Examensarbete

Civilingenjör i intelligenta system 15hp

Water Quality Device

Testing Through Electronic Measurements

Electronics, Physics & Embedded Systems

Halmstad vt2023, 20230821

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Preface

Ying Fu, the Developer of the Device

Ying Fu is a professor of applied electromagnetics in the school of information technology at Halmstad University. He is a professor, researcher, teacher and developer at the same time. Currently, he is working on many projects to develop society, health and the environment; one of the projects is the water quality device we are using in this project. Since he is the supervisor for this work, and his main area of research is in quantum and communication technology [1], he will be of great help to this project.

Acknowledgement

Words cannot express our gratitude to our professor and supervisor - Ying Fu - for his generous help and patience all the way through this project. We would not have undertaken this journey without all the knowledge, wisdom, help and advice that he provided us. We really hope that he is proud of us after completing this work and after we learned many things from him. Thank you so much, Ying, and thanks to all the teachers, examiners, our families and everyone who supported us during this journey!

A special thanks also to Henrik Kjellgren from LBVA and his colleagues for all their support and help!

- Best wishes,
Jihad & Philip

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Abstract

Water is the source of all life, but unfortunately, the water quality is getting only worse due to many factors like overuse, contamination, indifference and even by nature itself. By identifying the problem, we are one step closer to solving the problem, and that is why an intelligent water quality device is required to examine water and detect impurities within it. In this project, we are developing a device that uses an entirely new method to measure water quality. Even though the theory behind the device is very advanced, the device is still primitive in its functions and needs development to increase the usefulness and accuracy of the measurements!

Abstrakt (Swedish)

Vatten är grunden till allt liv, men tyvärr blir vattenkvaliteten bara sämre på grund av många faktorer som överanvändning, förorening, likgiltighet och till och med av naturen själv. Genom att identifiera problemet är vi ett steg närmare att lösa problemet, och detta är därför en intelligent vattenkvalitetsenhet behövs för att undersöka vattnet och hitta orenheter i det. I detta projekt utvecklar vi en apparat som använder en helt ny metod för att mäta vattenkvaliteten. Även om teorin bakom apparaten är väldigt avancerad så är apparaten fortfarande primitiv i sina funktioner och behöver utveckling för att öka användbarheten och noggrannheten i mätningarna!

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1 Introduction

Water is the source of all life on earth [2]. It consists of two hydrogen- and one oxygen atom (H_2O). The water on earth is limited since it was created in space 20 million years before the earth was created; it came down to earth through icy asteroids [3]. About 97% of all existing water is in the oceans. The 3 per cent left gets distributed between ice sheets, glaciers, lakes, water courses, groundwater and much more. Considering only freshwater, more than three-quarters of it is ice and snow. Therefore only one-fourth, $1/4$, is used as drinking water, where most of the drinking water, about 95%, exists in the form of groundwater [4, 5].

Sweden is one of the most countries that are rich in freshwater. There is an almost unlimited amount of freshwater of high quality here in Sweden [5]. Most freshwater comes from the ground, but even surface water is used [6]. Tens of years ago, there was no problem using water from lakes, rivers or water wells in the country; nowadays, it is not the case. About 150 years ago, when industrialism began, the freshwater became eventually contaminated and, in some instances, undrinkable. Industrial waste that came from countries nearby by the wind; ashes and sulfur waste that spread from coal combustion; and domestic waste that solves and transports with acid rain; all contributed to the pollution of the freshwater [2, 4]. For example, one drop of diesel oil could affect a thousand litres of freshwater [5]. After many years of insouciance, many freshwater sources are acidified today, and some have become unviable. Many living creatures do not endure such an acidic and polluted environment and, consequently, die. The quality of freshwater is still not improving, even after many investigations and actions in recent years, but only getting worse due to overuse and contamination [4].

It is here where this project comes in handy because it is about developing a device for controlling water quality. The device detects any charged or polarised material dissolved in water. Anything that contributes to water contamination or worsens its quality, like microorganisms, metals or poison, should be detected using various electrical frequencies generated by the device. The device's primary function, i.e. analysing water quality by detecting dissolved substances, is already working. However, many improvements are needed to make the electronic device more usable, functional and precise.

1.1 Purpose

This project aims to develop and improve many of the functions of the water quality controlling device. As mentioned, the primary function of controlling water is working, but many problems must be solved to advance the device. Some problems are: making the device self-sufficient, storing data to be used later, wireless communication, Bluetooth, hardware development, material development and more. The improvements will make the device easier to use and accessible to anyone. By making the device accessible, more people will understand the value of freshwater, and more will contribute to taking care of it.

1.2 Delimitations

This project will not focus on developing the internal circuit board or system. The primary function will be the same. The focus will be on developing the peripheral system outside the main circuit; for example, the sensors (electrodes), power source, memory, synchronising data, connection with the computer and communication.

1.3 Questions

General Questions

- How can we improve the device, make it usable, and make the measuring of freshwater easier?
- Can different dissolved materials in the water affect measurement results and give incorrect readings?
- Could different qualities of water spoil the device's electronics or hardware over time?
  - Which material will get spoiled and how?
  - Shall we change the material every once in a while, or shall we protect the material somehow?
- Does the measured data corroborate and correlate with other reliable sources?
  - If not, is the device defective, or is there anything wrong with it?
  - How can we interpret the data considering all the improvements on the device?

Technical Questions

- Can we implement a low-energy memory chip into the device to store measured data?
- Can we add a Bluetooth chip to send and receive the data at a range of at least 10m?
- Can we implement IoT to the device to put it later in the water and control measurements from a distance above water?
- Can we create a PCB expansion to a microcontroller to include all the new functions and added features on the same board?
- Can we find a solution to supply the device and all electronics with power without having it coupled to a PC?

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2 Background and Theory

2.1 Various Methods of Measuring Water Quality

2.1.1 Traditional Measuring Methods

There are many ways, methods and devices to measure water quality nowadays, some of which are more effective than others. One of the most ineffective yet conventional ways is by taking samples from water and sending them to a laboratory. In addition to the time consumption of this technique and the high expense, it also significantly impacts the sample [7, 8]. There are many ways and devices to take samples, and most of them alter the chemistry and impact the integrity of water. When taking samples, changes in water's pressure and temperature, as well as degassing, occur. Those changes impact many chemical parameters leading to a completely different sample structure. Some changes occurring in the chemical parameters are the pH, dissolved oxygen (D.O), total organic carbon (TOC), and the concentration of many other dissolved substances, solids or metals [8].

2.1.2 Modern Methods with Various Sensors

There are other modern ways to measure water quality; real-time measurements and analysis are obtained using embedded systems like Raspberry Pi, various sensors and the Internet of Things (IoT). This method provides high accuracy and efficiency and is much more economical. Since there are many parameters to measure - different sensors like pH, temperature, turbidity, Total Dissolved Solids (TDS) and many others must be used before determining water's total quality [7, 9]. One disadvantage of this method is that some sensors are very expensive, especially when many unique sensors are needed and if accuracy is required. Also, more advanced computers are necessary when using advanced analogue sensors.

2.1.3 Halmstad's Water Treatment Plant

In a meeting with the local water treatment plant in Halmstad, they explained how contaminants are detected in the plant. Since they are taking care of 24 different water treatment plants in the area, a mixture of the foregoing methods is used to make the work as effective as possible. Many expensive and advanced sensors are used made by companies such as Hach [10], while many samples are taken daily to be sent to laboratories, all of which require three integrations and take about 18 hours. Although many of the pollutions are well known by them - like Manganese, Escherichia coli, Intestinal Enterococci, drug residues, bacteria and viruses - an express analysis is needed occasionally to detect other unrecognized substances, which is very costly. The standard laboratory analysis gives results after three days. The samples are collected from pipes of different lengths and diameters ($50 - 100$ [mm]) and placed in different locations in water. The pressure in the pipes is about 6 [atm], and water speed is ≤ 10 [L/s] [11].

2.1.4 Using Nanosensors

Nanosensors are one of the most promising tools for controlling water quality. Its ability to detect contaminants in water - whether chemical, biological or physical - at the nanoscale (1×10^{-9} [m]), the low-cost, the high sensitivity and selectivity, and the real-time analysis and quick response has made nanosensors very attractive for research recently. These sensors consist of three parts where the recognition element interacts with the environment (water in this case) through the nanomaterial at the very edge. Then if anything is detected, a signal is sent through the physical transducer, where signals can be amplified and processed from nano- to the macroscopic scale [12].

2.1.5 The Ideal Device and the New Method in this Project

Considering all the methods and devices mentioned above, the ideal device is created by taking advantage of every method while avoiding any source of error. By avoiding taking samples from water and instead measuring in place. By using advanced embedded systems with sensors and IoT to get real-time measurements and analysis. Finally, we can create the most efficient and accurate device using nanosensors instead of ordinary ones.

In this project, the water is measured with a new device using electrodes on the nanoscale to detect contaminants in water using different electrical frequencies. It is a new and efficient method that detects any polarised or charged substances in water, i.e. any dissolved chemical, biological or physical matter. This device's peripheral system can develop when taking advantage of other preceding devices and methods, like the IoT system, embedded systems, real-time measurements and analysis, self-sufficiency, etc.

2.2 Water

Water comprises two hydrogen atoms and one oxygen atom (H_2O). As the oxygen atom attracts the electrons more, it becomes negatively charged, while the hydrogen atoms become positive. Since the hydrogen atoms are only $105°$ apart, they are on the same side, making water molecules polarised and very special. Figure 1 shows how water molecules are built, where $-\delta$ is the negatively charged oxygen, and $+\delta$ is the positively charged hydrogen atoms [13].

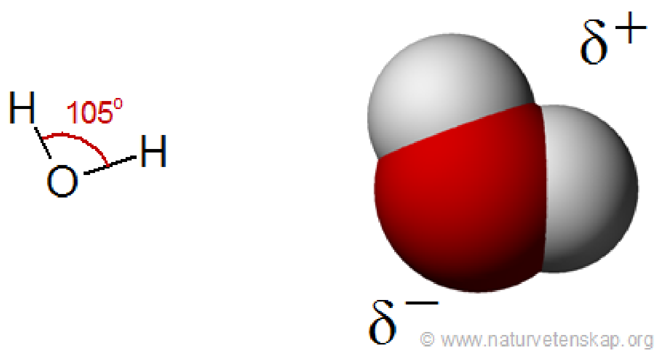

Figure 1: Polarised water molecule [13].

