multiflexmeter

Open-source water analysis equipment

Waterschap Scheldestromen

[Technasium]

'tRijks

ARDUINO

LoRa™

Commissioned by Scheldestromen

J. Goossen
J. van Kranenburg

Executed by

Jari de Dooij
Roel van den Elshout
Seppe van Mierlo
Tim van Osch

Abstract

This paper is the result of a research & development project commissioned by *Waterschap Scheldestromen* and executed by four pupils at *R.S.G. 't Rijks*. Both parties are located in the Netherlands.

This research & development project includes several important subjects: *Geographical Waters, Arduino, LoRa and LoRaWan, Power consumption*.
The commissioners explicitly stated that advancement on these subjects is sufficient enough to satisfy them. Therefore, several orientation, research or design subjects might and will not be fully coherent.

Geographical Waters

Today's analysis of waters in The Netherlands and other countries is fully performed manual and not always digital. Performing this task not only consumes an enormous amount of time, but is also expensive for the company responsible for watching these waters.
This project aims on digitalizing and cheapening this process by creating a cheap and easy-adjustable analysis device that requires preferably no maintenance.

Arduino

The previously mentioned device is controlled by an Atmega328p chip. This is the same chip used by the open-source Arduino prototype board. The use of an Arduino allows for cheap and reliable prototyping during research and design.
The Arduino also uses the Atmega chip, therefore it is no hassle switching from the Arduino prototype board to a production PCB which makes use of the Atmega328 as well.

LoRa and LoRaWan

Manually performing measurements means employees have to travel from place to place, this is both time consuming and, depending on the means of travel, is costly. These measurements can be performed autonomous by the Arduino and sensors. However, the data acquired has to be sent to a central point where it can be processed. The transferring of this data will be done by the LoRaWan protocol on a LoRa network, which is a network operating at low frequencies which in turn makes for low battery consumption and a long transmission range.

Power consumption

The device that will perform the measurements should be as good as maintenance free, therefore it needs a long-lasting battery with enough capacity to perform in less desirable situations. Requiring a device to last long on a non-persistent power source is not just expanding the battery, but also lowering the overall power consumption.

The product

As stated before, advancements on the previously mentioned subjects would be sufficient for the commissioners. However, the project not just aims on making advancements on these fields, but also combining them and showing the connection between them. Therefore, this project its goal was to deliver a prototype that can perform measurements autonomous then process the acquired data for transmission and eventually wirelessly transmit the data to a central point. All while being completely wireless, thus depending on its own source of power.

Index

Power source and storage

Generating and storing power is one of the most crucial things for an autonomous device that is required to run day and night. The device is responsible for reporting extraordinary changes in the area it is located at. If it is out of power then the device will not only be useless, but no one will know that the change occurred and this could have bad consequences.

Solar panels

The most utilized free source of power is solar panels. Being used everywhere they provide the most advantages and are commercially available in different varieties, which all have their own advantages.

Taking the Netherlands as example for calculating our solar power in watts. There is approximately 1637.8 peak-hours of sunlight in The Netherlands per year, which roughly translates to 18.70 percent of the time throughout a year.
A basic solar panel delivering 5 Watts in optimal sunlight conditions will now just provide an approximate of 0.935 Watts of power throughout the year. This is in optimal conditions which means that in reality this number will be even lower.

There are not many open-source or commercially available ways of generating power for small devices. The best candidate is solar panels, although there are quite a few factors like the orientation and positioning of the solar panel that needs to be accounted for.

Solar panels provide the most energy when they are perpendicular with the sun, however the sun moves throughout the day and a basic solar panel does not. Several solar panels exist with a mount that will keep the panel perpendicular with the sun, these are however expensive and need maintenance.

The previous option is not valid due to several factors. However, taking the average of the sun's angle at peak-hours per season results in an angle that can be used throughout the season for optimal power generation without moving parts. These results are displayed in Table 1.

This option is valid and would provide good results, however it still requires human interaction every season. The best angle per year would be the average of all seasons with respect to the number of peak hours of sunlight per season. This is 36 degrees.

Batteries

When there is no sun, either for the night or a few dark days, the device relies on backup power which comes from the storage.

The device is located outside and in all weather conditions. This means the battery should withstand this as well, either by itself or with isolation which would only delay the effects. Two batteries fit these factors with their properties: the lead-based batteries and lithium based batteries. Both allow for relatively a lot of energy per kilogram of battery and both can withstand great weather conditions whilst being a reliable energy source.

Lead-based Batteries

. Lead acid batteries are widely uses in the industry of batteries. It is the oldest rechargeable battery type. Despite having a low power to mass ratio and a low volume to energy ratio, is has a relatively high power to weight ratio. It doesn't cost a lot of money to produce. The battery consists of PbSo4 plates as the 2 electrodes and they are surrounded by sulfuric acid. They work like a normal electrochemical cell and electrolytical cell, with 2 reactions per electrode. It has multiple uses like:

- starting cars
- powering electric vehicles
- usable as uninterrupted power supply (UPS) and off-grid power storage
- marine appliances It has 3 cycle modes to support a variable usage of this battery type. However, it has its downsides, which makes it unsuitable for our situation:
- it needs to be refilled with sulfuric acid once every 6 months, this is since the sulfuric acid vaporizes when the battery charges
- The battery's capacity slowly uses its storage capacity, because the sulfate sticks to the electrodes and minimalizes their surface area
- It is possible that gases are created during the charging state if it is used excessively. This can cause explosions in the battery.

If the battery can't let the gasses escape, then there will be corrosion due to acid gases in the battery. This results in the formation of crystals in the sulfuric acid solution, which interferes with the battery's performance. these things only happen if the battery is discharged to 0% and if it's overcharged. If you keep it at approx. 50% charged, you'll only need to refill the battery once every 6 months, so it still is unsuitable for our purposes.

AGM and Gel battery:

AGM Batteries

AGM stands for Absorbed Glass Mat, which is a unique mat deliberately designed to trap the electrolyte between the plates inside the battery. This type of battery is also commonly referred to as a VRLA battery, which stands for Valve-Regulated Lead-Acid battery. Unlike wet batteries, AGM batteries only hold a small amount acid to help keep the mat wet. This is a major safety feature that prevents acid from leaking if the battery breaks. AGM batteries are normally referred to as “all-purpose batteries” due to their wide range of applications, such as emergency lights, alarm and security systems, EPS and UPS, which makes it interesting for our project.

Gel Batteries

Gel batteries contain a specially formulated paste, silica gel, where the battery electrolyte are trapped in. Unlike AGM batteries, Gel batteries allow the electrons to flow between plates. However, Gel batteries are similar to AGM batteries in the sense that they are both non-spillable when the battery breaks. The most common applications for Gel batteries include: renewable energy, medical equipment, golf trolleys, garden equipment and traffic lights.

Life expectancy of the AGM and gel battery

Battery life expectancy is not measured by a year count. Rather, it is measured by the number of times it can be charged and discharged. This is referred to as the battery’s cycle life. Both AGM and Gel batteries are recommended to always be fully charged when possible, and not to be discharged lower than 50%. However, Canbat (=the brand we researched) batteries have one of the highest cycle life in the lead-acid battery industry, and they can be discharged up to 60% without causing the battery any harm.

All-purpose AGM batteries have a cycle life of 500 cycles at a 50% depth of discharge. This means that an AGM battery can be charged and discharged 500 times. If the battery is charged and discharged once a day, an AGM battery can last for 500 days, which is roughly a year and a half, at full capacity. After 500 cycles, the battery will still work but at a lower capacity, meaning that it will not give you the same amount of energy as before.

Gel batteries work in the same manner, but they have a much higher cycle life of 1,200 cycles, at a 50% depth of discharge. If a Canbat Gel battery is charged and discharged once a day, it can last for 1,200 days, which is about 3 years and 5 months. Having a relatively high battery cycle life is one of the most striking features of a Gel battery.

