to mount the device on a lightning distractor tower. This will give a strong and stable mounting point. Figure 10 shows the mounting points with the dimensions of the lightning distractor tower on top of Technobothnia.

Figure 10 Dimensions mounting point

The pros of this mounting spot would be a level and sturdy mounting place. This mounting place has some cons. For example: The inability to easily move the weather station from Technobothnia to the Novia building. There is also a chance that the mounting spot has different dimensions on the Novia

building. This would mean there is a possibility that the second version would have to be a total new design.

The other options are to design a new mounting area. This may solve the cons, but it would mean a little bit more work. Fortunately, there is a lot of time for this project. This will be further investigated in the idea phase.

b) What kinds of production equipment is available?

A lot of equipment is available. The things that are not available are the 3D metal printer, the CNC machine and the robot arms. The other equipment located in Technobothnia are accessible. The materials to work with are wood, plastic and metals. A broad selection of design options is available. The best way to approach choosing the production process is to first look at what is the best for outdoor use. A professional look is wanted as well.

Most of the parts will be 3D-printed, because that is a good option to make intricate designs cheaply. Also, some metal work can come in handy to make sturdy bases.

c) Which professional examples are already available?

Figure 11 shows the searched professional examples of weather stations. It can be seen that most of them are built in similar ways, like SparkFun Electronics (1), Sectron (2) and Weatherspares (4). The one from Meter (3) looks more compact.

Figure 11 Display of professional weather stations

Table 5 Professional examples of weather stationsTable 5 shows some extra information about the different professional-made weather station. Information about the used materials and the things measured can be found.

Table 5 Professional examples of weather stations

NR.	MANUFACTURER	SENSORS AND MATERIALS	MEASURED	SOURCE
1	SparkFun Electronics	wind vane, cup anemometer, tipping bucket rain gauge, two-part mounting mast, rain gauge mounting arm, wind meter mounting bar, mounting clamps and zip ties	wind speed, wind direction and rainfall	(SparkFun Electronics, 2022)
2	Sectron	touch LCD with backlight, API, base station (receiver), wind direction sensor, wind speed sensor, rain gauge, USB cable and PC software	barometric pressure, outside temperature, indoor temperature, external and internal relative humidity, wind speed and amount of precipitation	(SECTRON, 2020)
3	Meter	pyranometer spectral response compliance, GSA, solar radiation, precipitation, humidity sensor temperature, vapor pressure, barometric pressure, horizontal wind speed, wind gust, wind direction, tilt, lightning strike count, lightning average distance, output, data logger compatibility, connector types, stereo plug connector and conductor gauge	air temperature, relative humility, vapor pressure, barometric pressure, wind speed, gust and direction, solar radiation, precipitation, lightning strike counter and distance	(Metergroup, 2020)
4	Weatherspares	WH57 lightning sensor, WH45 PM2.5/PM10/CO2/temperature and humidity all-in-1 sensor, WH31 multi-channel temperature and humidity sensors, WH51 soil moisture sensors, WH41/WH43 PM2.5 air quality sensors, WH55 water leak sensors and WN34 temp sensors	anemometer, solar radiation, UV level, light intensity, temperature, humidity, rain, rainfall, windchew, dew point and heat index	(Weatherspares, 2021)

d) Which amateur examples are already available?

Figure 12 shows the searched amateur examples of weather stations. These are some of the hand-made examples in DIY-form. The weather station made by S. Agrawal (4) is based on IoT and the one from Open Green Factory (2) is solar based. Those can be useful for this project. Some of the pictures only show the sensor set-up as the end product, those are from C. Barnatt (3) and S. Agrawal (4). U. Winberg (1) has made a design that looks similar to the one of Open Green Factory.

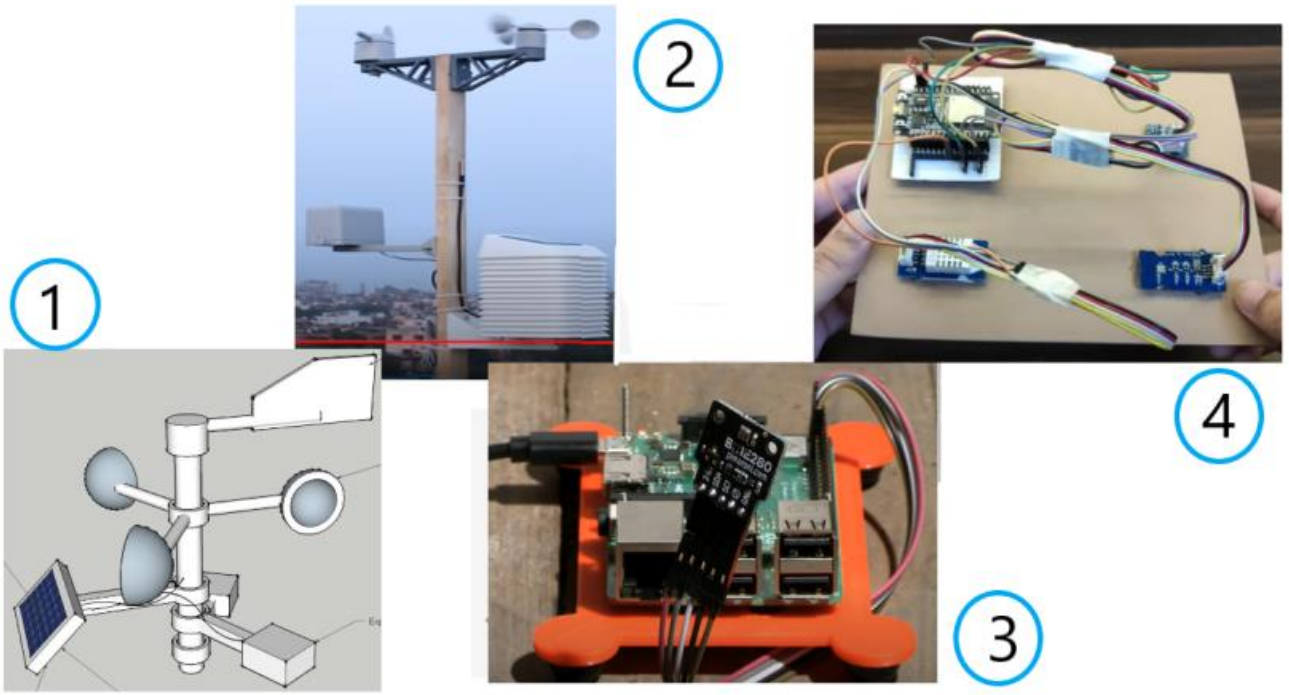


Figure 12 Display of amateur weather stations

Table 6 shows some extra information about the different professional-made weather station. Information about the used materials and the things measured can be found. Only a few home-made examples are listed in the table. More can be found in B. Appendices.

Table 6 Amateur examples of weather stations

NR.	MANUFACTURER	SENSORS AND MATERIALS	MEASURED	SOURCE
1	Ulf Winberg	push switch, voltage regulator XC6217, resistor 1k;2k;4k;6k, header pin, hall sensor, Bluetooth LE transceiver, Blue low energy device with programmable microcontroller, super capacitor 5F, solar cell, antenna, resistor 1M, capacitor 1u, resistor 2M;100hm;10k;150;300, header pin 2x1;2x10;2x3, CPC102N, CPC1117N, shottky diode CU5520 H3F and temp sensor LM94022	temperature, wind and sun	(Winberg, 2015)
2	Open Green Factory	ESP32 Dev Kit V1, TP4056, barometric pressure sensor BME280, temperature sensor - DS18B20, UV index sensor - GY1145, lux level sensor - BH1750, wind & rain sensor, MCP1700-3.3V, resistors - 2 x 1K, 1 x 10K, 3 x 4.7K, 1 x 27K, 1 x 100K, electrolytic capacitor - 1 x 100uF, ceramic capacitors - 4 x 0.1uF, TVS Diode - DT1042-04SO, RJ11 connector, male / female headers, jumper cap, screw terminal-2P - 5.08mm pitch, screw terminal -3P -3.5mm pitch, solar panel - 5V / 1.2Watt, 18650 battery, 8650 battery holder, 22 AWG wires and slide switch	internal temperature, humidity, barometric pressure, external temperature, wind speed, wind direction, rain gauge, UV-index and lux level	(Open Green Energy, 2021)
3	Christopher Barnatt	Bosch BME280 temperature, pressure, humidity sensor, I2C interface, Qwiic/STEMMA QT connector 3.3V or 5V compatible, reverse polarity protection, Raspberry Pi-compatible pinout, compatible with Arduino, compatible with Raspberry Pi and compatible with Raspberry Pi Pico	temperature, pressure and humidity data	(Barnatt, 2021)
4	Saiyam Agrawal	ESP32 development board, DHT11/21/22 temperature & humidity sensor, SI1145 sunlight sensor, BMP180 barometric pressure sensor, perfboard or breadboard, male to female jumper wires, grove connector cables and micro-USB cable	temperature, humidity, barometric pressure UV index IR radiation visible light	(Agrawal, 2022)

e) How to present the data?

The best way to present data is via a website or a mobile app. This will be quickly accessible and not too hard to realise. The data should be in numbers or in letters, but also visible by icons or for example a chart.

f) How to advertise the project?

There are diverse ways to advertise the project. There is at least a requirement to make a poster in A4 format. Furthermore, a website is also an effective way to promote the project and at the same time present the data. There is a screen in Technobothnia where the data can be shown. This would also advertise the project, by putting in a link and the logo.

g) What will be the logo?