Because water molecule is polar, any polar substance can dissolve into water, creating a homogeneous mixture. Although polar solvents only dissolve polar substances - like dissolves like - non-polar compounds like gases could dissolve in water using hydrogen bonds, creating new compounds and increasing solubility [13, 14]. One example is carbon dioxide, which reacts with water, creating a new compound.

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

The new compound reacts further with water which results in two charged ions.

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3{}^-(aq)$$

The ions can react efficiently with water since they are charged, and the non-polar gas lead to the creation of an utterly polar solution [13]. That means charged compounds, polar molecules, and non-polar gases could all react with water resulting in ionised or polarised solutions, i.e. electrolytes [14, 15].

2.2.1 What is Water Quality

Many factors and substances determine water quality, and these factors are caused by nature, contaminations, overuse of water, poor constructions, or even poor maintenance of a water supply plant. The Swedish Food Agency's (Livsmedelsverket) regulations based on The European Union's rules set the amount and limitations of the most common substances in water that affect the water quality. Some of the quality problems in Sweden are that the water is aggressive and consists height amounts of iron and manganese. Even the hardness of water is another problem, where the amount of calcium and magnesium matters. The table below (Table 1) classifies the hardness of water using dH-scale, where 1 [dH] = 10 [mg] CaO/L (calcium ion per litre) or 7,19 [mg] MgO/L (magnesium ion per litre).

Table 1: Variuos hardness classes of water, from Livsmedelsverket [2].

Hardness class	dH-scale	[mg] Ca/L
Very Soft	0-2,1	0-15
Soft	2,1-4,9	15-35
Middle Hard	4,9-9,8	35-70
Hard	9,8-21	70-150
Very Hard	> 21	> 150

Iron and manganese amounts in water switch fast since they depend on the surrounding pH- and redox conditions. However, only a tiny amount of iron ($< 0,4$ [mg/L]) can cause problems in cooking and cleaning while resulting in a foul smell and taste. The metal causes clogs in the pipelines too. At the same time, when the water is soft and aggressive, where low alkalinity and low pH are also present, the pipelines corrode and metals like copper, zinc and iron increase in drinking water, spoiling water quality.

Two other harmful substances that exist in water are fluoride (F) and radon (Rn). Fluoride usually exists in soft groundwater, especially deep-drilled wells at height concentrations. At concentrations of $1,5$ [mg/L], the fluoride starts to damage children's teeth, and at higher concentrations like $6,0$ [mg/L], there is a risk of skeletal damage. Radon, on the other hand, could harm in two different ways: by consumption through drinking water or inhalation through water steam. The limit value is 1000 [Bq/L] (becquerel/litre) for adults and half of that for children. Radon causes $35-70$ cases of lung cancer and $10-20$ cases of stomach and colon cancer yearly.

Regarding the anthropogenic impact on water contamination instead of nature's, humans contribute to much water pollution. Salty groundwater, for example, is one of the results of carelessly overusing water. The increased amount of chloride (Cl) in water also depends on the usage of road salt near water sources. Since height values lead to bad taste and corrosion, the chloride limit value in Sweden is 300 [mg/L]. For children and other people with diseases like hypertension and poor kidney function, the maximum amount of chloride should not exceed 170 [mg/L].

Fertilisers, pesticides and point sources of pollution play a huge role because many discharged pollutants make the water poisonous and even undrinkable. Nitrate (NO_3) is one of the common pollutions, only 10 [mg/L] of (NO_3-N) or $0,1$ [mg/L] of (NO_2-N) could lead to health problems in children. Nitrate is known to cause cancer and other health damage. Concerning pesticides, there should be no trace of them in water at all, according to The Swedish Food Agency [2].

Another consequence of discharged pollutants is the acidification of groundwater. Acidified water (pH ≤ 6) increases the percentage of toxic metals like copper, aluminium, and cadmium in drinking water through corrosion [2, 16]. Aluminium can increase the risk of dementia, bone damage and anaemia. Too much copper can affect the digestive system and harm the liver [17].

Water could contain many other pollutants, metals, salts, toxins and microorganisms, but the previously mentioned are the most common problems in Sweden's groundwater. Some other problems are the presence of lead, uranium, mercury, the pH percentage, the total organic carbon (TOC) and much more [17]. Common to all those things is that almost all are soluble in water.

2.2.2 Water and its Electrical Properties

Since the water molecule is dipolar in its nature and the attraction between two different water molecules is determined by hydrogen bonding, these properties create an electric field resulting in electrostatic charges on molecules without any current flow. When placing two condenser plates in water, the positively charged hydrogen pole will move towards the cathode while the negatively charged oxygen pole will move to the anode as in figure 2. As the dielectric constant, ε, of water is very high ($\varepsilon = 80.2$) compared to unity in a vacuum, significant polarisation occurs, reducing the electric field created by the condenser and thus lessening the current flow within water's volume [18].

Before the electric field is reduced, during the transient phase, few parameters affect the force and velocity in which molecules - or particles - are pulled to (or pushed from) the charged plates. Some of these parameters, according to Coulomb's law (equation 1), are the charge (q), distance (d) and dielectric

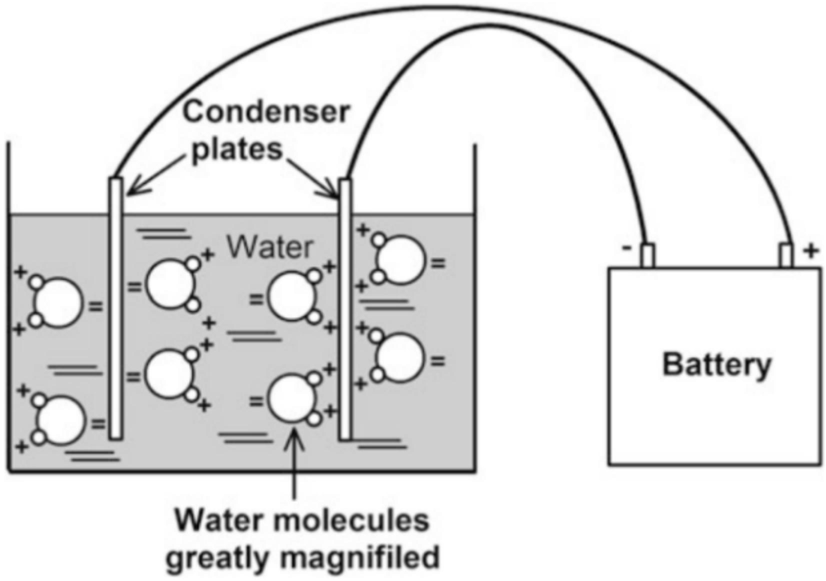

Figure 2: Different poles of water move towards different charged condenser plates [18].

constant (ε) [18]. Another parameter is the mass (m) according to Newton's second law (equation 2). It is during the transient phase that the water quality device determines the quality of water using the dielectric property of particles in water and applying the same concept as the condenser in figure 2.

$$F = \varepsilon \frac{q_1 q_2}{d^2} \tag{1}$$

$$F = m \times a \tag{2}$$

In (1) q_1 and q_2 are the charges of two particles, ε is Colombs constant and d is the distance between the particles. In (2) m is the mass and a is the acceleration.

2.3 The Device's Function

The device operates on the physics mentioned in the last section (section 2.2.2). Everything that is soluble in water, even microorganisms, acts in the way described earlier. Instead of plates, the device uses pointed electrodes, which have more spherical areas of influence compared to the plates. Switching the polarity of the electrodes makes the charged particles move between the electrodes. The device measures the voltage between the electrodes to generate data for analysis. This method works because the particles have a charge. Voltage only is the difference in charge between two points. When charged particles come in contact with the electrode of the opposite charge, the particle cancels out as much charge on the electrode as it has itself.

The core of the device is indeed the mathematical formulas, the advanced calculations and the advanced theory of physics, electricity and chemistry that lies behind the simple electronic device. The device that computes water quality is simple and does not have complicated electronic components from the beginning. It is made of some integrated circuits using microchips like the switch "$MAX635ACPA$" to switch poles in the electrodes that sense water. Another essential component in the primary device is the operational amplifier "$LP324\_N\_14$" to amplify the tiny electrical signals from the detected water pollutants through the electrodes. Some resistors, diodes, inductors and capacitors are coupled to stabilise the system and make the microchips function properly. Lastly, everything is coupled to a voltage supplier like a PC or a microcontroller, and a screen prints the measured result.

Since the theory behind the measurements and calculations is beyond the scope of this project, only the electrical function is explained here. The device sends electrical signals to the electrodes at five different frequencies. For every frequency, there are five switches in the poles except the first frequency, which is only for reference. That means the electrodes change polarity more than 20 times. For each frequency of the five present and for each switch of the poles, 64 samples are taken and printed as data. That means 1344 samples are taken in a very short period of time.

$$64\frac{samples}{switch} \times 5\frac{switches}{frequency} \times 4frequencies + 64reference = 1344samples$$

The purpose of changing frequencies is to detect different sizes of particles. The higher the frequency, the smaller the particles that are detected by the electrodes and vice versa. Below is a table (table 2) showing the different frequencies sent from the device and how many samples are for every frequency.

Table 2: Frequencies sent by the water quality device to detect different sizes of particles.

Number	Frequency	Samples & Switches
(1)	@ 100 Hz	First 64 is to get a reference
(2)	@ 800 Hz	5 ×(64 +/-, 64 -/+)
(3)	@ 100 Hz	5 ×(64 +/-, 64 -/+)
(4)	@ 25 Hz	5 ×(64 +/-, 64 -/+)
(5)	@ 6.25 Hz	5 ×(64 +/-, 64 -/+)

2.4 The Device's Hardware

The hardware of the current prototype is simple because it only needs a few components. The central part is the ATMega8535, an 8-bit microprocessor with many pins for interfacing with other components. There are two electrodes used for doing measurements. Doing the measurements require a negative voltage. Attached to the device is a DC converter to handle this. There are also OP amplifiers so that the readings from the electrodes can be appropriately measured.