<u>Advantages of gel/AGM batteries over normal lead-acid batteries:</u>

- Unlike flooded/unsealed batteries, SLAs require no maintenance beyond proper charging.
- Unlike FLAs, when being charged SLAs produce no gasses that must be vented.
- SLAs work well with small solar arrays and can be charged to lower voltages as lower charge rates.
- No water must ever be added and individual batteries will not need to be equalized to ensure proper operation of the overall system.
- SLAs don't leak or suffer terminal corrosion.
- The most commonly used type of SLA, Absorbed Glass Mat (AGM), is non-hazardous, and can be shipped between locations without precaution or extra expense.
- SLAs are easily stackable and will take up less space in a battery bank than other alternatives.

Advantages of the lead-acid battery over the AGM/Gel battery

- FLA's are cheaper
- FLA's are widely available in all shapes and size

(SLA = sealed lead-acid battery, such as the AGM and gel types) (FLA = Flooded lead-acid battery, the normal ones)

The AGM battery is currently the best option from the lead-acid based batteries, because it passes all our requirements and is in the optimal spot between performance and price, so this is the best choice from the Lead-based batteries.

Lithium-based Batteries

Lithium-based batteries have 2 things in common, they are lightweight and they have a very high power to weight ratio, meaning that they provide a lot of power. The two most promising types are the lithium polymer and lithium iron phosphate batteries.

Lithium iron phosphate based batteries possesses superior thermal and chemical stability which provides better safety characteristics than those of Lithium-ion technology made with other cathode materials. Lithium phosphate cells are incombustible in the event of mishandling during charge or discharge, they are more stable under overcharge or short circuit conditions and they can withstand high temperatures without decomposing. When abuse does occur, the phosphate based cathode material will not burn and is not prone to thermal runaway. Phosphate chemistry also offers a longer cycle life, so lithium iron phosphate batteries are safer to use than lithium polymer. However, lithium iron phosphate batteries are heavier than lithium polymer batteries, due to lower power to weight ratios

So overall, the lithium iron phosphate has the most advantages:

- it can operate between - 20 degrees Celsius and + 40 degrees Celsius during charging and discharging
- it has a very high power to weight ratio, almost 5 times the weight/power ratio of lead-acid batteries
- it has its own safety measurements to prevent overcharging and overheating
- it can provide sufficient voltages to power the system we have
- it is possible to build this type of battery in several shapes to fit in our housing However, the battery might need insulation to keep working in subzero temperatures

However, lithium iron phosphate batteries are expensive, they cost more than twice than our budget to get sufficient storage of energy.

The lithium polymer battery has the same specs as the lithium iron phosphate battery, but it lacks several safety features, such as temperature resistance, overcharging protection etc. Therefore, the most promising of these is the lithium polymer battery. The biggest disadvantage is the lack of resistance against sub-zero temperatures.

Conclusion

The AGM battery offers more advantages over the lithium polymer battery, since it can withstand more extreme temperatures, which make it suitable for outside usage. The difference in pricing is also minimal. Thus, out of these four promising batteries the AGM battery stands out as most suitable battery.

Measurable water data and related sensors

Sensors allow for autonomous measurements from a distance. That data can be instantly picked up by a micro controller. The most important information that needs to be collected is given here.

- Water height
    - if it is too high or low they need to close or open the dikes.
- Conductivity of the water
    - it shows how clean the water is.
- Temperature of the water
    - if it's too high or low the animals that live in the water might be harmed or affected.

Sensors

Each piece of important information can be measured by a sensor. The previously mentioned water properties are worked out with their appropriate sensor in the following paragraphs.

Water height

HC-SR04 is a sensor that uses ultrasonic sound waves to measure the distance to an object in front of it. Results are calculated with the speed of sound, note that this somewhat depends on the temperature, and time in between sending the sound wave and receiving the echo.

There are a few pros for this sensor. The sensor does not need to leave the housing, because of this it is less likely to take damage from weather or people. It is very reliable, after a few tests and checking the distance measured the outcome was that there was a maximum deviation of 2 cm close by and 1 cm for longer distances.

There is also a few cons. The waves that get send out can bounce of anything, meaning that if there is a leaf fluttering down at that moment, it will look like the water suddenly rises.

Ultrasound Measurements

1	Ultrasoon	Distance						
2	Meeting 1			Meeting 2				
3		Afstand H	Arduino		Afstand	Arduino		
4		2 cm	2 cm		50 cm	49 cm		
5		4 cm	3 cm		70 cm	68 cm		
6		6 cm	5 cm		100 cm	98 cm		
7		8 cm	7 cm		150 cm	148 cm		
8		10 cm	9 cm		200 cm	197 cm	Maximum	
9		30cm	29 cm		225 cm	2300 cm		
10		50 cm	48 cm		250 cm	2300 cm		
11								
12								

TABLE 2:

The ultrasonic sensor was tested a few times; the results were all the same and so it was concluded that it measurements were correct and that it was a viable sensor to use. The maximum of the sensor was 200 centimeters.

Conductivity

Gravity: Analog Electrical Conductivity Sensor, this sensor was specially build for the Arduino and is not meant for any other system then Arduino. The sensor uses electrolytes to check how clean the water is, this represents in the conductivity of the water. The more electrolytes in the water the dirtier the water is.

Pros and cons

The pros of the sensor are as followed. The sensor is specially build for the Arduino. The sensor is easy to use and to program.

There were a few cons as well. These were the fact that the sensor could not operate in the Netherlands if you take the extreme temperatures like –10 degrees Celsius in the winter and sometimes 40 degrees Celsius in the summer. Then there was the fact that it needed to be placed outside of the housing to measure the conductivity and not only be placed outside but it had a long cable hanging behind it.

Another option is to make your own EC-sensor. There where are few ways you could make your own conductivity sensor. One was simply a piece of wood pierced by 2 iron nails, but with this setup you would need stainless steel. These materials were not in the vicinity. After a few other ways, like 2 coper cables, a perfect solution came by. A hygrometer that also measured the conductivity. The results of this EC-sensor are in the attachments.

Pros and cons

The own made EC-sensor had a few pros. First, it would be a lot cheaper than to buy an already made conductivity meter. An own made EC-sensor is easier to fix then a sensor made by a company, because you know exactly what is wrong with the sensor.

There are a few cons too. If there is something wrong with your sensor and you do not see it early enough, then you will keep using wrong information. This is a huge risk and needs to be heavily controlled. Another con is the fact that you do not have a datasheet of your sensor. You will need to set it up yourself. In this process, there is a big chance of mistakes being made so be alert when you do this.

Conductivity Measurements

9	Gram zout	Coach meter	Arduino meter	Arduino meter (2e meting)
10	0	88	924	915
11	0,2	5256	404	403
12	0,4	10600	268	274
13	0,6	14377	230	250
14	0,8	18300	213	241
15	1	21551	222	229
16				

TABLE 3:

The Coach meter measures in Micro Siemens and the Arduino Meter measures a number between 0 and 1023. This number corresponds with a voltage between 0V and 5.5 V. These numbers are quite consistent which makes it believable that the sensor works and that you only need to set up a formula.

Temperature

DS18B20 Temperature Sensor (Waterproof) is a sensor that uses a thermal resistor. This resistor changes on ohm depending on how warm it is. This means that there is a difference in voltage, it uses this to measure the temperature.

There are a few pros to this sensor. The sensor is reliable and used in other projects. The power costs are a lot lower than that of the MLX90614.

There are a few cons. The sensor will need to leave the housing to measure the temperature of the water/air. The library used to program this sensor is outdated and did not work. The communication between the sensor and an Arduino is very sensitive.