The logo should include the name of the project team and some visual representation. The logo should be easily 3D printable and it should have a professional outlook.

h) What is our future vision?

In the future vision the team will describe what is important for them to focus on during this project.

2.3.2 SENSOR

a) What kinds of sensors will we be mounting on version 1?

The sensors that will be mounted:

- Temperature sensor
  - Temperature sensor FS 400-SHTXX
  - *Industrial Dustproof Temperature Sensor Stainless Steel Plastic Housing I2C Output FS400-SHT3X*. (z.d.). AliExpress. Checked on 14 September 2022 of https://www.aliexpress.com/item/4000117617368.html
- Wind speed + direction sensor
  - Davis vantage pro Anemometer
  - *Davis Vantage Pro2 Anemometer 6410*. (2021, 22 June). Weather Spares. Checked on 14 September 2022 of https://weatherspares.co.uk/products/davis-vantage-pro2-anemometer-6410?variant=20218104447072&currency=GBP&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_campaign=gs-2021-06-22&utm_source=google&utm_medium=smart_campaign&gclid=Cj0KCQjw94WZBhDtARIsAKxWG-_QSGN0U5Ch_GhEsf1bbqBpcDJ_5Tzjpli3pTBgN5dYSE2nTW7a0VwaAnHnEALw_wcB
- Rainfall sensor
  - Davis AeroCone® Rain Collector W/Vantage Pro2™ Mounting Base
  - Khunt, S. (2022, 20 September). *Davis AeroCone® Rain Collector w/Vantage Pro2™ Mounting Base*. Stock4less EU. Checked on 14 September 2022 of https://stock4less.eu/en-fi/products/6466-dav?variant=43158546940140&utm_medium=cpc&utm_source=google&utm_campaign=Google+Shopping&gclid=Cj0KCQjw94WZBhDtARIsAKxWG-87uEPYkIM08thNow4o6E_VQ9Tb79KHh_kfQJ-wlfJvFXV9FmnGSOIaAg1VEALw_wcB

b) How to connect all the sensors?

Figure 13 Display of an Arduino MKR NB 1500

The sensors will be connected to the Arduino via male cables. The Arduino used is the MKR NB 1500, see Figure 13. This Arduino allows communication over NB-IoT and LTE-M networks. Communication over these networks will make the weather station excellent for working in remote areas. The connection cable for the sensors still must be bought.

In addition, the following image, Figure 14, shows the pinout diagram to get a better idea of the functionalities of this board.

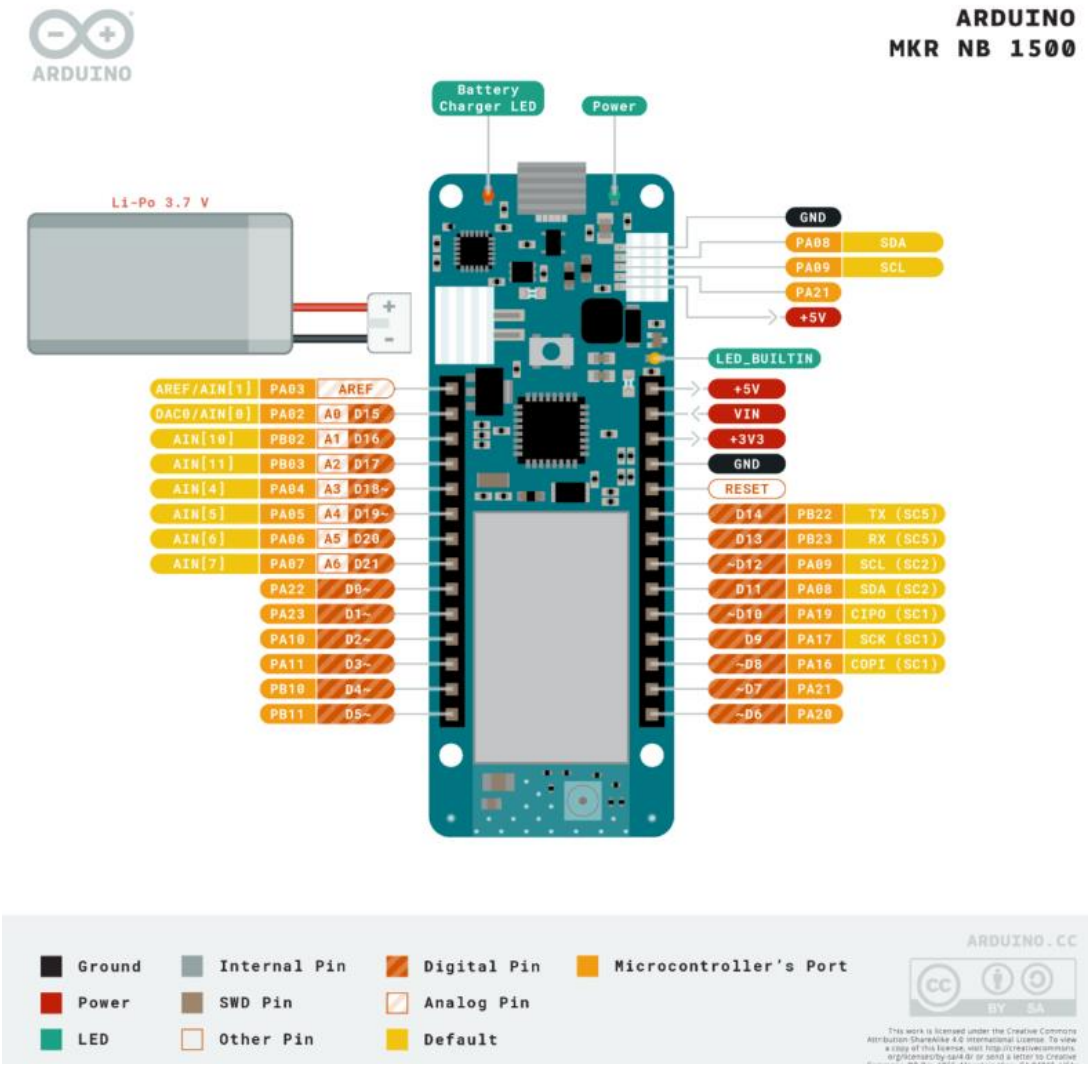


Figure 14 Closer look on the function of the Arduino with information about each pin

This Arduino is perfectly compatible with our goals. All these features make the Arduino MKR NB 1500 board an excellent for many of the basic IoT application scenarios. It is a smart choice for any beginner, maker or professional to get started with Internet of Things (IoT). Its wireless connectivity ability makes this board suitable for use in projects that will communicate with the cloud, such as collecting data from the sensors and uploading this data to cloud services.

c) *What voltage do the sensors work on?*

The sensors should work on the Arduino outputs voltage of 3.3V or 5V.

2.3.3 PROGRAMMING

a) What kind of libraries do we need to use?

As an example, for the Arduino the library C++ is used. C++ comes in two pieces: A header file that defines the functionality the library is exposing (offering) to the programs using it and a precompiled binary that contains the implementation of that functionality pre-compiled into machine language (Alex, 2022).

b) What is NB-IoT?

NB-IoT stands for Narrowband Internet of Things protocol using low-power wide area network technology. It is a new technology the enables a wide communication range. This enables the weather station to be used everywhere, wherever there is a mobile network connection.

2.3.4 DESIGN

a) How to protect the electronics against the outdoor environment?

It is best to choose sensors that are weatherproof, so the weather station can be placed outdoors in all-weather circumstances. The provided sensors are all weatherproof. The Arduino and the connectors are the only things that are needed to be placed inside a waterproof box. The antenna should also be waterproofed. This can be done by using a waterproof kit around the opening of the box for the antenna.

b) How to mount the weather station?

The weather station will be mounted on a moveable station. This will have some tripod feet to stabilize the thing. In the idea phase, more attention will be paid on the mounting station.

c) How to make the station modular interchangeable?

The easiest way to make the station modular interchangeable is to make a mounting station that has a long pole where the sensors can be mounted on. There should be some system to secure and remove the sensors. For example, a hook or a clamp. This will be further investigated during the idea phase.

2.4 Logo

The logo is found in Figure 15. The logo is designed to give attention to the group name, which is 'Weathercrew'. The name 'Weathercrew' came in mind, because the team is a crew that works on measuring different weather. The logo has a visual attention getter for the things that are important in this project. The visuals stand for the weather that gets measured by the weather station. All the symbols are connected, this is a reference to the weather station being wireless connected to the mobile networks. The colours are all in black, so it will give off a professional look. The logo is surrounded by a rectangle, which brings it all together.