2.4.1 The Arduino Uno Rev3

The Arduino Uno is a microprocessor based on the Atmega328p MCU. The MCU is an AVR microcontroller using a modified 8-bit RISC instruction set. It has both digital and analogue GPIO and supports pulse width modulation (PWM) on the digital port and analogue to digital conversion on the analogue input pins. It also supports both internal and external interrupts, which is helpful if code needs to run at a particular time. The Arduino is a good development board because it is easy to program. With the help of either the Arduino framework and C++ libraries or the lower-level AVR standard C libraries, one can write sophisticated, efficient code.

In addition to all that, the Arduino Uno needs an input voltage between $6 - 20$ [V] and 5 [V] operating voltage. Six out of 14 GPIO pins support PWM, and there are six additional analogue input pins. The current from the I/O pins is 20 [mA] while the current is much higher from the 3.3V pin where it is 50 [mA]. The memory is only 32 [KB], and SRAM is 2 [KB], while the clock speed is 16 [MHz]. The price for this version of the Arduino is about 300 SEK.

2.4.2 The HC-05 Bluetooth Module

This Bluetooth module (see figure 3) has low cost and low power consumption, very effective and simple. It can be connected to a microcontroller via its four connections, two connections for power and ground, and the other two are for sending and receiving data (Tx and Rx); the last two pins are the state and key, which are usually unconnected. The supply voltage of the module is low, between $3.6 - 6$ [V], and for logic levels, it is 3.3 [V], making it very suitable for Arduino. The Bluetooth version used is 2.0 with the Enhanced Data Rate (EDR) in addition, making the data transfer at speed up to 9600 [bits per second] at a range of 10 [m]. This module is small in size $(27 \times 13 \times 2)$ [mm] and can operate in temperatures between $-25°$ and $+75°$ [C]. The price of this module is around 100 SEK.

Figure 3: Bluetooth Module HC-05.

2.4.3 Bluetooth 4.0 BLE Module - HM-10

This Bluetooth Low Energy (BLE) module is more advanced; it uses Bluetooth version 4.0, which allows to send and receive limitless bytes at a speed of 6K [Bytes] or 48.000 [bps]. The power needed to operate is only 3.3 [V] and 50 [mA]. This Bluetooth module has a very long range, up to 100 [m]. There are 10 general-purpose input/output (GPIO) pins that can be controlled through a microcontroller. The size is almost similar to the HC-05, i.e. $(26.9 \times 13 \times 2.2)$ [mm] and the operating temperature is between $-5°$ and $+65°$ [C]. The cost of this module is 229 SEK.

2.4.4 The DataFlash AT45DB161D-SU

The ”AT45DB161D-SU” (see figure 4) is a serial-interface sequential access flash memory chip consisting of 8 pins and has a memory size of 16 [Mbit]. This chip only requires $2.5 - 3.6$ [V] to be programmed and thus simplifying the in-system re-programmability. The speed is 66 [MHz] or 66 [Mbps], and the memory is thus very useful for applications involving very high-speed operations. This flash memory also contains two SRAM memories in addition to the main one, allowing data to be received or sent while data on the main memory is being reprogrammed. The memory is also programmed by Atmel, the same system that is used in Arduino. Because of the memory’s low voltage and power consumption and because of its reliability and package size, it is very useful in many industrial applications. Operating temperatures are between $-40°$ and $+85°$ [C]. The price of this memory chip is about 179 SEK.

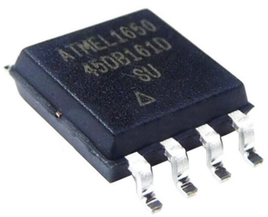

Figure 4: The DataFlash AT45DB161D-SU.

2.4.5 Voltage Regulator - LP2950ACZ-3.3V

The ”LP2950ACZ” is a voltage regulator that is specifically designed for extremely low input-to-output voltage regulations, i.e. the differential is slight between input and output (50 [mV] @ 100 [µA] and 380 [mV] @ 100 [mA]). It features a very low quiescent bias current of 75 [µA] and is able to supply output currents of 100 [mA] and more. The maximal input voltage is 30 [V], and the output voltage is 3.3 [V] $\pm 5\%$ with an output current of 100 [mA]. The operating temperature is between $-40°$ and $+125°$ [C], and the price is 19 SEK.

2.4.6 The LCD Module - TM12864FDCW

This Liquid Crystal Display (LCD) module consists of LED backlights and has a dot matrix of 128×64 Dots. The display colour is Blue-Black, and the background colour is Grey. This LCD has 18 pins that a microcontroller can control, and the supply voltage is 5 [V] while the LCD driving voltage to adjust the contrast is a variable up to 25 [V]. The LCD is capable of 8-bit parallel data transfer and can operate in temperatures between -20° and $+70^\circ$ [C]. The outline dimensions are $75.0 \times 54.7 \times 12.5$ [mm], making it very close to the Arduino Uno dimensions. This product costs around 400 SEK.

2.4.7 The PowerBank

The PowerBank in the picture (figure 5) has a Li-ion polymer battery with a capacity of 20.000 [mA h]. The output power is of total 66 [W] where 18 [W] comes from the USB-A port and the USB-C port can supply with maximum 60 [W] at 3 [A] current. Since this PowerBank has three output ports ($2\ \times$USB-A and $1\ \times$USB-C), it can supply three devices simultaneously. The charging time is, however, 2 hours using USB-C with 20 [V] input voltage. The price is 999 SEK.

Figure 5: Powerbank 20.000mAh 66W 2x USB-A 1x USB-C.

2.4.8 Oxidation States of Elements - Oxidation of the Electrodes

Oxidation is when an element loses one or a few electrons in a chemical compound. In theory, the oxidation could be: positive, where the atom loses electrons; negative, where the atom gains electrons; or zero, where the element is pure. When the oxidation is negative, i.e. the atom gains electrons, the process is called reduction. The oxidation state, or number, represents how much an element oxidises. It is either positive, negative or anything in between, and it could also be a fraction because the average oxidation state is not always a whole number. The term oxidation was only linked to substances reacting with oxygen, but later the term was extended to include all reactions with a specific element that leads to oxidation of that element regardless of the reactant. Figure 6 gives a brief indication of the oxidation number of the elements.

The oxidation number differs for the same substance depending on many factors, such as the reactants and their electronegativity (see Fig 7). Advanced knowledge of different areas is necessary to calculate oxidation in various situations. Deep understanding of chemical bonds, especially ionic ones; under-

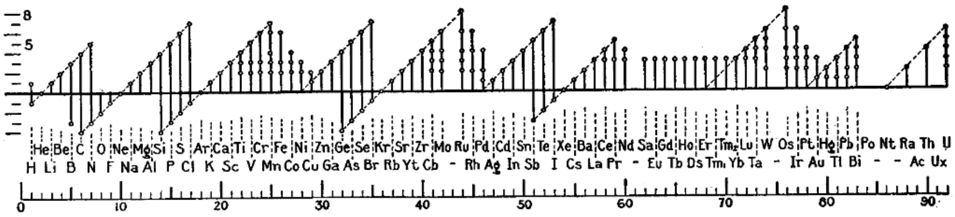

Figure 6: Rule of the oxidation number of the elements, used by Irving Langmuir (1881-1957) [19]. All the elements are displayed in order on the x-axis, while their most common oxidation numbers are on the y-axis.

standing of quantum-chemical calculations of charges; and more knowledge about chemical reactions [19].

V•T•E **Electronegativity using the Allen scale**

Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H 2.300																	He 4.160
2	Li 0.912	Be 1.576											B 2.051	C 2.544	N 3.066	O 3.610	F 4.193	Ne 4.787
3	Na 0.869	Mg 1.293											Al 1.613	Si 1.916	P 2.253	S 2.589	Cl 2.869	Ar 3.242
4	K 0.734	Ca 1.034	Sc 1.19	Ti 1.38	V 1.53	Cr 1.65	Mn 1.75	Fe 1.80	Co 1.84	Ni 1.88	Cu 1.85	Zn 1.59	Ga 1.756	Ge 1.994	As 2.211	Se 2.424	Br 2.685	Kr 2.966
5	Rb 0.706	Sr 0.963	Y 1.12	Zr 1.32	Nb 1.41	Mo 1.47	Tc 1.51	Ru 1.54	Rh 1.56	Pd 1.58	Ag 1.87	Cd 1.52	In 1.656	Sn 1.824	Sb 1.984	Te 2.158	I 2.359	Xe 2.582
6	Cs 0.659	Ba 0.881	Lu 1.09	Hf 1.16	Ta 1.34	W 1.47	Re 1.60	Os 1.65	Ir 1.68	Pt 1.72	Au 1.92	Hg 1.76	Tl 1.789	Pb 1.854	Bi 2.01	Po 2.19	At 2.39	Rn 2.60
7	Fr 0.67	Ra 0.89																

Figure 7: Allen electronegativities for simple estimation of the ionic approximation [19].

2.5 The Device's Software

The current prototype runs assembly code. Assembly is suitable for embedded programming because it allows for complete control of memory usage. Binaries also tend to become smaller because compilers that compile down to assembly may use more instructions than needed for the intended operation. The flip side is that code readability is worse than in higher-level languages such as C. Higher-level code also has comfort functions that do not exist in assembly. The current code only makes measurements and sends data via serial/USB to a PC, which is easy to do with assembly code.

3 Method

This section will describe how different methods and tools were used to complete this project. First comes the task specification, where we describe how the work was divided into tasks from the beginning. Then comes the introduction of the software tools and programs that we used during the work to program the Bluetooth and the memory, and the software for creating the PCB. Then the choice of components where we explain how different components were chosen and why, and if there were other alternatives. Then the programming where we present how different parts were programmed to make them function using Arduino Uno and Python. The PCB design comes next, and we explain how the creation of PCB went using the software OrCad. Lastly, the data analysis where some theory of how the graphs and measurements are calculated.

3.1 Task Specification

The supervisor has specified the task in two parts: gathering data from water in Halmstad, analyzing it, and implementing new features to make the measuring device more suitable for live use. Analyzing data and visualizing it is crucial to see if the device works properly and is necessary for the environment. If data shows concerning results, then that is a cause for worry. Making the device more suitable for real-life use means implementing new functionality is essential so that the device can run unattended for longer, just collecting data. If the device can be placed remotely and run without a stationary power source, then it could be used to detect a problem with the water quality quickly. It also makes sense for research as it minimizes the time spent in the field gathering data.