MLX90614 uses infrared to measure the temperature. It measures the wave length of the infrared that it receives. It knows the standard wave length of water at a temperature of six degrees Celsius. It compares the two wave lengths and calculates what temperature the water is.

The pros are the fact that it does not need to leave the housing.

A con is the fact that it measures in a cone and not a straight line, meaning that the sensor will need enough space to measure only the water.

LoRa and LoRaWAN

LoRa is capable of long range, hence the name, transmission on a low frequency, allowing for minimal power use.

LoRaWan creates structure in sending data. It also defines a LoRa endpoint called a Gateway which relays the received LoRaWan structured information to an internet based backend. LoRaWan connects the devices to the internet.

LoRa

LoRa functions on a low frequency allowing for low power consumption and great ranges in non-urban environments. LoRa transmissions is bi-directional. A module can receive and send, but not at the same time.

LoRa transmission has no structure. What you send will be broadcasted. Any LoRa capable receiver in range can receive the sent data. This data has no special format and uses bytes appended after each other. This is how every computer by far stores data.

FIGURE 1: A .TXT FILE CONTAINING "HELLO WORLD" IN BYTES

Atmega firmware, which the Arduino uses, can also be represented in bytes. Therefore, it would be possible to transfer firmware updates through a LoRa connection.

An important factor for using LoRa is using the appropriate frequency. This frequency is either around 433 MHz, 863 MHz or 902MHz.

LoRaWan

LoRaWan is a protocol designed to connect LoRa capable devices to the internet. The principle of connecting more and more devices to the internet is called Internet Of Things (IOT). LoRa and LoRaWan makes IOT more accessible for everyone, due to the lower costs.

LoRaWan is a set of definitions. A few are: Packet structure, end-devices and gateways. The basic idea works as follows. An end-device will broadcast some structured encrypted data in a format which LoRaWan has defined. A gateway, which is just a LoRa capable device with one purpose, will relay the information to a backend service of choice. The backend can then extract the data from the package and decrypt it. The backend is middleware which allows other third parties to access their API to retrieve data.

LoRaWan is fully open-source, so in case one does not want to depend on a backend service they can create their own. The full documentation and protocol definition is available online[1].

[1] https://www.lora-alliance.org/portals/0/specs/LoRaWAN%20Specification%201R0.pdf

Prototype

The final prototype, which is the most reliable due to the latest and most complete LoRaWan library currently available, is only set up to transfer data to the backend service.

Devices

Our prototype had a custom end-device and gateway. The end-device consisted of a RM95F LoRa module controlled by an Arduino. The end-device is shown in Figure 2; LORAWAN END-DEVICE.

The RFM95W module is connected by 5 pins, these consist of the default MISO, MOSI, SS, CLK pins and three more for the module: PIN 2, PIN 3 and PIN 4 connected to DIO0, DIO1 and DIO2 respectively.

It is also important for range to ensure the antenna is 81 millimeters. This is necessary to achieve the right wavelength and thus frequency.

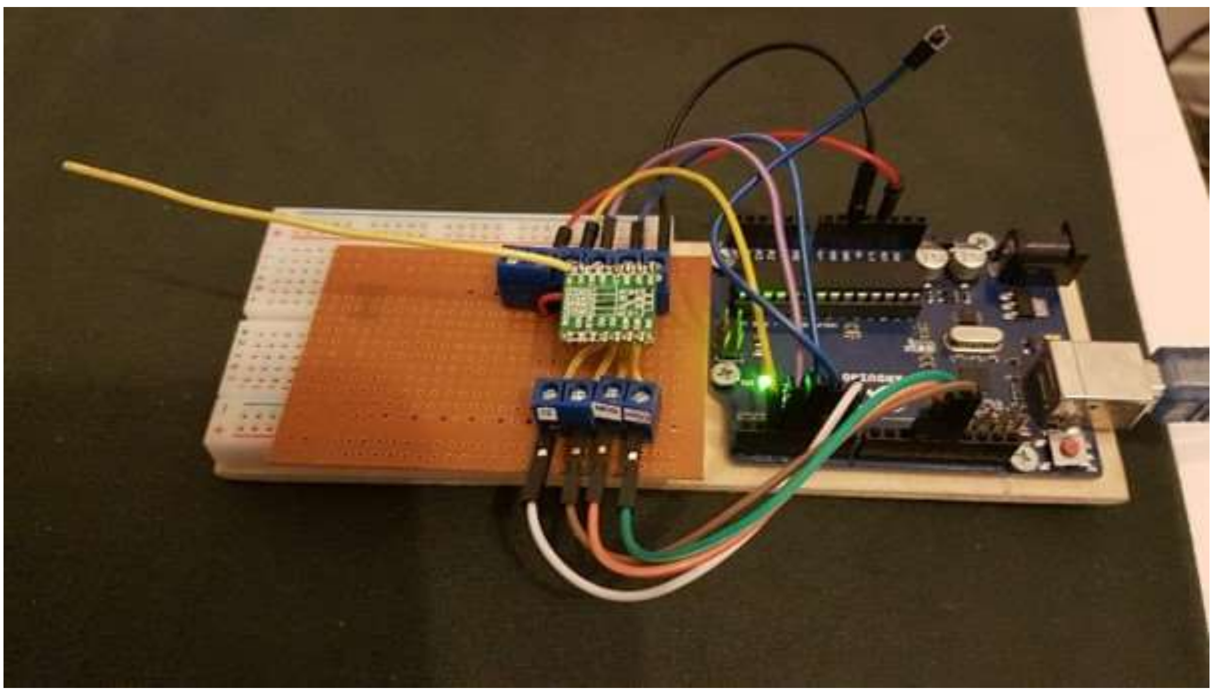


FIGURE 2; LORAWAN END-DEVICE

For relaying the information broadcasted by the end-device, a gateway is necessary. Our gateway was powered by a LoRank8 Ideetron gateway. This device is shown in Figuur 3; LORAWAN GATEWAY WITH ANTENNA

FIGUUR 3; LORAWAN GATEWAY WITH ANTENNA

Source-code

The gateway, LoRank8, is set-up by Ideetron therefore does not require any setup to begin with. The end-device in contrast is an Arduino and therefore has to be programmed correctly. We have used a LoRaWan library for Arduino called *LMIC-Library*[2]*.* All that's left to do is set up some basic event listeners and a custom loop for sending and receiving. The latter is available at our github page[3].

The full documentation is available at the library's github page.

[2] https://github.com/matthijskooijman/arduino-lmic
[3] https://github.com/TimVosch/Aqua/tree/master/Prototypes/LoRaWan_2_Extended_TxRx

Model

All the research found above this subject needed to be placed into a housing and our commissioners had a few extra requirements. The MFM needed to be vandalism proof, because it would be hanging in all kinds of places where kids or loiterers could hang out. The strongest shape is the triangle.0 The commissioners also asked us to keep the price below €150,00.

Here are some of the important parts that needed to be integrated in the housing:

- Triangles; strongest shape in math and it provides the angles we need for optimal the reason why triangle is the strongest shape energy delivery to the main system
- Frontal Angle of 36 degrees and side angles of 63 degrees
- Enough solar panels to provide the power we need for our system
- Vandalism proof
- Enough distance from the shore
- Insulation from water and cold temperatures
- Enough space for the sensors, batteries and Arduino.
- Cost must be below €150,00

Mock up

We started with a design of our model with some basic math. We needed a model to get 2 optimal angles for maximum solar power, and we needed a strong and sturdy casing to house all of our equipment. To prove our concept of a triangular design, we used Grasshoff's law to show that it is indeed the best option to choose a triangle.