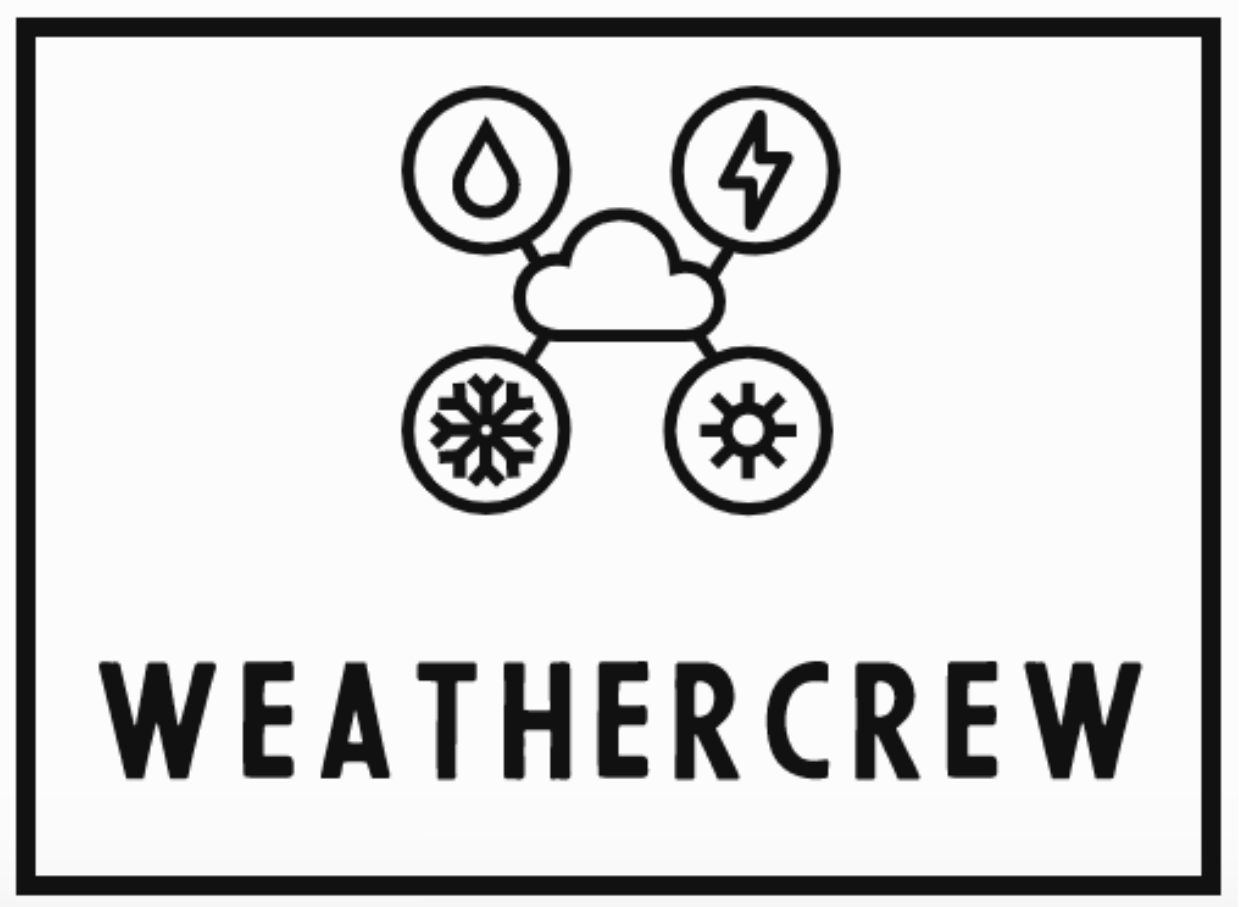


Figure 15 Display of the group's logo

2.5 Future vision

Our aim is to design a low-cost weather station that will endure for the upcoming years. It will work with renewable energy so it will also be environmentally friendly.

1. IDEA PHASE V1

The chapter 'Idea phase V1' will contain the first sketches, ideas and designs for the first version of the weather station. It gives information about the mounting station, the material that will be used, the housing for the sensors and which additive manufacturing material is best to use.

3.1 Problems

3.1.1 GENERAL LAY-OUT

First thing to figure out is the general lay-out of the weather station. For example, how are the modules going to be mounted and what is on the weather station. In Figure 16 is a sketch of how the general lay-out should look like. Thought has been given on the weight balance and the guideline height standards. The height standards are important for accurate measurement readings. The rain sensor is mounted 200mm sideways form the main pole.

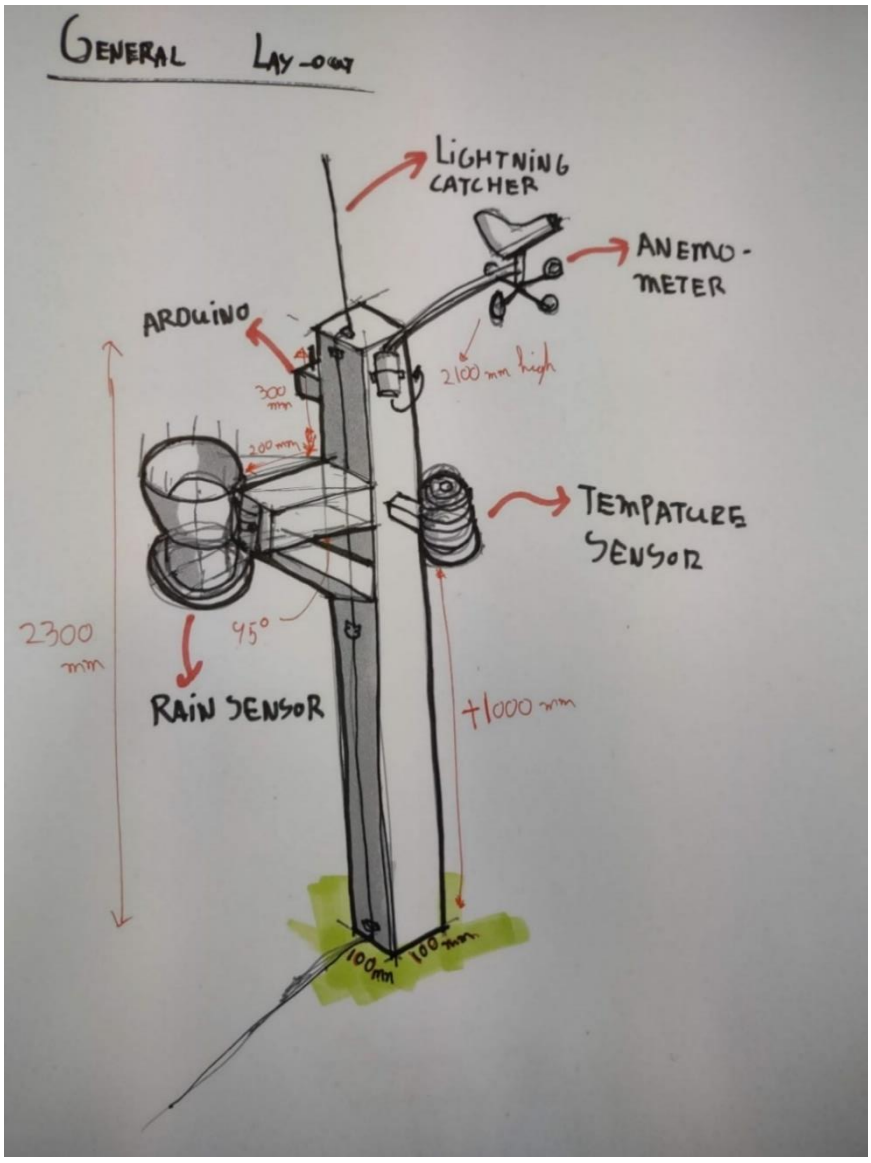


Figure 16 General lay out sketch

3.1.2 MOUNTING STATION

The design of the mounting station is also required. In the next figure, Figure 17Figure 17, there are some sketches of possible mounting stations. The best ones are worked up with more detailed sketching. Design one has the most advantages, such as that it is a stable structure. This will be the first suggestion to make. Design two is the quick fix, if design two doesn't work like it should.