3.1.1 Research Process

The gathering of information for this work was first through searching in databases like Google Scholar, IEEE and ScienceDirect to find the most relevant articles, books and similar devices if any exist. From these reliable sources, we could find the most current devices for water quality and which methods were used. Even though we did not find any similar concepts or devices to ours, we could benefit from the methods used in our measurements and the intelligent features we later added to our PCB, like wireless communication and the microcontroller.

We even searched for reliable scientific books about water quality in libraries. There we found many valuable resources which describe water quality in detail, especially in Sweden. The books revealed that ”The Swedish Food Agency” (Livsmedelsverket) had the most recent updates about water quality in the country. We also learned about the water treatment plant in Halmstad, which we contacted later to collaborate with and to use some of their knowledge in the field, calibrate the device against their treated water, and simultaneously get water analysis to compare to our measured data.

Lastly, we used parts of the most critical document about this new water quality device. Since the documents are secret and have yet to be published, we could only get a small portion that was enough for this project's scope. We could not refer to the article due to confidentiality issues. Still, from the small review, we found some formulas briefly describing how particles are detected in water and how the device operates using electricity and different frequencies.

3.1.2 Calibration of the System

After building our first prototype with the professor, we had to calibrate the device to ensure it was measuring accurately. Since another device was already calibrated, we used different waters - tap water and salt water - to get similar results to the calibrated one. We had to clean and change the copper electrodes before the process was successful. Maintaining the copper electrodes after each measurement and changing them regularly was essential to get accurate measurements since the copper electrodes oxidate due to dissolved substances in water. That is why when the measurements deviate significantly from the daily trend, we always check the electrodes to see if they cause the unusual results.

Later during the project, we got three water samples with known chemical analysis from the local water treatment plant ("Laholms Buktens Vatten AB") to correlate them with our measurements and calibrate the device further. Since the chemical analysis had many substances (see table 4 in appendices) and the calculations of the measured results were beyond the scope of this project, we took help from the professor, who confirmed later that the measured results from the device agreed with the chemical analysis from the water treatment plant.

3.2 Software

3.2.1 Python

Python [20] will be used to analyze the data. Python has many good third-party libraries for scientific processing. For this purpose, SciPy [21] and NumPy [22] will suffice. SciPy provides functions for fitting data to curves. These tools are essential to get a clear representation of the data. NumPy provides fast data structures like arrays and functionality like appending arrays.

3.2.2 PlatformIO

PlatformIO [23] is a plugin for Visual Studio Code that makes flashing and debugging code for microcontrollers much more unified. The only thing the developer has to do to set up a development environment is to tell PlatfromIO what platform the code is supposed to run on and PlatformIO.

3.2.3 AVR-libc

AVR-libc [24] is the standard C library written for the 8-bit AVR family of microcontrollers, which include the AtMega328p, which is the base of the Arduino Uno. Not only does it contain the standard modules such as string and stdio, but it also has modules, value definitions and macros specific for embedded development. When values are just names in the programming part of the method, then that means that they have a definition in this library.

3.2.4 OrCad

OrCad is an electronic circuit modelling program allowing users to design components and whole schematics models. It has a PCB editor to which you can import your circuit schematic. This makes it easier to design the PCB as it already has all the components present and the connections between the components highlighted.

3.3 Choice of Components

3.3.1 Choosing the Most Energy Efficient Components

During the phase of choosing components, we searched for the most energy-efficient components that do not require much supply power or voltage. That was our goal because the device should be developed to operate for a long time underwater without any maintenance or charging. For the supply power, we choose a powerful PowerBank with a capacity of 20.000 [MAh] and a short charging time of 2 hours. That makes the device one step further to operate independently for a long time without any PC coupling or any wall connection. We also considered the price of the components, and as seen in the sections above (section 2.4), the components chosen are inexpensive.

3.3.2 Wireless Communication

The easiest way to implement wireless communication that could work for remotely deployed devices is by implementing a network module with a SIM card slot to communicate long distances. A simpler and cheaper demo implementation would be to connect a Bluetooth low energy (BLE) module and use a Bluetooth-enabled device to collect stored information from the measuring device. BLE is short-range high-frequency communication that draws minimal current when on standby, which makes it an excellent choice for our device. Among other things, current consumption is dependent on throughput when active, which is at most in the tens of milliamperes for some popular BLE modules [25]. There are not enough monetary resources nor the time to buy new hardware, so instead, a standard Bluetooth module is used because some of the model HC-05 already exist.

3.3.3 Choosing Bluetooth Chip

For Bluetooth, we considered two efficient and powerful chips. The goal of this project is to be able to send and receive data at a range of at least 10m. At the same time, we considered the feasibility of the chip programming as well as the energy efficiency of the chips. We found two suitable Bluetooth chips, where one is more advanced than the other and has a range of 100m. Since this Bluetooth chip (”HM-10”) was unavailable at that time, we chose the other best one, which is the ”HC-05”, and has enough technical features to fulfil our specifications. The programming of this chip was successful, and the task of communicating through Bluetooth was successful.

3.3.4 Power and Battery

The early prototype runs on power over USB. If the device is supposed to be deployed remotely, it will need to be powered by a battery instead. The Arduino has been compared to some smaller microcontroller boards. If the Arduino is supposed to be used, then a big battery bank may be needed to get a decently long run time. The Arduino works fine for test purposes, though, in terms of testing battery usage. This is a straightforward step, so it is not as important as the other things.

To save battery, one can also put the device to sleep. Interrupts could be used to wake the device from sleep so that it can do measurements. A real-time clock will be needed if the device sleeps for long periods in between measurements. Again, there is no time or money to buy these modules, so it is out of this project’s scope.

3.4 Programming

3.4.1 Bluetooth Module

To use the Bluetooth module for sending data, the Arduino needs to communicate with it over some protocol. For the HC-05, that is UART. UART stands for Universal asynchronous receiver-transmitter. Asynchronous here means that no clock signal is needed. The Arduino has a transmit pin and a receive pin for UART transmissions. Enabling UART on the Arduino UNO is done in a few steps. First, the Baud rate is set by first calculating the Baud rate with the macros UBRRH_VALUE and UBRRL_VALUE and writing these values to the UBRR0H and UBRR0L registers. The macros mentioned above need the CPU frequency F_CPU to be defined. PlatformIO does this for us, but if we were not using PlatformIO, we would have to use the #define directive to specify the CPU frequency. The rest of the configuration for UART needs three registers UCSR0A, UCSR0B and UCSR0C, which also act as status registers. In the first register, we only set whether to use double or single-speed transmission. In this project, single-speed transmission is favourable because it is more robust than double-speed. The value U2X0 defined by AVR-libc enables double speed, so it is bitwise operated on, inversed and written to the register to ensure it is disabled. UART can send different-sized packets, from 5 to 9 bits in size. Choosing eight bits is better because it is the size of a measurement point and because it is a power of 2. To achieve this, the values UCSZ00 and UCSZ01 are bitwise operated and written to UCSR0C. The last step is enabling the transmit and receive pins by using the bitwise operation on the values TXEN0 and RXEN0 and writing them to UCSR0B. Putting the code for the configuration into a function makes it easy to set up in the program’s main function.

Two other functions are needed: a send function and a receive function. The functions for sending and receiving data are similar. Check and wait if data is being sent or received; otherwise but receive or send data. AVR-libc has a function called loop_until_bit_is_set () that takes a register and a bit as arguments. It checks whether the given bit is set in the given register and loops until it is. The send function waits for the UART Data Register Empty(UDRE0) to get set in UCSR0A, then puts exactly 8 bits onto the data register UDR0. The receive function waits for UART Receive Complete(RX0) flag in UCSR0A and then reads 8 bits from UDR0 which automatically clears it. These functions work for a single data to send or receive. AVR-libc has a macro called FDEV_SETUP_STREAM() that takes a send function, a receive function and file privileges to create a variable of custom type FILE. Doing IO operations is just a FILE object being read from or written to. The send function has to be modified to send a \r character after \n character in a string so that the cursor returns to the start of the line if the data is received in a terminal. A FILE called uart_str gets created in the code with _FDEV_SETUP_RW privilege. _FDEV_SETUP_RW is a defined value in AVR-livs for read and write privilege. Setting the macros stdin and stdout equal to the pointer of uart_str makes it so that standard IO functions write and receive data via UART.

3.4.2 DataFlash Memory

The DataFlash memory uses another protocol called Serial Peripheral Interface, or SPI for short. SPI is synchronous, meaning that it sends or receives data on clock pulses instead of later or when ready. SPI communication requires four pins: master in slave out(MISO), Master out slave in (MOSI), slave/chip select (SS/CS) and the serial clock pin (SCK). All pins except the MISO pin should get configured as outputs.

Enabling SPI is different from enabling UART. There are no definitions for the de SPI pins in AVR-libc, so they must be manually added. The table below shows how the SPI pins get mapped on the Arduino UNO.

Table 3: SPI pin mappings on Arduino UNO.

Pin Mappings		
Pin name	Pin number on Arduino	Pin number in code
SCK	13	5
MISO	12	4
MOSI	11	3
SS/CS	10	2

The MOSI, SS, and SCK pins must get configured as outputs by left-shifting the pin numbers and OR them to the correct Data Direction Register, DDRB, for the Arduino UNO. The MISO pin gets configured as an input by left-shifting the pin number, inversing it and AND it to DDRB. The pin numbers to enable SPI are defined in AVR-libc. SPI is therefore enabled by left-shifting SPI enable bit number (SPE) and Master mode bit number(MSTR) and OR them onto the SPI configuration(SPCR). The double-speed bit number is also left-shifted, inverted and AND onto the SPI Status Register(SPSR) to turn off double speed for robustness.

Sending and receiving data over SPI is similar to UART. For the send function, data gets written to the SPI Data Register. Then using the same loop function in the previous section, the program waits until the SPI Intterupt bit gets set in SPI Status Register. Reading the data register clears the flag and the data register for a new transmission. The receive function is the same, but junk data gets written, and the reading from the data register gets returned from the function.

The DataFlash chip operates by issuing commands. The significant commands for this application are Main Memory Page Read, Main Memory Page Program Through Buffer 1, and the unique Binary Page size option [5,6]. The DataFlash gets programmed to use a 512 bytes sized page using the Binary Page size option, which is essential because one complete measurement is also 512 bytes. The Binary Page size command codes must get sent while the SS pin is LOW. The code waits for the chip to be ready before returning to the main function. A function achieves this by performing the Status Register Read command(D7). A macro then AND the register and the hex value 80, representing that the DataFlash is ready.