The triangular chain consisting of three rigid links or bars connected to each other by pin joints (allowing rotation between two joined links). The degree of freedom (n) of a plane chain is given by the Grasshoff's law as

$n=3(l-1)-2j-h$

for a triangular chain we have

l=number of links=3

j=number of binary joints=3

h=number of higher pairs=0

Hence, we get

$n=3(3-1)-2(3)-0=6-6=0$

The degree of freedom of the triangular chain (equivalent to plane triangular shape) has zero degree of freedom this indicates that links of the triangular chain can't move even a bit if links are strong enough even under the application of external forces.

Thus, a triangular shape is the strongest one which is also called a rigid structure. It is also called a perfect frame in physical structures.

Now we will continue with the size of our model. We were limited to support beam with a maximum height of 15 centimeters. We began with a attachment plate of 15x15cm, which has 2 angles of 63 degrees, which is near the optimal angle for solar panels in summer. We also needed a frontal angle of 36 degrees, so we could get the most solar energy in spring and autumn. To get an angle of 36 degrees, we needed a bottom plate with a height of 21 cm, and 15 cm wide. The sides would be 22.5 centimeters long. With these sizes, we could connect the lines and this gave us 2 side panels with the size of 22.5x16.5x28 cm. We have drawn these sketches on paper and made a simple paper model to see if it was mathematically correct, these can be seen in attachments (see sketches).
Our sketches were correct and we went on with our designing process and we made a 3d-model which enabled us to visualize our model and we could also see how much we could fit in our model. There was plenty of space in our 3d-model for multiple Arduino boards and we also added a temperature sensor in our model.

We have not completed our model to be 3d-printed, but we have correctly calculated the size of each panel and we have shown that it does have the correct angles, which are needed for optimal solar energy from the solar panels. We simply did not have the time to make a complete model and to eventually print it with a 3d-printer to showcase it.

Recommendations

The Multiflexmeter is an ongoing project. The research showed some extra routes that needed to be explored, but there was not enough time. These routes are shown and explained here.

Infrared sensor MLX 90614

The temperature sensor from Dallas Temperature did not work, because of previously told problems, and showed some flaws like having to be outside of the MFM to do its work. The MLX90614 is an infrared sensor that measures the temperature using infrared signals. This sensor has some benefits; it does not need to leave the MFM to measure the temperature.

Super capacitors

These new capacitors, which can be used as batteries, can be used in fast charging and discharging appliances, like kinetic braking systems in vehicles and for compact energy storage over longer periods of time. They are vastly superior than lithium batteries in every aspect and they also beat every lead-based competitor in our research. They come at a very low price, even lower than some LiPo batteries, starting at 10$ per supercapacitor. They have very interesting specifications and they have plenty of potential to be used in the MFM. We have not had the time to research these capacitors, because these capacitors are technically not a battery, since they used to be made to store energy for a relatively short time and after they could not hold their energy for any longer periods. That was until the supercapacitor came along, and this could be used as a battery. So, we have not researched this thoroughly, because it did not cross our minds that supercapacitors could also be used as batteries and they did not show up when looking for info on batteries.

Different Temperatures

The conductivity sensor was tested at room temperature, but the conductivity can be different depending on the temperature. Again, there was not enough time to set up different temperatures with the same amount of salt to do this research.

Remote firmware upgrade

An Arduino uses the AtMega328 chip. These chips are capable of getting reprogrammed. This reprogramming is enabled by connecting an SPI connection, shown in Figuur 4; SPI Connection, to another device which is capable of SPI. This second device has to enable reprogramming on the target chip by sending a set of four bytes. The target chip will then reply by sending the second byte it has received. Once the chip is in programming-enabled mode, it can be reprogrammed.

FIGUUR 4; SPI CONNECTION

Thus if Multiflexmeter has an extra AtMega chip which can interface with the LoRa module. The second chip can then listen for an update command on the LoRa module, receive the new firmware in bytes and reprogram the main chip.
More information about reprogramming AtMega chips is available at the Atmel website[4] paragraph 32.8.2. *Serial Programming Algorithm*.

[4] http://www.atmel.com/Images/Atmel-2545-8-bit-AVR-Microcontroller-ATmega48-88-168_datasheet.pdf

Attachments

Power

Season	Angle (degrees)
Spring	36 degrees
Summer	60 degrees
Autumn	36 degrees
Winter	12 degrees
Average	*36 degrees*

Table 1

This table shows the optimal angles per season. This table was used to design our model and this was fundamental for our design. With these angles, we would get the most energy out of our sonar panels and these angles would also add up to the triangular shape we wanted to build, because of its strength. This table was calculated with a formula from the solar electricity book. To simply this formula, you should take the latitude and subtract 40 in winter, add 8 in summer and subtract 16 in summer and this should give you an optimal angle.

Measurable water data and related sensors

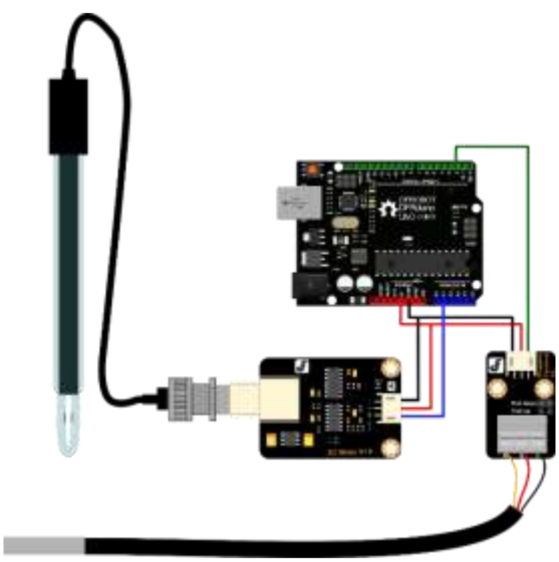
Ultrasonic sensor

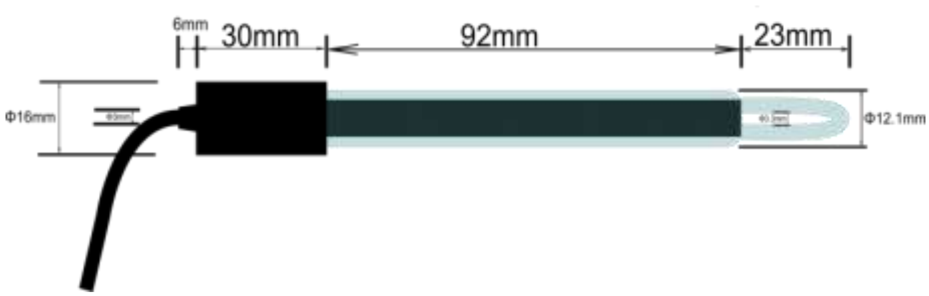
This is the second table used in the thesis. This table is used to show that the sensor we are using is reliable and consistent.

1	Ultrasoon	Distance						
2	Meeting 1			Meeting 2				
3		Afstand H	Arduino		Afstand	Arduino		
4		2 cm	2 cm		50 cm	49 cm		
5		4 cm	3 cm		70 cm	68 cm		
6		6 cm	5 cm		100 cm	98 cm		
7		8 cm	7 cm		150 cm	148 cm		
8		10 cm	9 cm		200 cm	197 cm	Maximum	
9		30cm	29 cm		225 cm	2300 cm		
10		50 cm	48 cm		250 cm	2300 cm		
11								
12								

Conductivity Sensor

This is the Gravity: Analog Electrical Conductivity Sensor, which was the first sensor we used to try and measure the conductivity with.