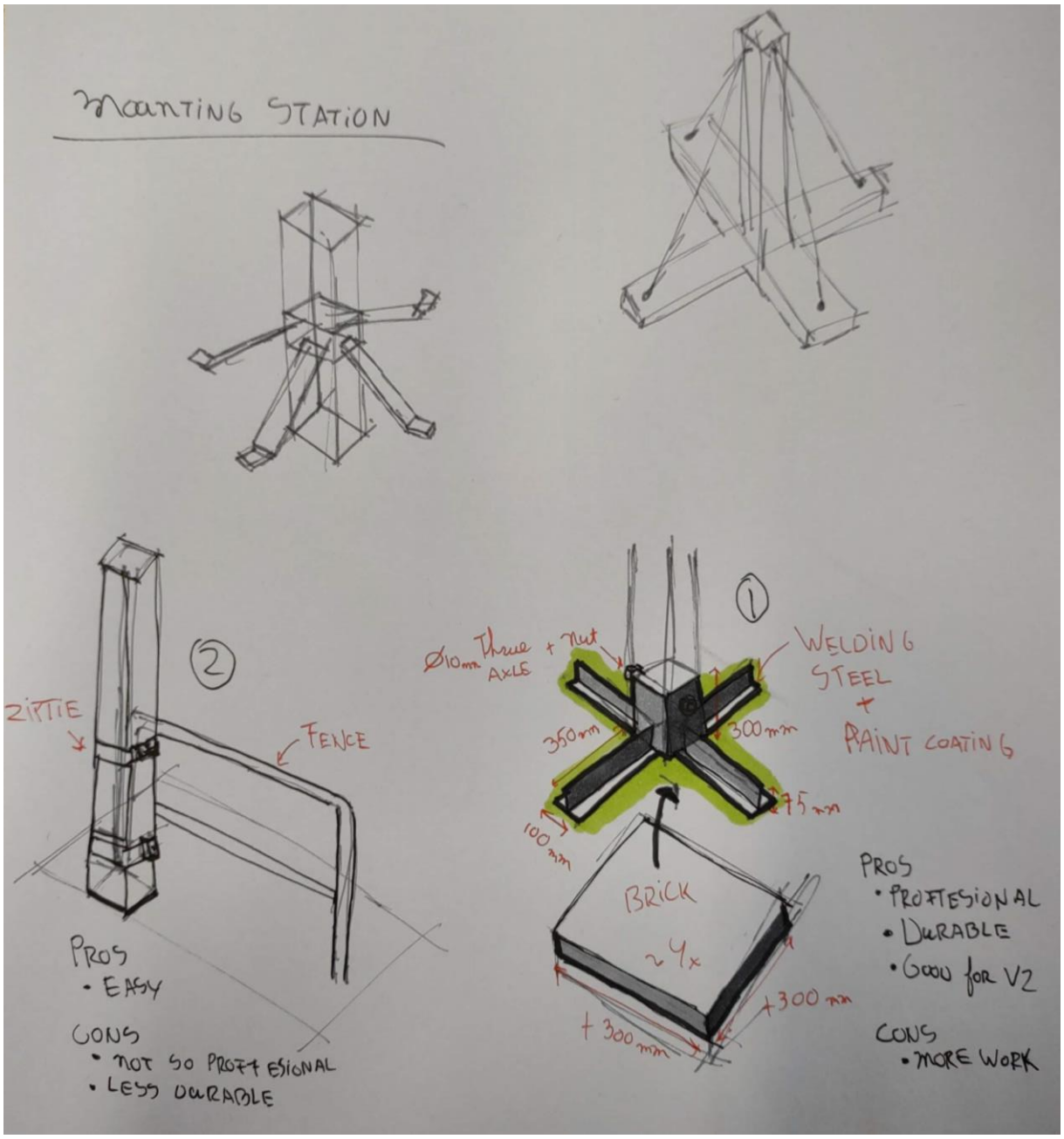


Figure 17 Mounting station designs

3.1.3 INTERCHANGEABLE

By choosing a wooden post for mounting the modulus are easily interchangeable by screwing or unscrewing the modulus. This solution is fine for the first version and might also be a workable solution for version 2.

3.1.4 HOUSING

A weatherproof housing is required to keep the Arduino battery and the antenna safe. In Figure 18 it is shown how the housing for the sensors is designed.

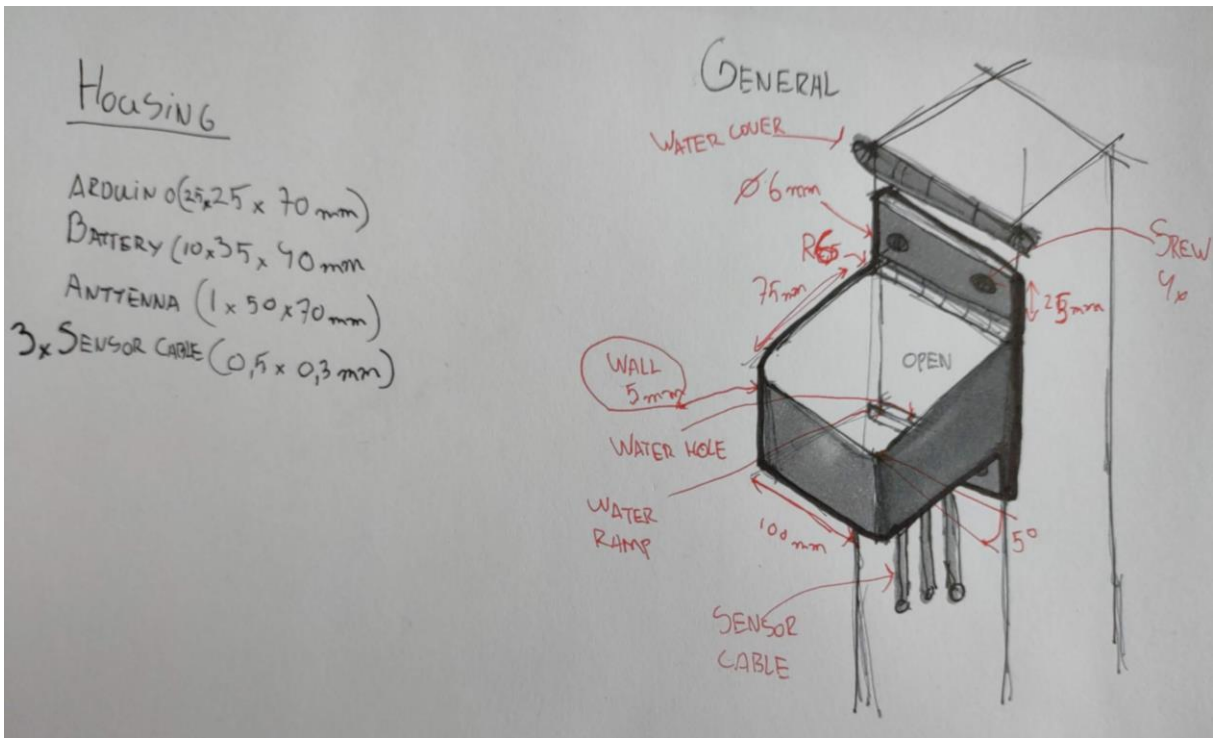


Figure 18 Housing for the sensors

3.1.5 SUN PROTECTION TEMPERATURE SENSOR

The temperature sensor is sensitive to temperature. If the sun hits the sensor, the temperature will spike. This is not favourable for the measurements of the air temperature. A sun protector is needed, that also has free flow of air.

3.2 Material choice

3.2.1 MOUNTING STATION

The mounting station will be the structure that will support the housing for the sensors. Furthermore, it is a structure to mount the rest of the sensors. Extra information about the durability of the materials is given in B. Appendices.

3.2.1.1 Pole

Figure 19 Wood used

The pole will be made of Parru PROF wood that is 100x100mm. The wood is used to support structures that are in contact with earth, water and concrete. It is sustainable, which means that it's versatile for yard and environmental construction (K-Rauta, 2022). The size of the wooden pole is chosen to be a bit smaller than the designed housing for some extra leeway. *The chosen shape is a square, instead of a circle, because more surface area can be used for the housing and the mounting. Moreover, it is easier to find wooden poles in square shape.*

3.2.1.2 Base

Figure 20 Concrete used

For the base Concrete slab grey BL305 300x300x50 offer Varnish (Hartman, 2022). *This concrete may support the pole to stand up straight, because of their weight.* The squares will be put on every side of the pole structure to make an even distribution of weight. To secure the concrete slabs in place, L-shaped steel will be used. This can be seen in Figure 17.

3.2.1.3 Assemble point

Figure 21 Steel used

A PROF post leg is used to secure the pole and the concrete together (K-Rauta, 2022). The size is 102x102mm and fits the wooden pole perfectly. *It will make the structure stronger and better resistant to the wind.*

3.2.2 ADDITIVE MANUFACTURING

For additive manufacturing different plastic and materials can be used. A closer look will be given on Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG) and Acrylonitrile Styrene Acrylate (ASA). Table 7 shows the advantages and disadvantages of each material on key features (Flynt, 2020).

Table 7 Additive manufacturing filament and their advantages

3D-print filament	PLA	ABS	PETG	ASA
Waterproof	Low	Low	High	High
UV-proof	Low	Low	High	High
Low temperature proof	Medium	Low	High	Medium
High temperature proof	Low	High	Medium	High
Price	Low	Low	Medium	High
Printable	High	Medium	Medium	Low
Strength	Medium	High	Medium	Low

For the first few designs and prototypes PLA will be used. As seen in Table 7 it is low in price and it is easy to print, which shortens the time of the print. Eventually, for the final version of the weather station it is better to use PETG. The weather station will be places outside and needs to be as weatherproof as possible. PETG scores high on waterproof, UV-proof. Furthermore, it can endure at low temperatures. PETG is a bit more expensive than PLA, but the functionality compensates it.

4. CONCEPT PHASE V1

In the concept phase the first version concept will be displayed and explained. A closer look is given on the coding and all the designed and printed parts will be explained.

4.1 Design

4.1.1 MARKETING

4.1.1.1 Display of logo

To display the responsible project team, the logo has been put on the top of the weather station with a little house to pull some extra attention. The final design is also made with dual 3D-printing to add different colors for even more pull towards the logo, seen in Figure 22.

Figure 22 Marketing house

4.1.1.2 Poster

A poster is made to show the project to the other students and teachers. In Figure 23 the first version of the poster can be seen. The QR-code to the website works.