A read-page function gets implemented by writing the Main Memory Page Read command to the memory followed by three address bytes, 12 bits for the page number, and 9 bits for the byte address to start on. Four do not care bytes are then sent to start the read operation. On the Arduino side, the bytes get received one by one. The send function works similarly, but instead of reading bytes from memory after the command code, address, and do not care bytes are sent, data bytes get sent one by one.

3.4.3 Measurement Function

The old prototype code is written in Assembly code. The method is simple, so the translation from Assembly to C is straightforward. Because the measurement gets done by flipping the polarity of the electrodes, two digital pins are needed to control whether there is negative or positive voltage on the electrodes. An analogue pin connects to the output of an operational amplifier which amplifies the signal from one of the electrodes. Pins on port C got used for both digital and analogue pins. The steps for enabling pins as outputs are the same as in the section Bluetooth and DataFlash. The rest of the pins on port C are for ADC input use. To enable the ADC conversion ADC Enable (ADEN) pin number is written to the ADC Control and Status Register A(ADCSRA). The prescaler for the ADC must be set and is to 128 by ADPS2, ADPS1 and ADPS0 to ADCSRA. The conversion is started by writing the ADC Start Conversion bit to ADCSRA. The last thing is to set the ADC result register as left adjusted and the reference voltage to Vcc by writing the ADLR and REFS0 bits to the ADMUX register.

Measurement points get made with specific timing in between them. Precise timings get achieved with timer interrupts. Timer1 interrupt got chosen because it is a bigger counter allowing for more precise time measurements. Prescaler must be determined, and compare numbers must be set so the timer interrupt runs at the right time. The formula is:

$$CMR = \frac{f_{sck}}{prescaler * f_{desired}} - 1 \quad (3)$$

In (3) CMR is the value written to the Output Compare Register OCR1A to determine the time before interrupt launches, f_{sck} is the CPU frequency, and $f_{desired}$ is the desired interrupt frequency.

The next step is turning on Clear Timer on Compare mode by writing WGM12 to TCCR1B and writing OCIE1A to TIMSK1 to enable the Timer Compare Interrupt. Finally, the counter gets initialized to 0 by writing 0 to the Timer/Counter1 register.

3.4.4 Considerations

The Arduino digital out is 5V. Both the Bluetooth chip and DataFlash logic are 3.3V. To not put too high voltage onto the devices, the voltage needs to be stepped down. The transmit signal between the Arduino and the Bluetooth can be stepped down by voltage dividing with resistors to get to the right level. The DataFlash chip is a bit more sensitive and therefore requires a voltage regulator between the MOSI port on the Arduino and the SI port on the DataFlash. This is because the DataFlash requires a current that is hard to get with just voltage division.

3.4.5 Testing

The idea was that the device gets tested by doing a measurement. A complete measurement generates 2560 bytes, equal to 5 pages, on the DataFlash. After the data gets generated, it gets sent to a PC with the Bluetooth module and written to the DataFlash. After both things have happened, the data gets read from the DataFlash, sent with Bluetooth to the PC, and compared to the original data. If they are the same, then the Bluetooth and the DataFlash work. The new system's data could be compared to the old prototype measuring on the same sample.

Unfortunately, the new device is not ready. The Bluetooth and the data flash can get tested. Instead of measuring data, the Arduino generates a string, sends it to a mobile device with a Bluetooth serial console and writes it to the DataFlash. The data can then be read from the DataFlash and sent with Bluetooth to a mobile device where the data can get compared manually.

3.5 The PCB Design

The schematic for the printed circuit board was first drawn in OrCad, where the main components ”MAX635ACPA” (the switch) and ”LP324_N_14” (the amplifier) were included. Then we created symbols with different amount pins for the other components like the LCD screen (TM12864FDCW), Bluetooth (HC-05), the memory chip (AT45DB161D-SU) and connectors for the Arduino Uno. The schematic was ready for the design after connecting all the components and adding mounting holes to fit the Arduino Uno.

In the designing process, we considered the dimensions of the Arduino Uno pins and all other components to make their footprints. We chose to make our footprints instead of using existing ones because we wanted a unified design throughout the board. A further reason for making our own footprints is to control the sizes of pads and all other things like the outlines to make the board as small as possible to hold in hand. Later we placed the pins and mounting holes carefully to fit the Arduino pins and holes as well as the holes for the LCD screen to be on top. All the other components were placed tight next to each other, making the board as small as possible.

3.6 Gathering and Analyzing Data

Gathering data was done manually with the old prototype. Water was collected every weekday from three water sources: Nissan, Östra stranden and from the tap. The samples were taken in the morning of each day for consistency. We also got data (table 4) and samples from Laholmsbukten VA to check if the data is consistent from a broader perspective.

The data from the old measuring prototype device was analyzed using Python and the NumPy and SciPy libraries. A plot of the data is suitable for a broader perspective of the contents of the water. For a better plot and to get some required parameters. As mentioned in the section about how the device works, voltage is applied between the electrodes. The measurement starts with 64 samples when the voltage is negative, so the measurement has some base samples. What we can see after that in the plot is four sets of measurements that are 64 samples with a positive voltage and as many with a negative voltage applied to the electrodes. These four sets are different sampling frequencies. That is, between every point of data, there is a different amount of time for the four sets. The slope settling value represents how much the charge has diminished because of the charged particles cancelling the charge of the electrodes.

Particles need to be modelled or the analysis of the data. In collaboration with the professor, a model based on the forces on the particle,

$$m * \frac{dv}{dt} = -6\pi\eta av + X + q \begin{cases} 0 & t < 0 \\ E & t \geq 0 \end{cases} \tag{4}$$

The left-hand side is the sum of forces on the particle with mass m and acceleration dv/dt. The first term on the right side is the drag force of the particle in water based on Stokes law; η is the viscosity of water, and a is the radius of the particle. The second term is the small forces from other particles acting on the particle, and the third term is the force asserted on the particle by the electric field: q is the charge, and $E$is the electric field. If X is neglected and the electric field is not switched on, then the equation (4) can get solved for v:

$$v = v_0(1 - e^{-t/\tau}), \tau = \frac{m}{6\pi\eta a} \tag{5}$$

Here, τ is the time constant until the ions have settled the electrodes, and v_0 is the particles' initial speed. τ is proportional to the size m/a. . For fitting to appropriate function is then:

$$f(x) = \alpha(1 - e^{-\beta * t}) \tag{6}$$

The parameters a and b are taken as concentration and size. Variable t is time. To fit data onto this function, we use the SciPy Python library and the function curve_fit to fit the data. This function returns every variable set as a parameter. These parameters are arbitrary; that is, the unit is not known. Therefore, it is impossible to tell exactly what particles are present or at what precise concentration there is.

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4 Results

4.1 Software Results

4.1.1 Schematic and PCB Using OrCad

In the figures presented below (figure 8 & 9) are the results of creating the schematic and PCB using OrCad. The schematic shows all the electronic components used and all the wiring and connection of the different components. The connectors on the schematic represent the standard size pin connectors of 1 inch (or 2.54mm), and they are made to fit the pins of the Arduino Uno since this board will be placed above the Arduino as an expansion board.

The PCB in figure 9 has the dimensions 115×80 [mm] to fit all the components mentioned in section 2.4: the LCD screen, the Bluetooth, the DataFlash, the voltage regulator and most importantly, the Arduino Uno. Of course, it is also designed to fit the original components, which perform the main function of determining the water quality, like the operational amplifier, the switch and all the other components and parts. The dimensions between the components, especially the pins and mounting holes, are carefully calculated and set according to the technical specifications of the hardware to fit the Arduino pins, the LCD screen, and all the other hardware components.

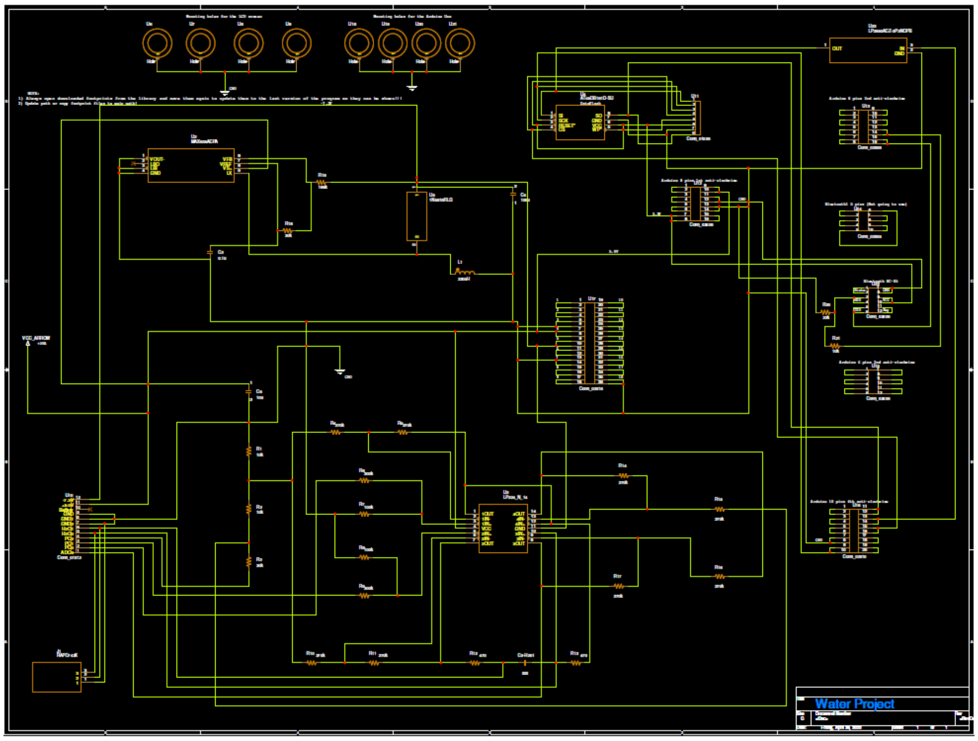

Figure 8: Schematic of the device.