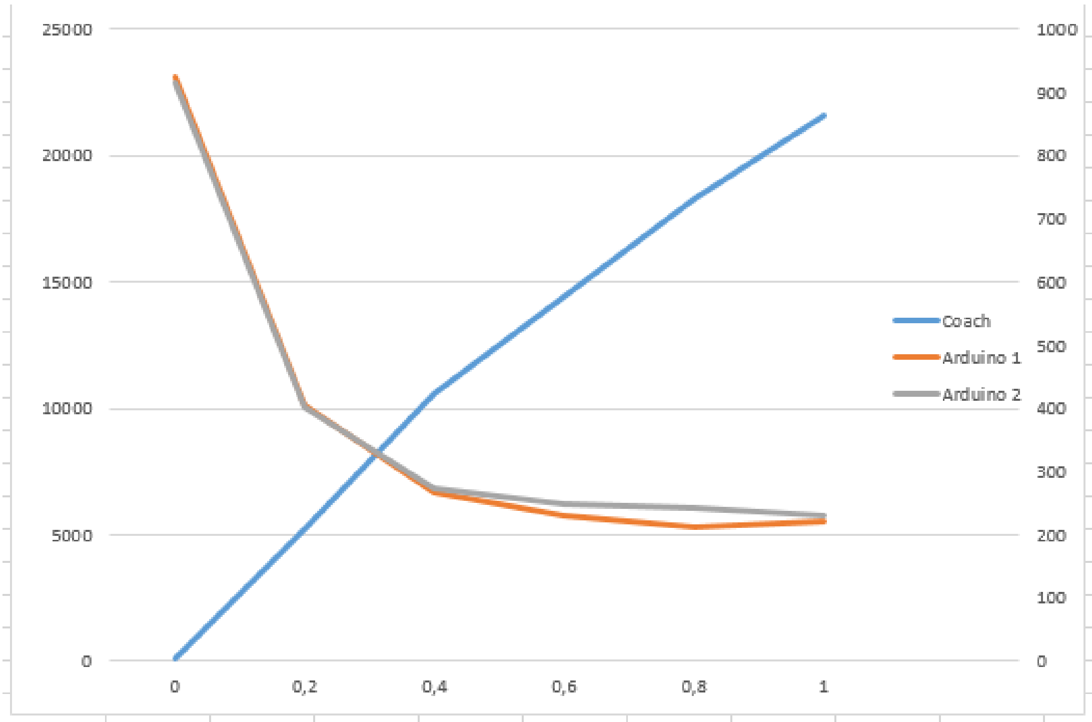




Conductivity Measurements

This is the third table in the thesis. These tables are our measurements for the own made conductivity sensor, to see if it was reliable.

1						
2		Coach meter	Arduino meter			
3	kraanwater	551 uS	480			
4		29 uS	970			
5		3968 uS	220			
6		6544 uS	250			
7						
8						
9	**Gram zout**	**Coach meter**	**Arduino meter**	**Arduino meter (2e meting)**		
10	0	88	924	915		
11	0,2	5256	404	403		
12	0,4	10600	268	274		
13	0,6	14377	230	250		
14	0,8	18300	213	241		
15	1	21551	222	229		
16						

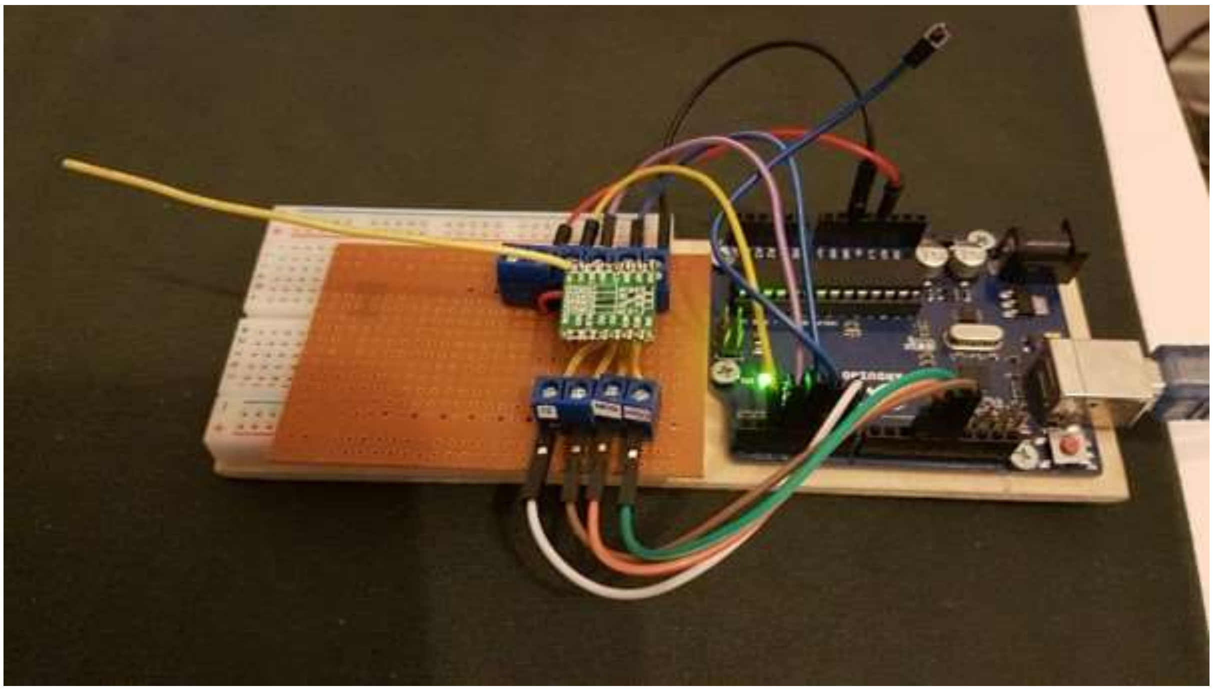

25000
20000
15000
10000
5000
0
1000
900
800
700
600
500
400
300
200
100
0
0
0,2
0,4
0,6
0,8
1
Coach
Arduino 1
Arduino 2

LoRa and LoRaWAN

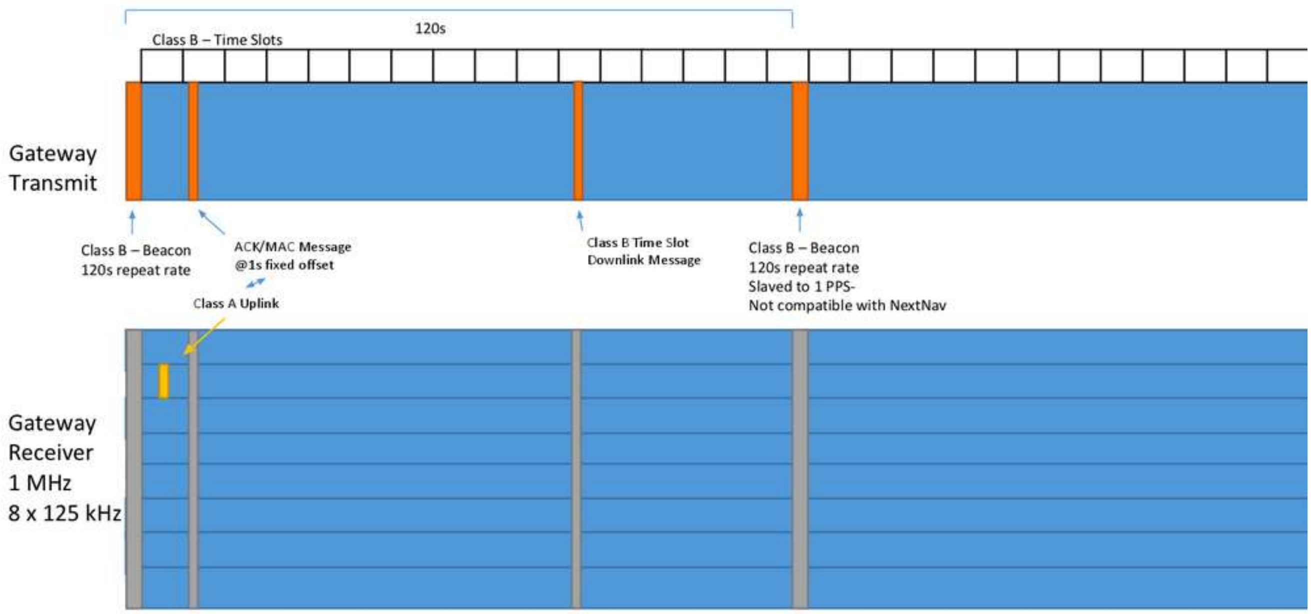
This was the first figure we used in our thesis and describes the words Hello World in bytes.

```
00000000  48 65 6C 6C 6F 20 77 6F 72 6C 64  Hello.world
```

This was the second figure we used in our thesis, it shows you the RFM98 Module we used for the node for LoRaWAN.