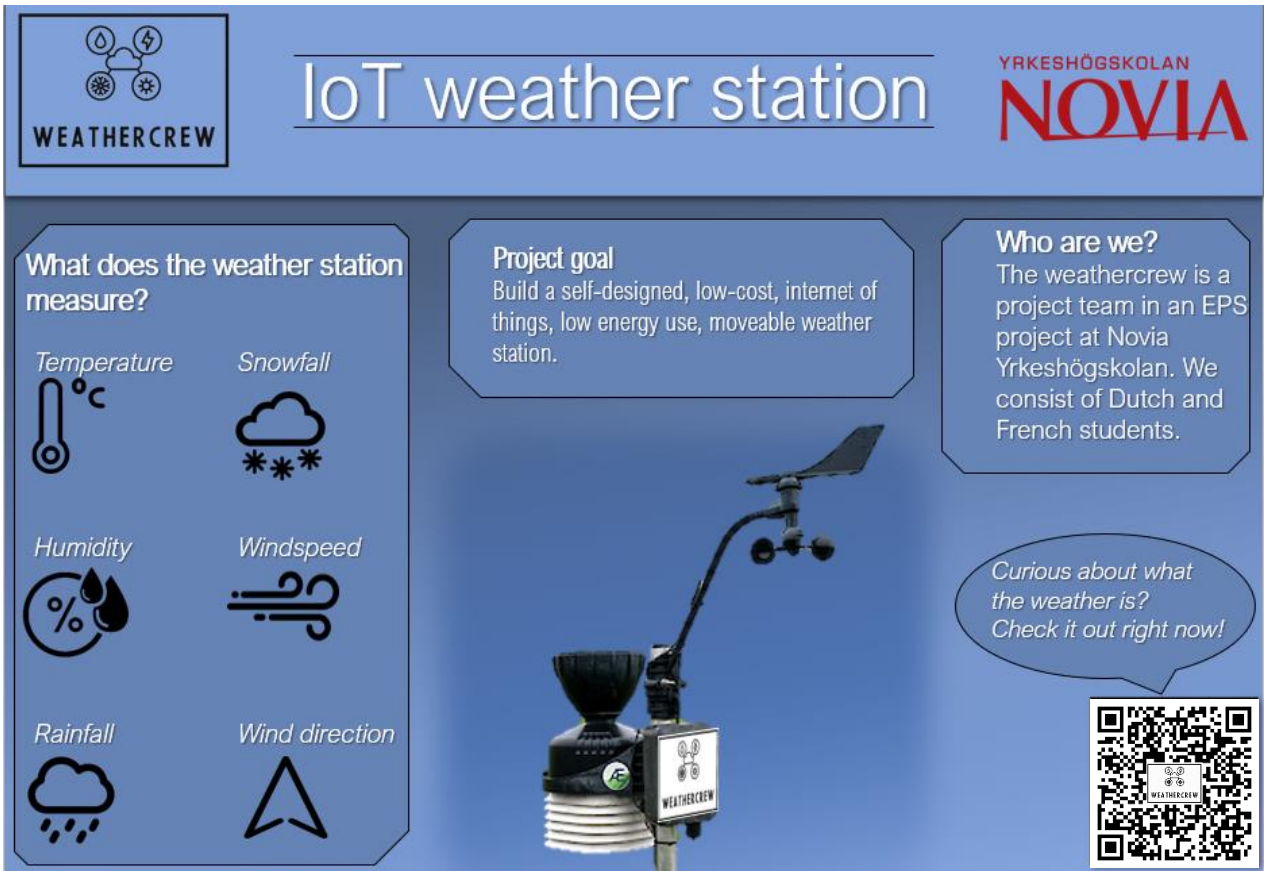


Figure 23 shows the first poster that has been made for marketing

4.1.2 GENERAL DESIGN

The general design is to be found in Figure 24. The mounting pole is fabricated by woodworking. The sensors are placed with the requirements of the sensors. For example, the windspeed/direction sensor is placed at 2100mm and does not have any wind obstructions. The rainfall sensor is placed 300mm to the side, so there is no obstruction of rain. The Arduino housing is placed at a place that is easy to reach, so this helps with maintainability. The temperature sensor is also easily reachable, because there is not a height requirement.

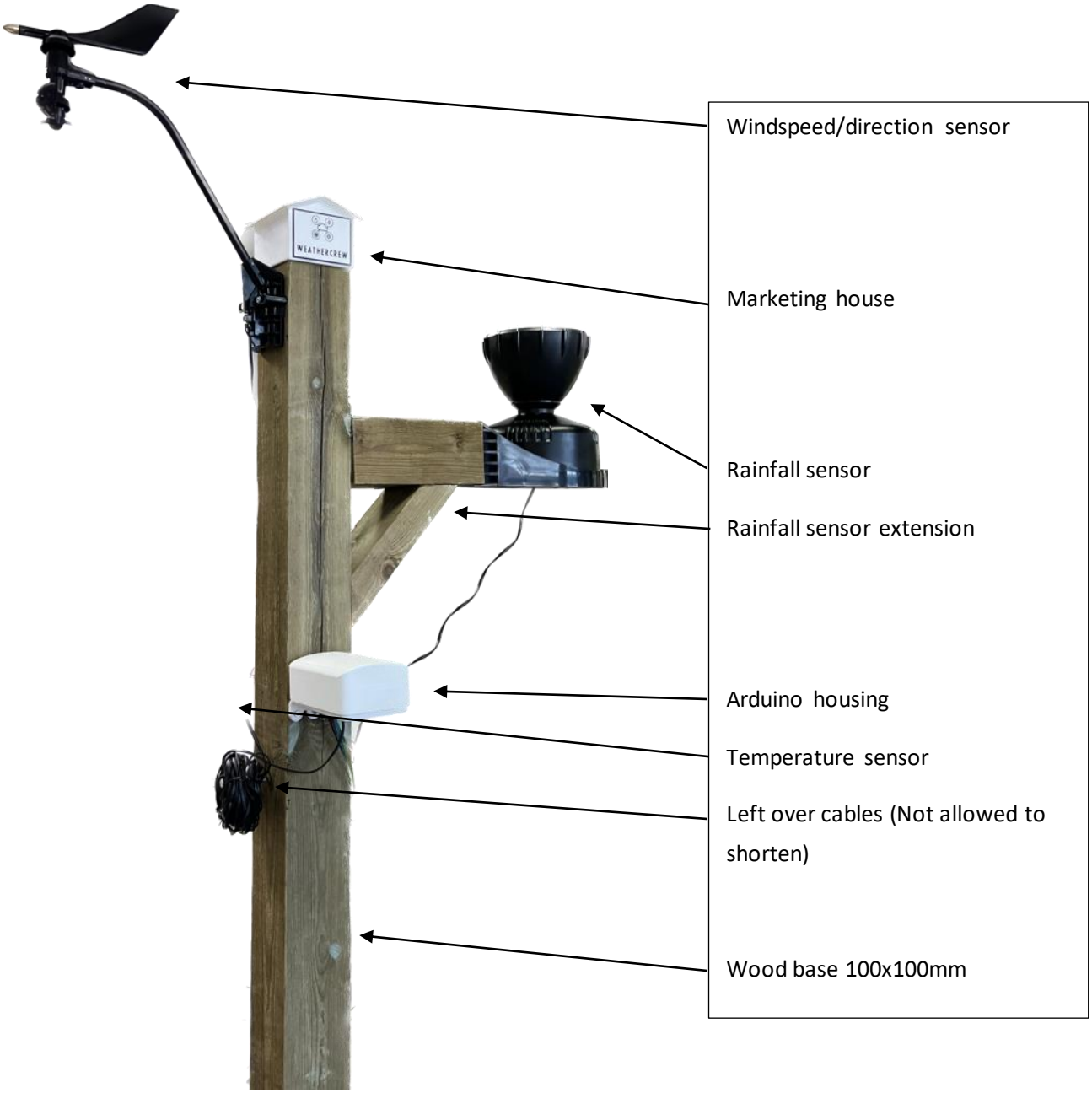


Figure 24 General design

4.1.3 MOUNTING BASE

The mounting base is important, because if it fails it could break all the sensors. Therefore, the mounting base is built out of metal, because it is stronger than wood and has more weight. The mounting base is fabricated with a garden pole mount and 4x 300mm steel L-beams. These L-beams are for stability and to put extra weight in the form of garden tiles. This keeps the weather station on the ground.

It is built by sawing the l-beam into four pieces. Then it's grinded down and cleaned up. This made it possible to weld the pieces together. After the welding, the entire thing is leveled out by force. After that, it was time to sandblast the entire thing to make it ready for painting. The painting is done in black, because it fits the theme of the weather station very well. In Figure 25 the technical work drawing is to be seen. This was used to fabricate the mounting station.