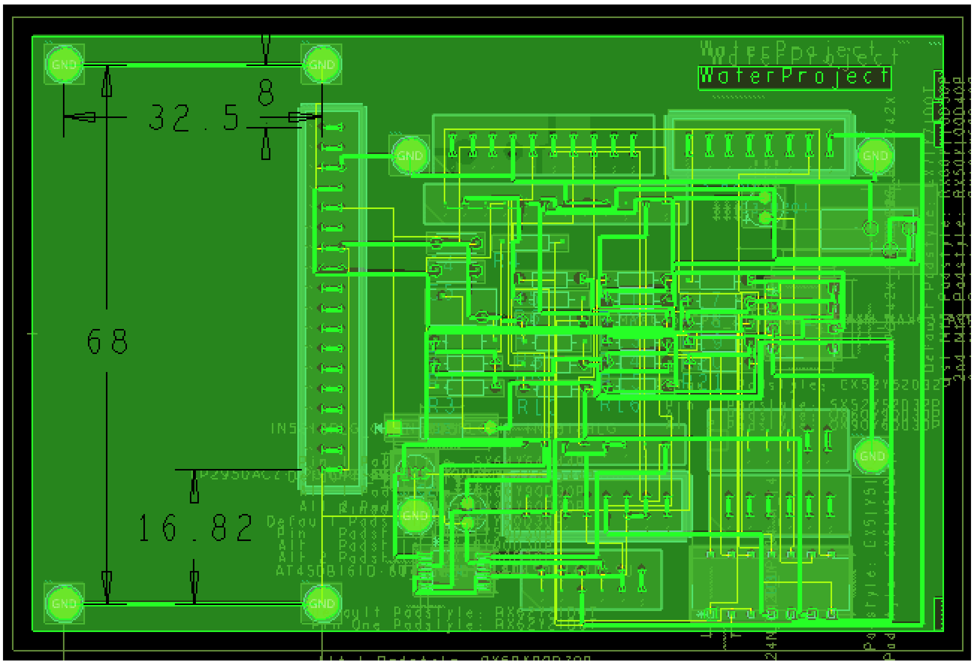

Figure 9: The PCB.

4.2 Hardware Results

4.2.1 Connecting Bluetooth and DataFlash to Arduino

In the demonstration in figure 10 below, the coupling of the Bluetooth module HC-05 and the memory chip (AT45DB161D-SU) to the Arduino pins is shown. As seen, there is also the voltage regulator, LP2950ACZ-3.3V, in the circuit to regulate the high voltage coming from the analogue pin 11 to the serial input (SI) pin, which is between $2.5 - 3.6$ [V], as mentioned in the technical specification section 2.4.4. In this way, the voltage regulator prevents the high voltage from damaging the DataFlash.

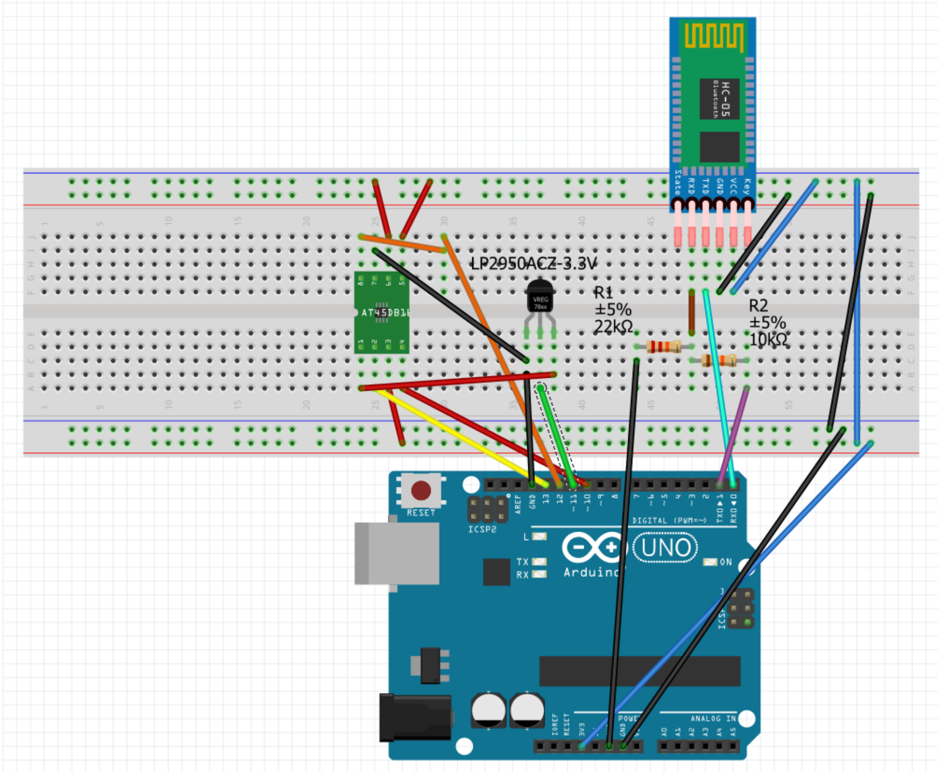

Figure 10: The DataFlash and Bluetooth are coupled to the Arduino Uno Rev3.

4.3 Measurments Results

The graphs below represent data collected from water by the device from different sources in Halmstad during a five months period. It is collected daily from January to May to see how water quality changes over time and seasons. In figure 11a and figure 11b, the quality of water is measured from tap water in school, i.e. the water we drink. The results show how tap water particle concentration follows some trend. Then a sudden increase happens in the middle of Mars, where the smallest particles of sizes $10^{-2} - 10^{0}$ [mm] increase rapidly in concentration.

For the river Nissan, the same thing is happening but slightly shifted in time; all the particles had a low concentration at the beginning, and then of a sudden, an increase of all the particles occurred at the end of April as seen in figures 11c and 11d.

Lastly, the particle concentration at the sea level in Halmstad is also heading upwards, but it is happening at a slower rate than the previous water sources. The concentration is still following the same course as in the other graphs and started to increase during the spring season, i.e. at the end of Mars.

In the beginning, during February month, the concentration of the red particles was not stable, and the other particles were not seen (figure 11e), exactly like all other graphs. Still, at the end of that month, the other particles started to appear, and the reason for that is explained in the discussion section below.

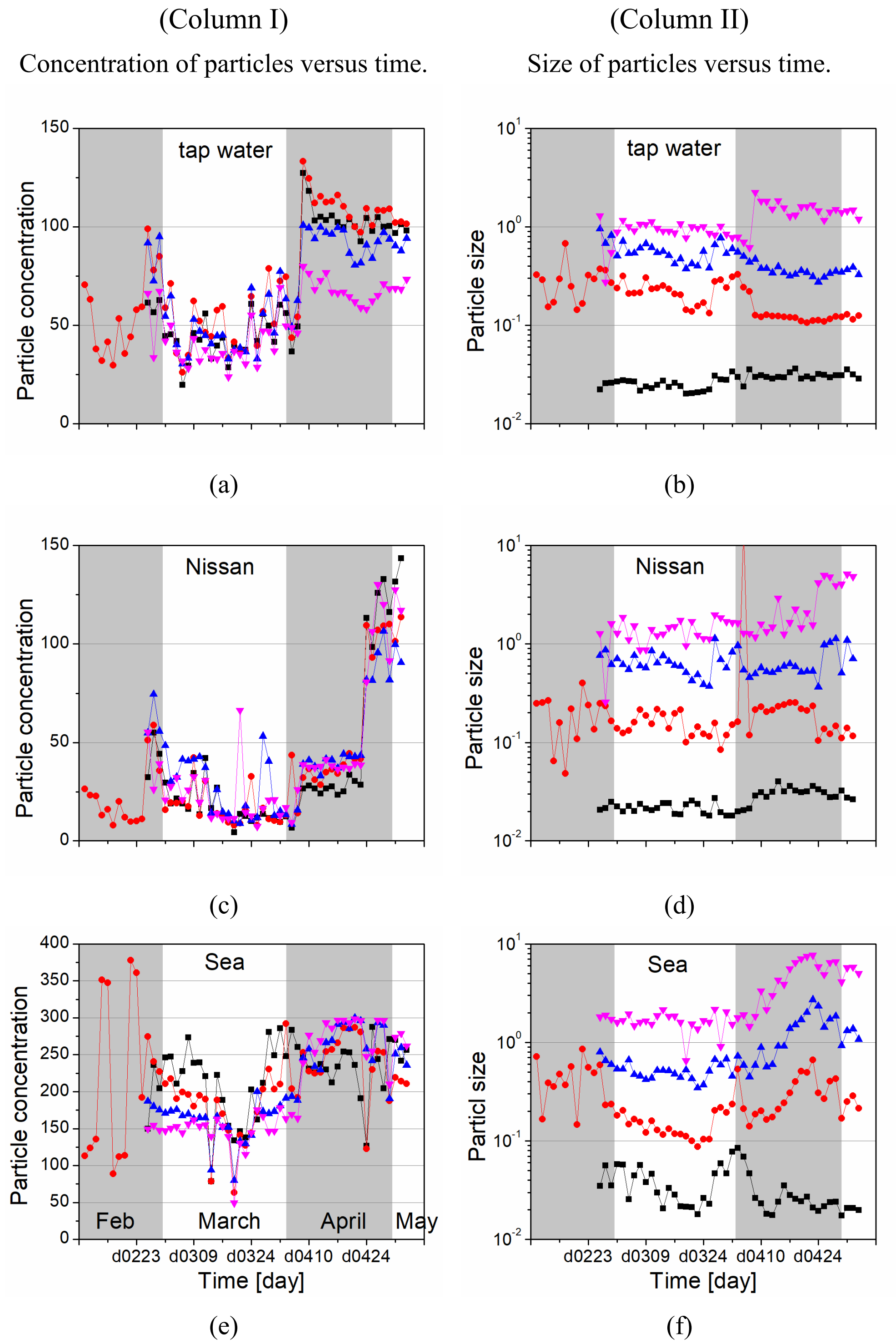

Figure 11: Water quality measurements from three different areas in Halmstad using the first prototype, from January to May 2023. Different colours correspond to different frequencies where the black particles are detected using 800Hz, orange 100Hz, blue 25Hz, and pink 6.25Hz.

5 Discussion

5.1 Discussion of Software Results

5.1.1 The Schematic and PCB

The creation of a schematic and PCB using OrCad was challenging, there are a lot of components, and many of them must be invented from the ground up. Considering all the time it took to get a student license and the time to solve errors with the paths as well as when the program shut down and the schematic vanished many times, a lot of time was spent to make everything work properly.