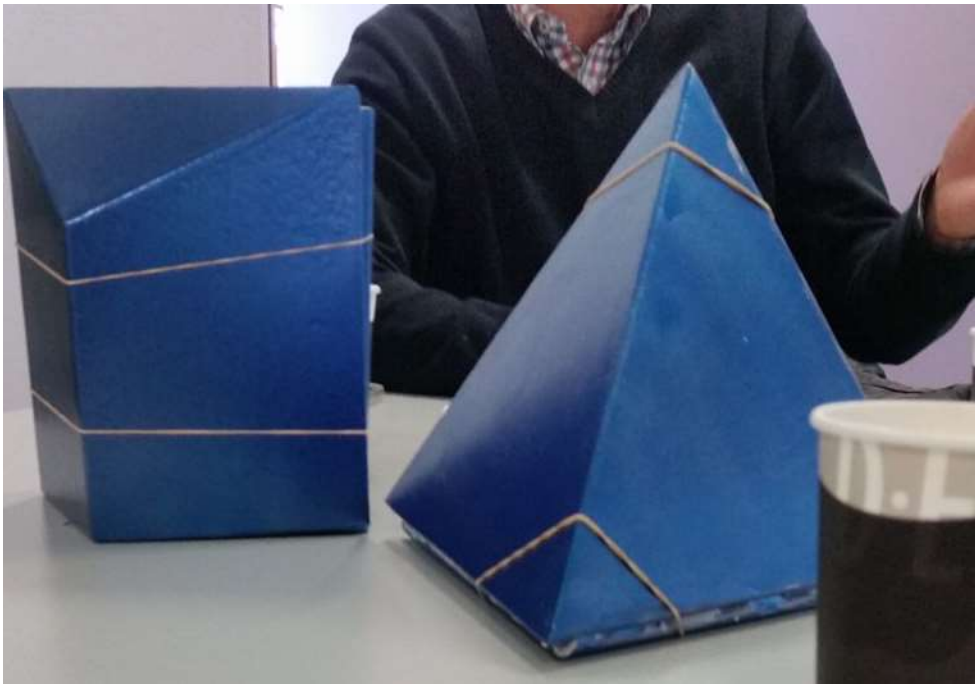
The next picture shows you how a gateway uses the different classes of LoRaWAN.



Pure Aloha Uplink (18.4% Capacity without up/down collisions)
Un-coordinated, Time Slaved Asynchronous Downlink (Class A & C)
Class B is Time Slotted Downlink