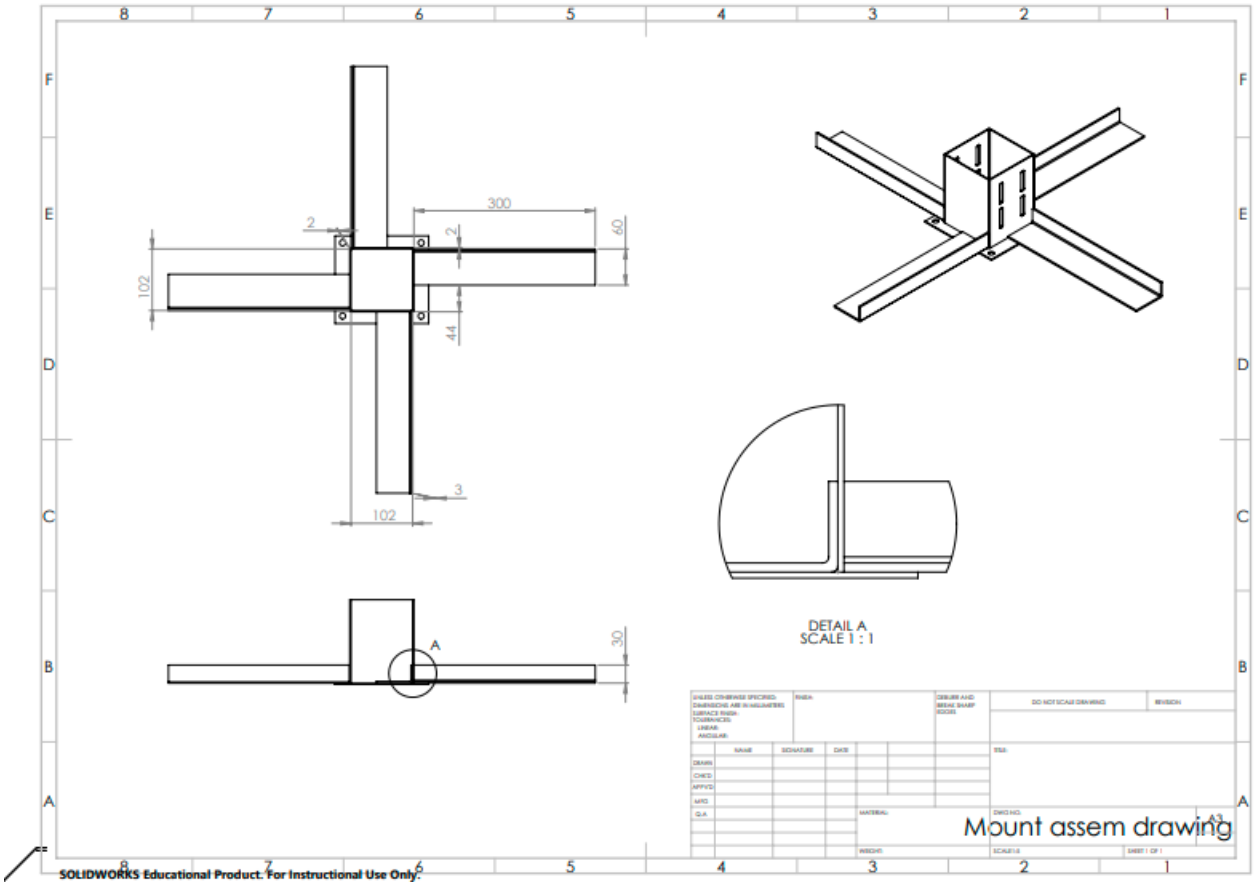


Figure 25 Mounting base drawing

The fabricated piece looks like Figure 26.

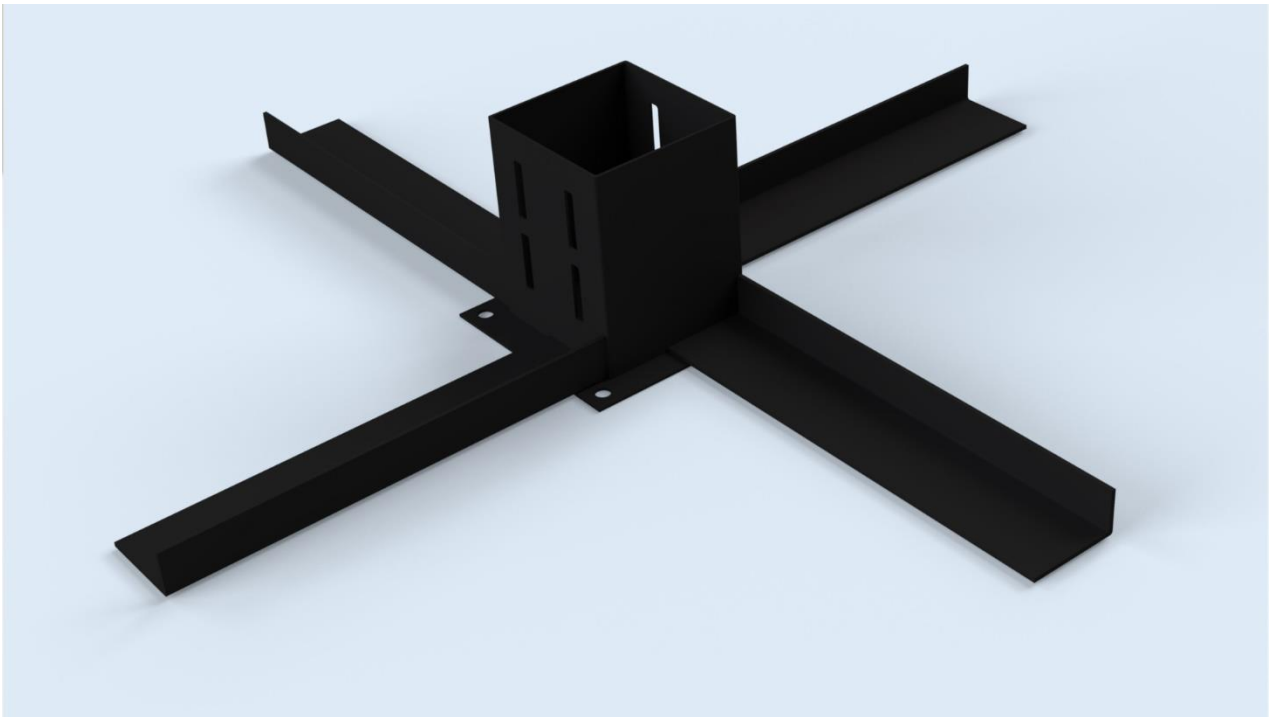


Figure 26 Mounting base

4.1.4 ARDUINO HOUSING

4.1.4.1 Version 1

The Arduino housing is to keep the Arduino, connectors, antenna and battery far away from the elements. This is done by mounting the housing directly to the wooden pole with a rubber seal in between. Any condense that still could come in rolls down to the cable opening, because there is a 5-degree slope on the design. After discussion, it was decided not to use this design, because it would mean the hole housing had to be unscrewed to access the Arduino. In the next the design the top should be easily removable. The first version is to be seen in Figure 27.

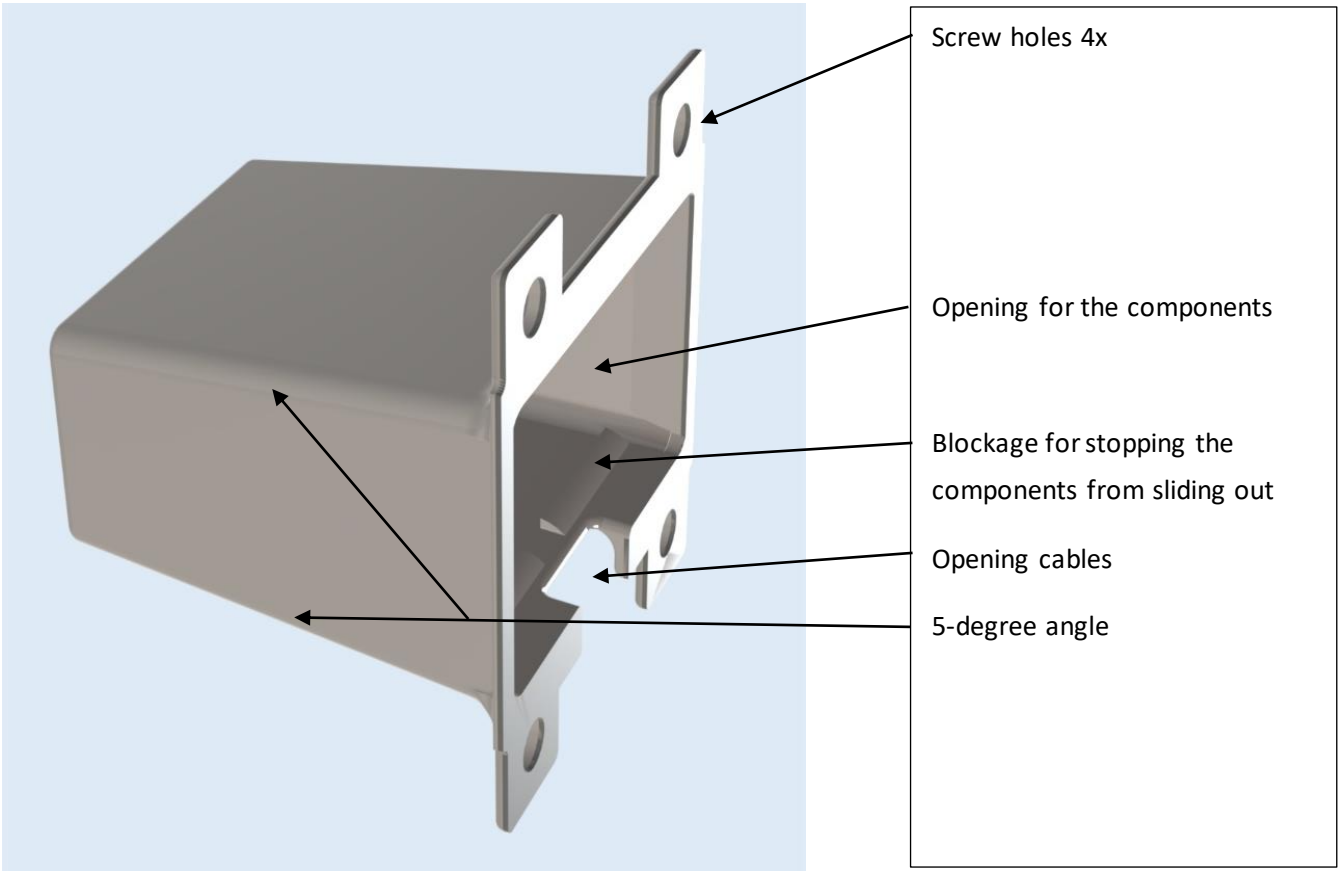


Figure 27 V1 Arduino housing

4.1.4.2 Version 2

The second version should have a removable top to access the components. The version 2 is 3D-printed with ASA filament. There are some extra improvements to the housing, such as a thinner wall as a place for the antenna. The top is to be found in Figure 28 and the bottom is to be found in Figure 29.