In the end, however, we managed to create the design for the PCB required at the beginning of this project. All the original components are included, and all the new components are put on the board, making the board ready to be mounted on an Arduino Uno Rev3, where there is a place for the Bluetooth chip ”HC-05” and the DataFlash ”AT45DB161D-SU”, and even the LCD screen ”TM12864FDCW”. The board dimension is 115$\times$80 [mm], which makes it very easy and comfortable to hold in hand despite all the components. Unfortunately, the board has not been printed and tested yet since the PCB printer in the school is not advanced, and we must therefore find other solutions to print it. Meanwhile, all the components are mounted on another prototype and a breadboard until we print this board.

5.1.2 The Programming of the Bluetooth and DataFlash

However, the programming of the Bluetooth chip and the memory was successful. After studying the pins needed to couple these two components to the Arduino, we started to program them using C language since we are familiar with this programming language, and it is the best language suitable for hardware and for other reasons mentioned in the previous sections. Now we can use Bluetooth and memory to send, receive and store data. Unfortunately, there is still one little problem left to solve; since the generation and calculations of the data are programmed in Python, we have to make an interface between the data from the Python code to the programs we have written in C to connect both systems.

5.1.3 The IoT System

Unfortunately, we could not implement an IoT system due to the time limit and because it needed a completely new project since this task is much more advanced than we thought. The plan is, therefore, to gain more software knowledge by taking some courses to be able to create and implement IoT systems to the device. Some of these courses we need are about creating cloud platforms, artificial intelligence, machine learning, and advanced analytics.

5.2 Discussion of Measurements Results

The measurements and the results from the device are some of the pieces of evidence that we have succeeded and completed our task of measuring water quality and improving the device. The main task of this project is to search for improvements and make the device better so we can measure accurately and efficiently. We have come very far in the process by choosing the electrodes and the power supply as PowerBank, the memory to store data, and the Arduino as a microcontroller to control components like Bluetooth. Through the PCB was created as an expansion to the Arduino; other features can be connected to make the device smarter. One of the plans that can be extended with our PCB is to connect a WiFi chip and a sim card to implement even more functions in the future.

5.2.1 Interpreting the Measured Results

As we can see from the results how the water quality is collected daily during a five months period of time. The reason that only the red particles are represented in the graphs at the beginning of every month is that the frequency sent to the electrodes was only 100Hz. After the code was modified to send five different frequencies, we started to discover other particles with different sizes in the water. That is why the other particles started to appear in February at the timeline because the code was improved.

One of the problems we faced during the measurements was the electrodes. The assumption made in the beginning was correct that the electrodes might corrode and oxidise due to the substances in the water. That is why proper maintenance of the electrode and changing them frequently is essential to get correct measuring results. We know from the theory section that copper is one of the most electro-negative metals. However, we also know from the same section that water contains many corrosive substances that would damage the copper electrodes. This is why some measurements are affected in the graphs, and the results would jump up and down because of something faulty in the electrodes.

Another problem with the electrodes is the gap between them. The distance between the electrodes is very important to get accurate measurements. If the gap is too small, they might end up connected to each other, which leads to a short circuit. On the other hand, if the distance is too large, the electric potential between them will decrease, leading also to incorrect measurements. This is why the electrodes should be designed at the nano-scale exactly like the nano-sensors we mentioned. That would lead to improving the accuracy and increase the surface of the electrodes were designed like two small combs facing each other. This topic needs an in-depth understanding of nano-technology to solve this problem and make the device as efficient as possible.

With that said, we know now that different substances and measurements affect the hardware of the device and especially the electrodes that should be changed regularly. We also know that very small detail in the construction of components can make huge differences in the measuring and the results. That is why more time is required to check the other components if they get affected underwater - when the device is placed there in the future - by the environment and the pressure with time. That is a topic for another research!

Lastly, we can see that the particle concentrations are increasing in all sources of water in Halmstad during the last months. This is an indication that something strange is happening. The particles are either increasing because of the season change, from winter to spring. Or it could be because something unknown is happening with the water, and more analysis and data gathering is required to find out more. After talking to the water treatment plant in Halmstad, they still do not know the reason. That is why we have to make more measurements to understand the issue and perhaps solve it before it's too late.

5.3 Social Requirements

Measurements for determining water quality. While it only generates general results for what particles are in the water, the device can tell and show that changes are happening over months. If the measurements can become more precise, the machine and method of measuring will be a great addition to other methods. It is also worth mentioning that, compared to other methods of measuring particles in water, this method is faster and cheaper than conventional methods. In our talks with Laholmsbukten VA, they said that taking a sample and sending it away for analysis can take one or more weeks, depending on how busy it is. Our non-specific measurements take around 5 minutes for four different measurements. Given that these measurements, in turn, are pretty high-speed, specified measurements may take longer if we are measuring nigger particles. Nonetheless, it would take less time than similar measurements today for a fraction of the price.

5.4 Comparing the Results and the Product

5.4.1 Comparing Results

Our device is unique and novel, and so are the data about ionic microparticles in water; thus, there are no other peer works that we can compare our work directly.

However, in figure 12, we show the measurement results on the water samples from Laholmsbuktens VA AB (LBVA) and the tap water from the F-building at Halmstad University. The two LBVA samples are raw water before processing and processed water. Our results clearly show a huge difference between raw and processed water.

Below is a table (table 4) of differences in the chemical analysis reports of raw water ("Råvatten") and processed water ("Dricksvatten"). It is observed that the chemical analysis reports do not show significant differences in many chemical contents except conductivity, pH-value, HCO_3 and Na.

There are, however, many indicators showing the validity of our work. We studied sea water, Nissan river water, and tap water in Halmstad. As generally well known, ion concentrations in seawater are very high, while watershed soils easily expose river water, thus always muddy, which cluster quickly individual ionic microparticles, making the river water less conductive [26]. All these are clearly reflected in our measurement data.

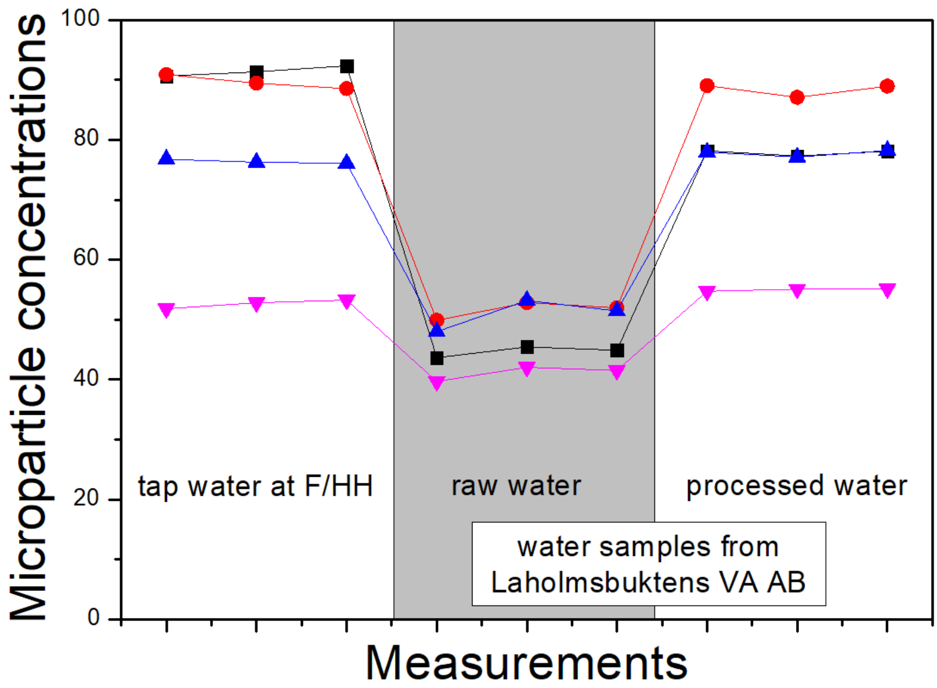

Figure 12: Microparticle concentrations from three different samples: Halmstad University and the other two are raw and processed water from LBVA. A huge difference is shown between raw and processed water where different colours indicate different sizes of particles; refer to section 2.3 — starting from the smallest particles: black, orange, blue, and pink.

5.4.2 Comparing to Other Products

Nevertheless, although the primary function is not similar to any other device's, the peripheral functions can be compared to other devices and methods mentioned earlier in this work. Even other water quality devices can be compared to ours from different perspectives. Below are some articles where similar quality devices were developed and their strengths and weaknesses.

In the work of Chandrappa, S. et al. [7], the authors mention that their device is built with a Raspberry Pi 2 [27], three analogue sensors (Temperature, Turbidity, and pH), analogue to digital converter (ADC), and Ethernet cable to transfer the data to PC. For the software, a data storage facility was implemented with an SMS gateway using the platform "Way2SMS.com" to notify users about sudden water quality variations every 5 minutes. Raspberry Pi, which has 1 [GB] RAM, replaces the need for external memory. Even the SMS gateway is much more efficient than any limited-range Bluetooth. However, the need for various sensors for different measurements is very costly. Moreover, since the device must be coupled with a PC during operation, it becomes unusable in underwater implementations.

R. P. N. Budiarti et al. [9], developed an IoT real-time water quality monitoring system using active and passive sensors, IoT, Raspberry Pi 3 Model B [27] as well as 4G communication. The sensors used are the active sensor, "YSI 600R", which measures parameters including Temperature, TDS, DO and pH, and the other passive sensor, the ”WTW IQ SensorNet 2020 XT”, which measures, among other things, the Turbidity, pH, TSS, DO and Chlorine. Several programs and databases had to be built to collect and use sensor data. Some are a database for IoT with a User Interface, MQTT protocol for data transmission, SQLite and MariaDB for data storage and processing, and even a web-scrapping program to get the data from the passive sensor. Even another application, ”Watermond”, was developed to store and retrieve data when connections to the internet fail. The connection to the internet to get real-time analysis is one of the advantages of this device; another is the retrieval of data if the connection is lost. The drawbacks, however, are the complexity of integrating the distinct systems and programming different programs. The system also wastes energy when both sensors measure almost the same parameters.