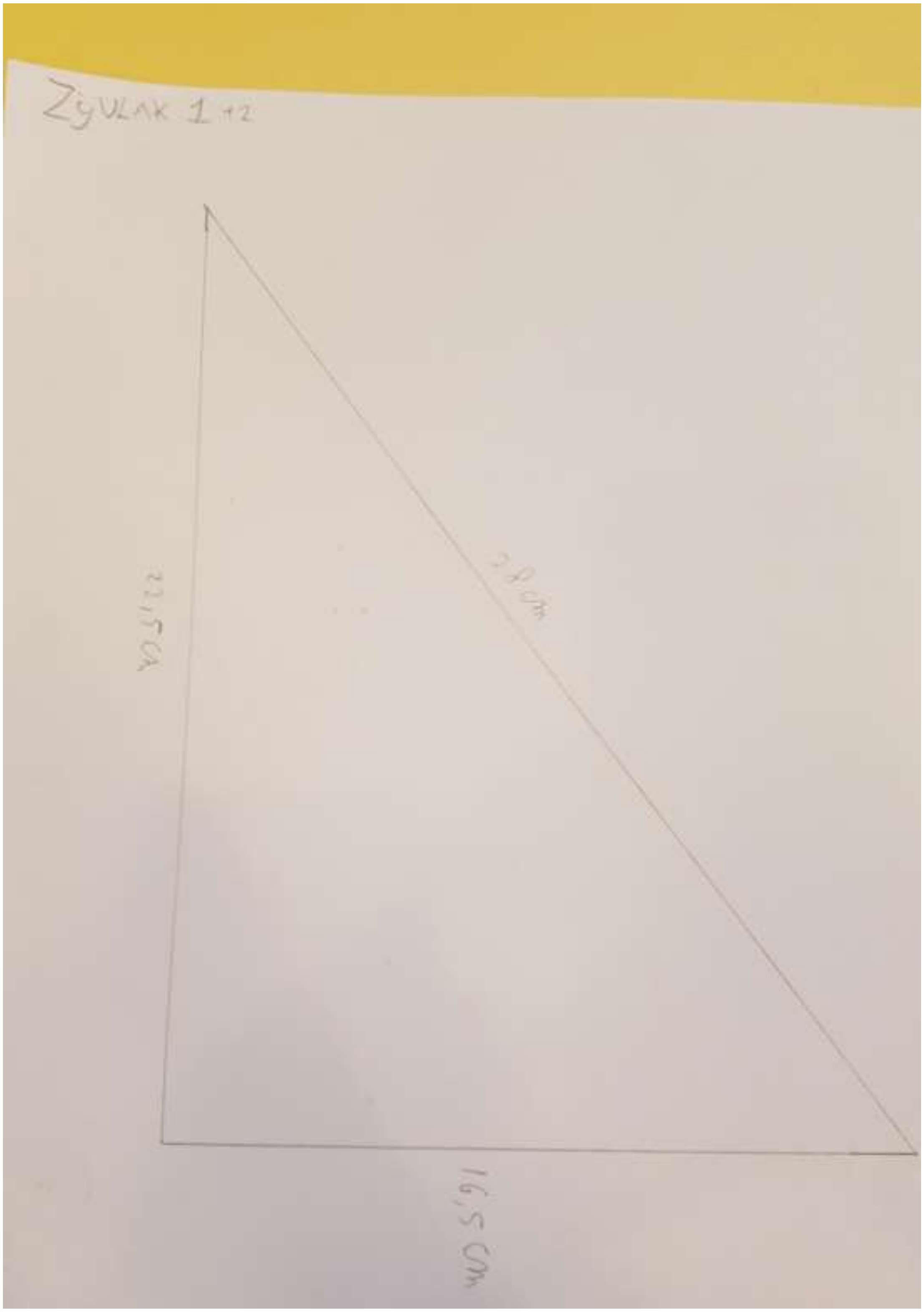
LoRaWAN System

Model

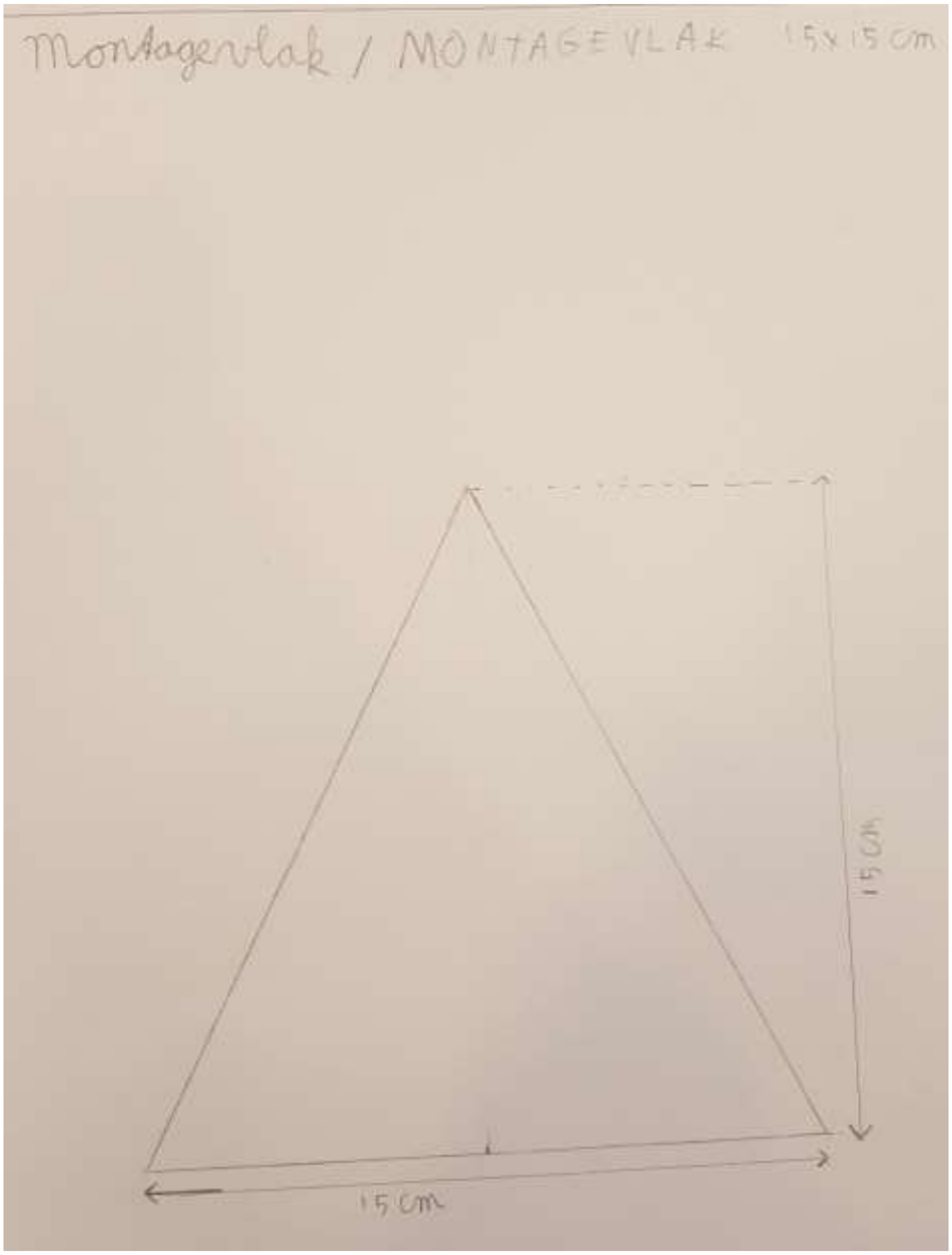


These are the prototypes designed by Waterschap Scheldestromen. These models were an inspiration to our work.

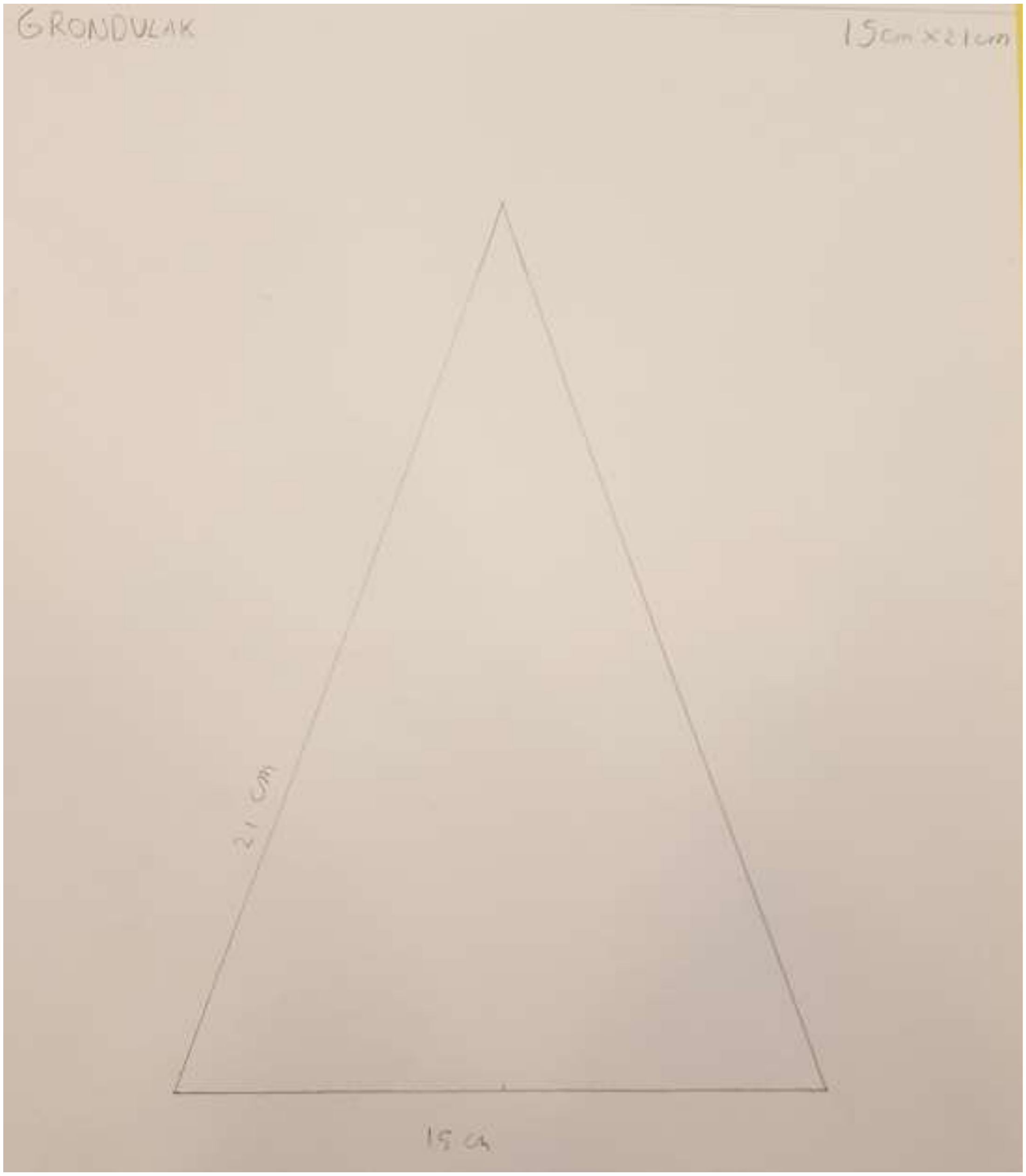
Sketches:



These are the sizes of our side panels.



This will be our baseplate, which will be attached to the support beam.



This is our bottom panel or ground plate and its sizes. This will hang directly over the water and this panel is at a 90-degree angle with the baseplate.

This is our simple paper mockup to see if it was mathematically correct and if all angles would fit together. This was a pure test to see if it was correct.

Logbooks

Instead of manually writing the logs we had decided to try out an automated online system that for our project, this system already includes logging to a certain degree. The site used is called Github. We are hosting our project, all the orientation, research and prototyping files on this website.