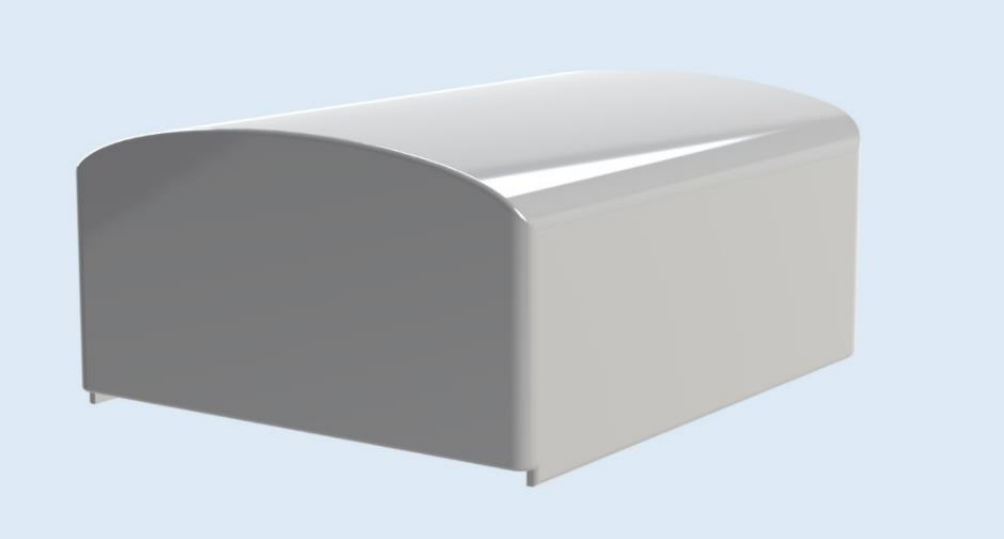


Figure 28 V2 Top Arduino housing

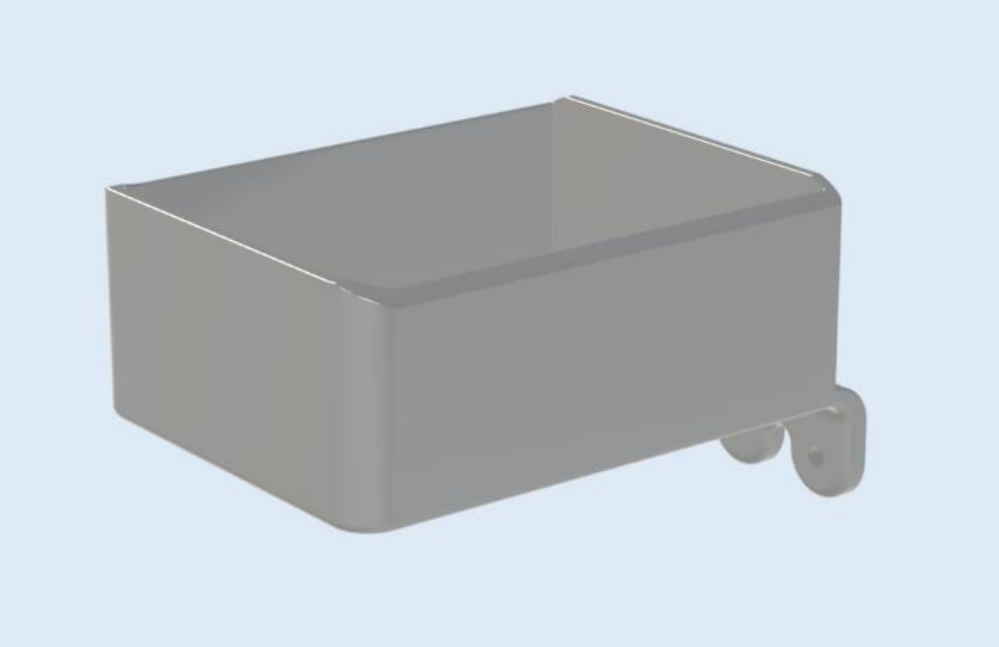


Figure 29 V2 Arduino housing

In Figure 30 the design of the inside of the Arduino housing is explained. All the components are lifted, so condense will not touch the components.

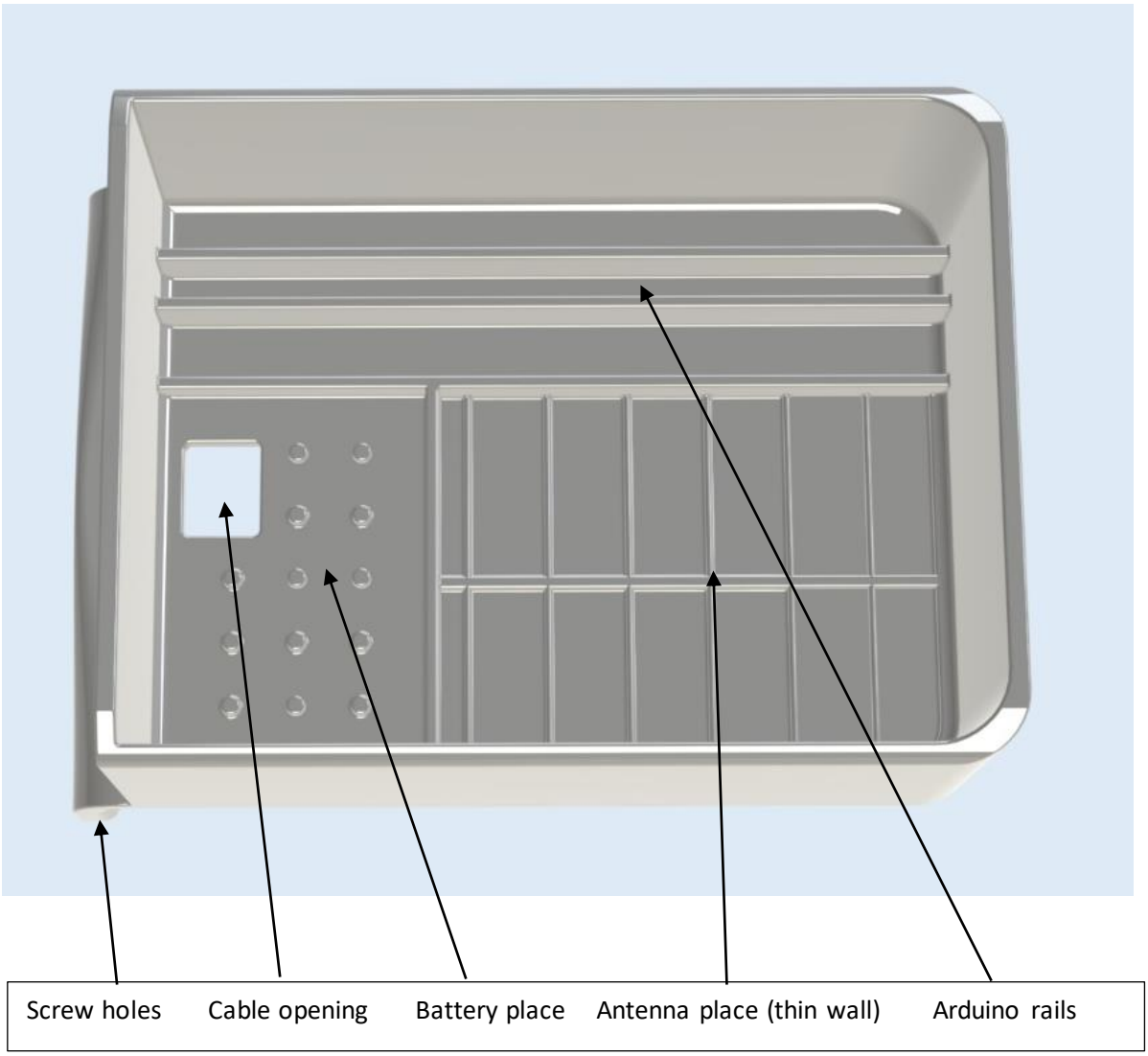


Figure 30 V2 Arduino housing

4.1.3 TEMPRATURE SENSOR HOUSING

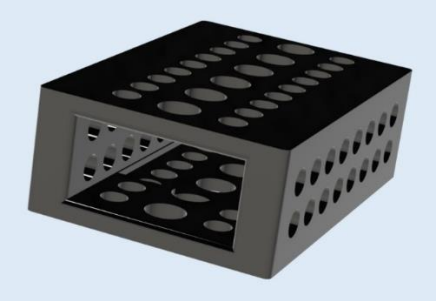


Figure 31 Temperature sensor component

The sensor that will be used for the temperature and humidity is small and not weatherproof. This means that it should be protected against the elements, but there should also be free airflow to the sensor for it to be accurate. This makes it a little hard. Therefore, the sensors are first placed inside the component from **Error! Reference source not found.**. This has many holes so there is free airflow and it can be mounted to the top of the housing design from **Error! Reference source not found.**. The top of the housing design also has airflow openings. This product is glued to the bottom housing. This part of the housing also has some openings, but these are for letting out any snow/rain inside of the housing. The bottom part of the housing is used to mount the entire product to the pole.