Another article by Akila U et al. [28], presented a system built on Arduino Uno Rev3, a Global System for Mobile communication (GSM) modem which uses SIM300 with RS232, and a sensing module consisting of a pH- and a Temperature sensor. When the system detects any deviation from the threshold values, pH $\neq 7$ or T $< 36°$, pollution is detected, and a message is sent using the GSM modem. The use of a GSM modem and the simplicity of coupling it to the Arduino Uno Rev3 is one of the advantages of this device. Some drawbacks are the limitations in measuring other substances other than Temperature and pH. It is not clear how data storage is done in the system.

Comparing all these devices to ours, we can conclude that there are things we can benefit from to develop our device further. For example, instead of focusing on implementing a Bluetooth and memory chip to the Arduino Uno, we could have used another advanced microcontroller that already has these features. In that case, we would have focused on advancing the device further by implementing IoT or a GSM to send information with an unlimited range and users. If we had used a Raspberry Pi microcontroller, the programming and the integration of different systems would become easier since only Python is used instead of the two languages we used (Python and C). Those things are to consider the next time the device is developed. However, since the unavailability of Raspberry Pi in the market when this project started, the Arduino Uno Rev3 was the only option.

From another view, some of our device’s functions are better than those mentioned earlier. All the other devices use different sensors to detect specific pollutants in water, yet we know from section 2.2.1 that water contains many particles that would not be detected if we only relied on specific sensors. That is why a universal sensor is required to detect all sorts of particles despite their size or type. That is why our device is one step ahead regarding the sensors used and the method of detecting pollutants. Another advantage of our device is that it is very energy-efficient due to carefully picked components; thus, it is independent of any coupling to the PC or adapter. Using the PowerBank, the device will operate independently for a long time, making it suitable for underwater implementations.

5.5 Answers to General Questions

Q: *How can we improve the device, make it usable, and make the measuring of freshwater easier?*

A: We can improve the device in many ways to make it more user-friendly. By adding features like memory, wireless communication, making the device waterproof, and connecting the device to wifi and a cloud to maintain different functions, all those things can improve usability and make the device much more functional.

Q: *Can different dissolved materials in the water affect measurement results and give incorrect readings?*

A: Yes, as we have seen, all elements and materials react with substances in water and oxidate, especially because water is acidic. If we use the same electrodes, despite the material used, for a long time, the measurements will be affected, and we will have incorrect readings.

Q: *Could different qualities of water spoil the device's electronics or hardware over time?*

– Which material will get spoiled and how?

– Shall we change the material every once in a while, or shall we protect the material somehow?

A: Yes, since different water contains different substances, some of which are acidic and others are basic. All of these are corrosive and could affect all materials in contact. That is why all materials exposed to water, like the sensors, must be changed regularly. We should have more knowledge to figure out how to protect different water materials for a long time.

Q: *Does the measured data corroborate and correlate with other reliable sources?*

– If not, is the device defective, or is there anything wrong with it?

– How can we interpret the data considering all the improvements on the device?

A: According to the professor, the founder of the device, the measurements correlate with other reliable sources like Laholms Buktens Vatten AB. Unfortunately, we could not test the final version of the improved device as a whole, but the prototype we made first does corroborate and correlate with reliable sources.

5.6 Answers to Technical Questions

Q: *Can we implement a low-energy memory chip into the device to store measured data?*

A: As you have seen in the results, we implemented and tested the efficient DataFlash ”AT45DB161D-SU” successfully. It can store data, but the only problem is integrating the two systems since they use different programming languages - C and Python - and we could not connect them yet.

Q: *Can we add a Bluetooth chip to send and receive the data at a range of at least 10m?*

A: Yes, that task was also successful. The memory and Bluetooth were coupled to Arduino Uno and programmed using C. The program used to measure water quality is Python. That is why we have to solve the problem and connect the two systems, even though every system works successfully separately.

Q: *Can we implement IoT to the device to put it later in the water and control measurements from a distance above water?*

A: Adding the Internet of Things (IoT) requires much knowledge in software, which we are not capable of yet. That is why we could not implement Iot to control the device at a distance. We have first to take more courses before we can solve this problem.

Q: *Can we create a PCB expansion to a microcontroller to include all the new functions and added features on the same board?*

A: Yes, we created that PCB and made it suitable for the Arduino Uno. The PCB was almost successful; only a few corrections are needed before it can be useful. Corrections like the wiring and pad sizes. We could only manufacture one complete PCB with all the added parts during the project, as the ordering and arrival times are about three weeks. If we had more time, we would adjust and edit the PCB further to correct all the small mistakes and order a functional one again.

Q: *Can we find a solution to supply the device and all electronics with power without having it coupled to a PC?*

A: There are a few solutions to supply the device with power, like batteries, solar cells, PowerBank etc. We chose a powerful PowerBank since it was the most efficient and easiest solution for now. The one we chose is powerful and can supply the device for a long time since all components are also chosen to be efficient.

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6 Conclusion

The purpose of this project was to develop and improve a water quality measuring device that uses an entirely new and advanced method to measure the quality of water. The method used to calculate the quality is based on advanced physics, chemistry and electronics - yet the device hardware and the way it operates is very simple. In this project, we are developing the hardware and software of the device by implementing new features to simplify the measuring and collecting of data. A few chips are added to the device, like Bluetooth, DataFlash, a power supply in the form of PowerBank, a microcontroller Arduino Uno, an LCD screen and more. That is why a PCB was also designed to include all the new, and the old, components in one device. Data was also gathered during the whole time this project took place, and the data is represented in graphs indicating some changes in Halmstad's water quality recently.

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Appendices

Table from LBVA

Below is a table of differences in the chemical analysis reports of råvatten för dricksvattenproduktion (”raw water for drinking water production”) (Rapport Nr 22349367) and dricksvatten för allmän förbrukning (”drinking water for general consumption”) (Rapport Nr 22404794) from LBVA, Henrik Kjellgren (henrik.kjellgren at lbva.se, 2023-04-23).

Table 4: Principal differences in the chemical analysis results of Råvatten för dricksvattenproduktion (Rapport Nr 22349367) and Dricksvatten för allmän förbrukning (Rapport Nr 22404794), Laholmsbuktens VA Vattenverket.

Analys/Undersökning av	Råvatten	Dricksvatten	Enhet
Uran, U	$< 0.01 \pm 0.006$	0.012 ± 0.006	µg/L
Turbiditet, FNU	$< 0.1 \pm 0.12$	0.17 ± 0.12	FNU
Nitratkväve, NO_3-N	0.81 ± 0.12	0.77 ± 0.12	mg/L
Nitrat, NO_3	3.6	3.4	mg/L
Fluorid, F	0.062 ± 0.10	0.052 ± 0.10	mg/L
Sulfat, SO_4	7.4 ± 1.1	7.2 ± 1.1	mg/L
Kalcium, Ca	6.2 ± 0.934	6.6 ± 0.99	mg/L
Kalium, K	0.6 ± 0.1	0.7 ± 0.1	mg/L
Magnesium, Mg	2.7 ± 0.41	2.9 ± 0.44	mg/L
Arsenik, As	0.026 ± 0.015	0.023 ± 0.015	µg/L
Krom, Cr	0.21 ± 0.032	0.29 ± 0.044	µg/L
Aggressiv kolsyra, CO_2		< 5	mg/L
Bly, Pb	0.21 ± 0.032	0.049 ± 0.012	µg/L
Radon, Rn	17.7 ± 5.00	$< 10 \pm 5.00$	Bq/L
Konduktivitet 25°C	9.85 ± 0.985	17.2 ± 1.72	mS/m
pH vid 20°C	6.3 ± 0.2	7.9 ± 0.2	
Alkalinitet, HCO_3	22 ± 3.3	67 ± 10	mg/L
Natrium, Na	6.9 ± 1.0	26 ± 3.9	mg/L

The Barrel Connector

Barrel connectors usually provide two connections; the pin in the middle is mostly the higher voltage, while the sleeve outside is the lower one or ground. Figure 13 illustrates the standard polarity of the barrel connector. There are two genders of barrel connectors. The male (Plug) is known to have a pin at the centre, and this connector is mainly attached to a wire, while the female (Jack) is the mating connector that can be mounted on PCB or panel. Figure 14 gives an example of each [29, 30].

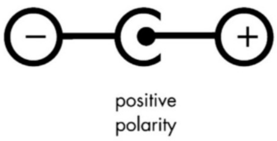

Figure 13: Positive polarity of a barrel connector [30].

Figure 14: Example of male and female barrel connectors [29].

The ”142-04-863” power plug has a 2 [m] long cable and a diameter of 5.5 [mm], and the ”142-05-126” is a chassis-mounted power jack with a diameter of 5.5 [mm]. These connectors are good matching pairs and can operate in 12 Volt DC and $0.5 - 1$ Ampere [31].

Command Tables for DataFlash

Table 5: Tables of special commands for DataFlash.

Command	Opcode
Main Memory Page to Buffer 1 Transfer	53H
Main Memory Page to Buffer 2 Transfer	55H
Main Memory Page to Buffer 1 Compare	60H
Main Memory Page to Buffer 2 Compare	61H
Auto Page Rewrite through Buffer 1	58H
Auto Page Rewrite through Buffer 2	59H
Deep Power-down	B9H
Resume from Deep Power-down	ABH
Status Register Read	D7H
Manufacturer and Device ID Read	9FH

Table 6: Tables of read and write commands for DataFlash.

Command	Opcode
Main Memory Page Read	D2H
Continuous Array Read (Legacy Command)	E8H
Continuous Array Read (Low Frequency)	03H
Continuous Array Read (High Frequency)	0BH
Buffer 1 Read (Low Frequency)	D1H
Buffer 2 Read (Low Frequency)	D3H
Buffer 1 Read	D4H
Buffer 2 Read	D6H
Command	Opcode
Buffer 1 Write	84H
Buffer 2 Write	87H
Buffer 1 to Main Memory Page Program with Built-in Erase	83H
Buffer 2 to Main Memory Page Program with Built-in Erase	86H
Buffer 1 to Main Memory Page Program without Built-in Erase	88H
Buffer 2 to Main Memory Page Program without Built-in Erase	89H
Page Erase	81H
Block Erase	50H
Sector Erase	7CH
Chip Erase	C7H, 94H, 80H, 9AH
Main Memory Page Program Through Buffer 1	82H
Main Memory Page Program Through Buffer 2	85H