Github also shows changes made by person, when and what. See Figuur 5; Online logging via Github.

FIGUUR 5; ONLINE LOGGING VIA GITHUB

You can see what changes were made per files by simply clicking on the update-description on the right-hand side of the file name. Or the latest changes can be seen at the commit history page[5].

[5] https://github.com/TimVosch/Aqua/commits/master

Bibliography

3dprintingfromscratch. (2015, 6 29). *common 3d printing fillaments*. Retrieved from http://3dprintingfromscratch.com/common/3d-printer-filament-types-overview/#pet

ABB. (2013). *Data sheet TB2CS Conductuvity Sensor 2-Electrode.* Retrieved from ABB: https://library.e.abb.com/public/d661a28ddd231379c1257bc50032a1e8/DS_TB2CS-EN_E.pdf

All3dp. (2016, 12 13). *3d materials information*. Retrieved from https://all3dp.com/metal-3d-printer-guide/

Annual sunshine in the Netherlands. (2010). Retrieved from Currentresults: https://www.currentresults.com/Weather/Netherlands/sunshine-annual-average.php

Boxwell, M. (2016, 12 29). *solar panel angle calculator*. Retrieved from http://solarelectricityhandbook.com/solar-angle-calculator.html

Chilson, L. (2013, 1 26). *difference pla and abs*. Retrieved from http://www.protoparadigm.com/news-updates/the-difference-between-abs-and-pla-for-3d-printing/

Cobox. (2014, 10 17). *Li-ion and LiFePo4 battery info*. Retrieved from http://www.cobox-ebikes.com/296/basic-understanding-of-lipo-li-ion-and-lifepo4.html

Conductivity Sensor Implementation. (n.d.). Retrieved from http://www2.latech.edu/~dehall/LWTL/ENGR121/notes/3_conductivity_sensor_intro.pdf

Cooking hacks. (n.d.). *Extreme Range Links: LoRa 868 / 900MHz SX1272 LoRa module for Arduino Waspmote and Raspberry Pi*. Retrieved from Cooking hacks: https://www.cooking-hacks.com/documentation/tutorials/extreme-range-lora-sx1272-module-shield-arduino-raspberry-pi-intel-galileo/

corporation, C. (2015, 3 25). *agm battery info*. Retrieved from https://www.canbat.ca/guide-agm-batteries-gel-batteries/

corporation, P. (2017). *Battery voltages*. Retrieved from http://www.power-sonic.com/ps_psg_series.php

dardan, B. (2017, 2 16). *FAQ on lead-batteries*. Retrieved from http://jgdarden.com/batteryfaq/

DFRobot. (2017, January 25). *Analog EC Meter SKU:DFR0300.* Retrieved from DFRobot: https://www.dfrobot.com/wiki/index.php/Analog_EC_Meter_SKU:DFR0300

DFRobot. (n.d.). *Gravity: Analog Electrical Conductivity Sensor / Meter For Arduino.* Retrieved from DFRobot: https://www.dfrobot.com/product-1123.html electronics, O. (2015, 6 5). *Arduino info*. Retrieved from https://www.open-electronics.org/the-power-of-arduino-this-unknown/

F., N. (2013, 7 3). *Solar energy and storage*. Retrieved from http://www.offthegridnews.com/grid-threats/the-absolute-best-batteries-for-off-grid-energy-systems/

Ideetron. (2016, 7 11). RFM95W_Nexus. *https://github.com/Ideetron/RFM95W_Nexus*. Github.

Kooijman, M. (2016, 2 23). Arduino-LMIC Library. *https://github.com/matthijskooijman/arduino-lmic*. Github.

Lab, N. R. (2016, 9 16). *Information about renewable energy*. Retrieved from http://www.nrel.gov/rredc/solar_resource.html

Landau, C. R. (2015, 11 15). Retrieved from http://www.solarpaneltilt.com/

Libelium. (2014, June 14). *New Ion Sensor Probes “PRO” for Smart Water.* Retrieved oktober 30, 2016, from Libelium World: https://bay157.mail.live.com/default.aspx?rru=home&livecom=1#!/mail/InboxLight.aspx?n=1860453249!n=1360225876&view=1

Libelium. (2015, June 2015). *Libelium Smart Water Sensor Platform Adds Ion Monitoring.* Retrieved from Libelium World: http://www.libelium.com/smart-water-ions-sensors-calcium-fluoride-chloride-nitrate-iodide-lead-bromide-cupric-silver/

Libelium. (2017). *Smart Water Board Guide.* Retrieved from Libelium World: http://www.libelium.com/development/waspmote/documentation/smart-water-board-technical-guide/

Link Labs. (2015). A comprehensive look at low power wide area networks. 16.

LoRa Alliance. (2015). *LoRa Specification*. Retrieved from LoRa Alliance: lora-alliance.org/portals/0/specs/LoRaWAN Specification 1R0.pdf

LoRa Alliance. (2015, 10 08). *What is LoRaWAN?* Retrieved from Link-labs: https://www.link-labs.com/blog/what-is-lorawan

Mirza, U. (2011, 8 29). *Additional info on batteries*. Retrieved from http://www.brighthubengineering.com/power-generation-distribution/123909-types-of-batteries-and-their-applications/

Ratcliffe, M. (2015, September 21). *Three Dollar EC - PPM Meter [Arduino].* Retrieved from Hackaday.io: https://hackaday.io/project/7008-fly-wars-a-hackers-solution-to-world-hunger/log/24646-three-dollar-ec-ppm-meter-arduino

Rijkswaterstaat. (2017, 10 16). *Salinity Oosterschelde*. Retrieved from http://www.rijkswaterstaat.nl/apps/geoservices/rwsnl/awd.php?mode=html&projecttype=chlorositeit&category=1&loc=OS4b&net=LMW

RS Hydro. (n.d.). *Manta 2 Water Quality Sonde.* Retrieved oktober 28, 2016, from RS Hydro: http://www.rshydro.co.uk/water-quality-monitoring-equipment/water-quality-testing-equipment/multiparameter-water-quality-sonde/manta-2-multi-parameter-water-quality-sonde/

Schwartz, M. (2013, 9 13). *Arduino+battery info*. Retrieved from https://openhomeautomation.net/arduino-battery/

Shapeways. (2017). *information on 3d printing with steel*. Retrieved from https://www.shapeways.com/materials/steel

Shorr, G. (2015, 5 13). *Home solar panels pros cons costs*. Retrieved from https://www.expertise.com/green/home-solar-panels-pros-cons-and-hidden-costs

SODAQ. (2017). *another similar situation*. Retrieved from http://www.instructables.com/id/SODAQ-solar-powered-autonomous-Rain-observation-st/step9/Setting-up-your-computer-to-program-Arduino-boards/

Tinkercad. (2017, 6 27). *materials guide 3d printing*. Retrieved from https://blogdottinkercaddotcom.files.wordpress.com/2012/06/material_guide.pdf

TTN. (2016, 7 1). *Similar situation to ours*. Retrieved from https://www.thethingsnetwork.org/forum/t/any-tips-for-a-lipo-battery-charger-and-solar-panel-for-an-always-on-node/2892/4

Tukiainen, M. (2017). *sunset and sunrise times from the entire world*. Retrieved from http://www.gaisma.com/en/

Waterschap Scheldestromen. (2016.2017). Meetings with the commissioning company. Middelburg, Zeeland, the Netheralnds.

What is the best battery? (2010, 11 1). Retrieved from Battery University: http://batteryuniversity.com/learn/archive/whats_the_best_battery

Wikimedia. (2017). *Acid-battery information*. Retrieved from https://en.wikipedia.org/wiki/Lead%E2%80%93acid_battery

Wikimedia. (2017). *Battery comparison*. Retrieved from https://en.wikipedia.org/wiki/Comparison_of_battery_types