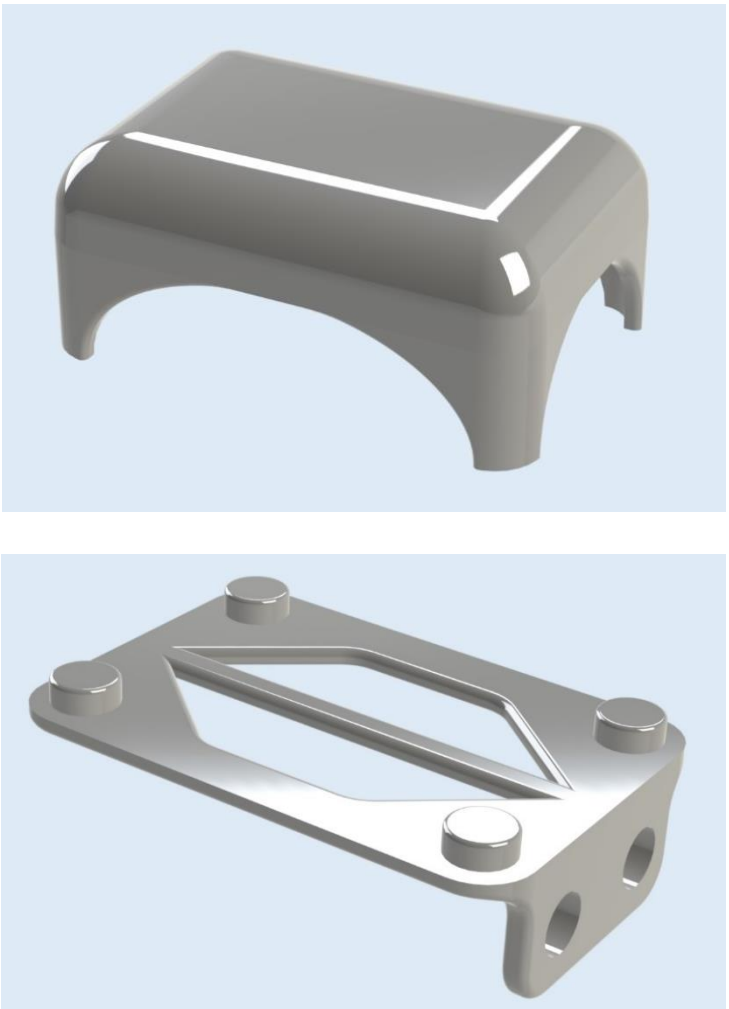


Figure 32 Temperature housing top and bottom

4.2 Code

4.2.1 WIND SPEED

Register WindSensorSpeedPin and attach interrupt:

```
pinMode(WindSensorSpeedPin, INPUT);
attachInterrupt(digitalPinToInterrupt(WindSensorSpeedPin), isr_rotation, FALLING);
```

Add one rotation when there is a full rotation:

```
// This is the function that the interrupt calls to increment the rotation count
void isr_rotation ()
{
  if ((millis() - ContactBounceTime) > 15 )
  {
    Serial.println("add ratation");
    Rotations++;
    ContactBounceTime = millis();
  }
}
```

Calaculate wind speed for Miles and Kilometer per hour:

```
WindSpeedMPH = Rotations * 0.0375;
WindSpeedKPH = WindSpeedMPH * 1.609344;
```

Reset rotations after calculating speed:

```
Rotations = 0; // Set Rotations count to 0 ready for calculations
```

4.2.2 WIND DIRECTION

Reads analog data with a value from 0 to 1023 and converts it to rang of 0 to 360.

If the wind direction has an offset, it will be added.

```
AnalogDirectionValue = analogRead(WindSensorDirectionPin);
DirectionDegreesWithoutOffset = map(AnalogDirectionValue, 0, 1023, 0, 360);
WindDirectionDegrees = DirectionDegreesWithoutOffset + WindDirectionOffset;

if(WindDirectionDegrees > 360)
{
    WindDirectionDegrees = WindDirectionDegrees - 360;
}

if(WindDirectionDegrees < 0)
{
    WindDirectionDegrees = WindDirectionDegrees + 360;
}
```

4.2.3 RAINFALL

Register RainSensorPin and attach interrupt:

```
pinMode(RainSensorPin, INPUT_PULLUP);
attachInterrupt(digitalPinToInterrupt(RainSensorPin), isr_bucket, RISING);
```

Add bucket amount to hourly and daily rain value when the bucket tips:

```
// This is the function that the interrupt calls to increment the bucket tips
void isr_bucket ()
{
  if ((millis() - ContactBounceBucketTime) > 1000 )
  {
    Serial.println("add bucketAmount");
    HourlyRain+=bucketAmount;
    DailyRain+=bucketAmount;
    ContactBounceBucketTime = millis();
  }
}
```

Reset the hourly and daily rain value:

```
if(rtc.getMinutes()== 0) {
   Serial.println("Reset Rain");
   HourlyRain = 0.0; // clear daily-rain at new hour
}
else if (rtc.getHours()== 0){
   Serial.println("Reset Rain");
   DailyRain = 0.0; // clear daily-rain at midnight
}
```

4.2.4 TEMPRATURE AND HUMIDITY

Reads digital data by protocol I^2C from the AM2320 sensor.

```
// initialize the library instance
Adafruit_AM2320 AM2320 = Adafruit_AM2320();

AM2320.begin(); //start readering temprature & Humidity

// Read the temperature and the humidity:
float tempC = AM2320.readTemperature();
float humidity = AM2320.readHumidity();
```

4.2.5 BATTERY

```
// read the input on analog pin 0:
int sensorValue = analogRead(ADC_BATTERY);
// Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 4.3V):
float voltage = (sensorValue * (4.3 / 1023.0))*0.9725;
```

4.2.6 SETUP

Start Serial port:

```
Serial.begin(9600); // Begin serial communication at a baud rate of 9600:
while (!Serial) {
    Serial.println("Wait for serial port to connect");
}
Serial.println("Start setup procedure");
```

Set date and time for the Arduino:

```
rtc.begin(); // initialize RTC 24H formats
rtc.setTime(12, 00, 11); // add 11 sec for boot load
rtc.setDate(22, 10, 2022);
```

Connect to Internet:

```
boolean connected = false;
while (!connected) {
  if ((nbAccess.begin(pinnumber) == NB_READY) && (gprs.attachGPRS() == GPRS_READY)) {
    connected = true;
    Serial.println("Connected to internet");
  } else {
    Serial.println("Not connected to internet");
    delay(1000);
  }
}
```

Connect to MQTT:

```
mqttClient.setUsernamePassword(username, password);

if (!mqttClient.connect(broker, port)) {
  Serial.print("MQTT connection failed! Error code = ");
  Serial.println(mqttClient.connectError());
  while (1);
}
```

4.2.7 COLOR CABLES

The cables assemblies are made easy and maintainable by using different colors for different functions.

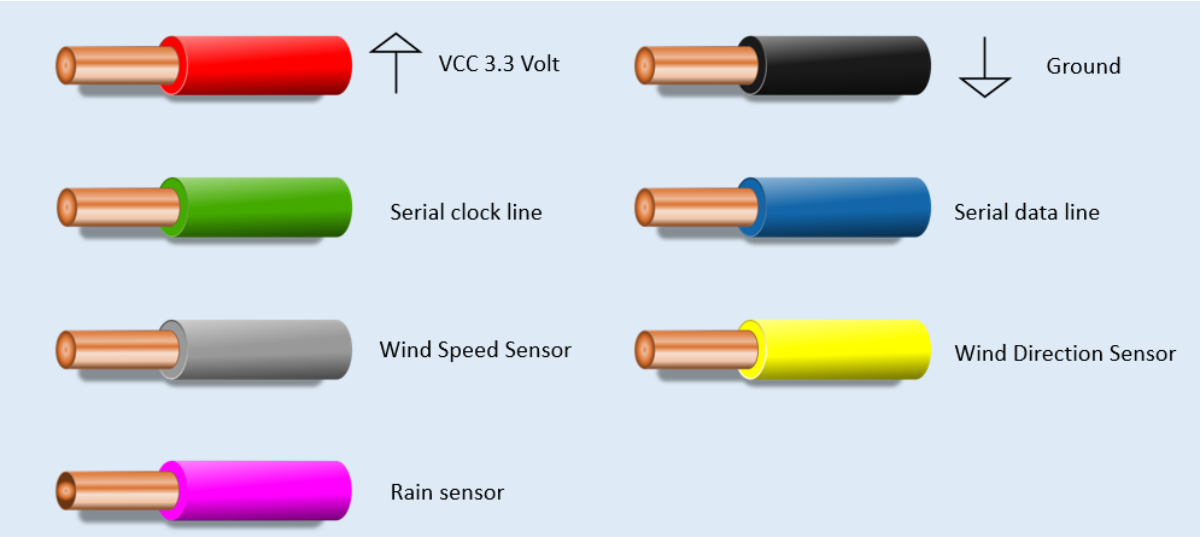


Figure 33 Color cables

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B. APPENDICES

This chapter consist of extra information needed for the project, such as figures, tables, maps, raw data and computer programs.

B.1 DIY weather stations

Some of the DIY weather stations not mentioned are giving below in Table 8.

Table 8 DIY YouTube videos given with some information

BUILDER	TITLE	DATE	LINK
MICHEAL KLEMENTS	I Upgraded My 3D Printed IoT Weather Station Using Your Suggestions	October 27, 2021	https://www.youtube.com/watch?v=xVK4bF5U2Xk
MODEST MAKER	Argent Weather Station Arduino Hacks - Hardware and Code	January 8, 2020	https://www.youtube.com/watch?v=KHrTqdmYoAk
HANS SCHMITZ	Advanced At-Home Weather Station	August 12, 2016	https://www.youtube.com/watch?v=nG7bF15tK-Y

B.2 Material choice

Table 9 Materials and their properties

Mounting station material	Wood	Steel	Aluminium	Stone	Sandbags
Weather resistant	High	Medium	High	High	Medium
Corrosive resistant	High	Low	High	High	High
Weight	Medium	High	Medium	High	High
Re-usable	High	Medium	Medium	High	Medium
Price	Low	Medium	High	Low	Low
Complexity to work with	Low	High	Medium	Low	Low
Strength	Medium	High	High	Low	Low