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Using Multiflexmeter system on chip sensor

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Abstract

Waterschap Scheldestromen is curious about a 4-electrode conductivity sensor from Interuniversity Microelectronics Centre(imec), which provides a larger working range than Waterschap's commercial 2-electrode sensor. The project aims to test the performance of this imec sensor, and couple it with Arduino for direct observation of conductivity as preparation of future online measurement under the premise of controlling the cost of coupling part within €100.

The project conducted under the guidance of V-model approach. It broke the design into small pieces to achieve the final work. To adapt the methodology to the condition of this project, V-model was used once in performance investigation and once in coupling design.

The results indicate that the obtained imec sensor can give out good measurement values in a solution of 270-13000μS/cm with an accuracy of 10%-30% and stability of less than 5%. The solutions other than 50-13000μS/cm are unable to measure. It does not match the performance provided by imec. It implies that the obtained sensor is damaged to some extent. Further development and more tests are needed to confirm the usability in the future. The results also show a great success in coupling system design, which can show conductivity and temperature directly via LCD and show all the outputs given by the sensor in the serial monitor of Arduino IDE.

These results suggest that imec new generation conductivity sensor needs to be further optimized to improve its robustness and reliability. In addition, the sensor will have the opportunity to be integrated into the Multiflexmeter system in the future for continuous online measurement.

Foreword

Before you lie in the thesis report “Using Multiflexmeter system on chip sensor”, the basis of which is a new generation conductivity sensor based on the principle of 4-electrode from Interuniversity Microelectronics Centre(imec). It has been written to fulfill the graduation requirements of Engineering-Mechatronics Bachelor Program at HZ University of Applied Sciences(HZ). I was engaged in researching, developing, and writing the thesis report from February to July.

The project was driven at the request of Waterschap Scheldestromen, where I undertook my bachelor graduation internship. My research question was formulated together with my in-company mentor, Jos Goossen. Since the project was related to a third party, both researching and communicating are significant. Thanks to the patient guidance of Jos Goossen and my tutor from HZ, Willem Haak and Connor Reekers, I found out the pertinent information as to the assignment, optimized my written documents, and kept in contact with imec engineer, Thijl Boonen, smoothly for more questions regarding the new sensor.

I would like to thank my in-company mentor and the engineers from imec first for their excellent match-up and timely support amidst the process, without whose cooperation I would not have been able to conduct this project.

I also hope to thank Willian Haak, my first examiner, who gave me plenty of advice on documents, time arrangement, and instruction on applying V-model.

To my colleagues at Waterschap, especially Yuyao Tian, Xianglong Li, Chong Zhan, Pinqi Guo, I would like to thank you for giving me some extra tips during the whole project weekly. It was always worth sharing progress and ideas with you.

I benefitted from sharing my anxiety with my friends and family. Whenever I am anxious about my rate of progress, your words released my pressure. My parents deserve a specific thank-you: your wise advice and friendly words have served me as always.

I hope you enjoy your reading.

Feifan Du

Vlissingen, July 7, 2021

List of Abbreviation

ACC	Accuracy
Bd	Baud
℃	Celsius
Cond.	Conductivity
EC	(Electrical) Conductivity
imec	Interuniversity Microelectronics Centre
I	Current
mins	Minutes
mS/cm	Milli siemens per centimeter
M	Molar mass
MFM	Multiflexmeter
P	Power
P_{EC}	The phase of the EC measurement
ROD	ROD error
RSD	Relative standard deviation
S	Sample standard deviation
Sb	Stability
ST	Sensitivity
Temp cond.	The temper corrected conductivity
T_{st}	Water temperature (sensor-tested)
T_u	Water temperature(unknown)
U	Voltage
WC	Water with different salt concentrations
WR	Working range
μ S/cm	Micro siemens per centimeter
Ω	Ohm

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Chapter 1 Introduction

In this section, the basic information of the project has been introduced. It includes the company background, the problem analysis, objectives, and research question.

1.1 Background

1.1.1 Company background

Waterschap Scheldestromen has existed since 1st January 2011 in Zeeland as a government agency. Regarding main products, the company takes charge of safe dikes and dunes, clean surface water, safe roads and cycle path, and the right amount of water in the ditch (Scheldestromen, 2020).

1.1.2 Multiflexmeter Project

The Multiflexmeter (MFM) is a comprehensive water measurement device being developed by a project team from Waterschap Scheldestromen. The device implements multiple measurements on water continuously, for example(Figure 1), the water level, temperature, and salinity of the water, and transmits the result online(IoT).

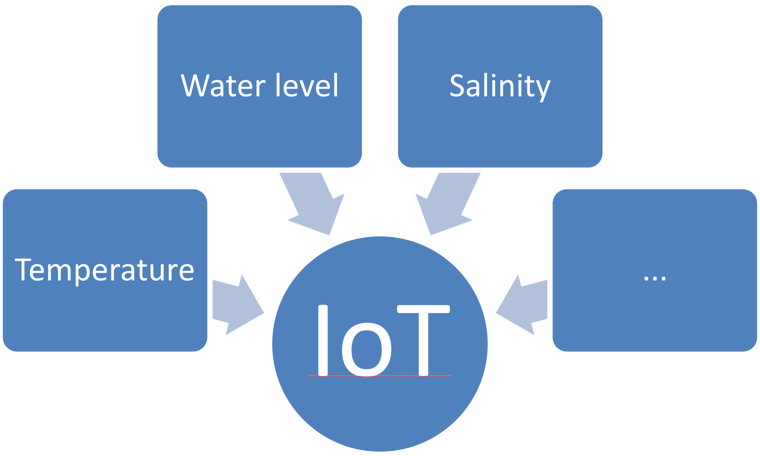


Figure 1 The measuring parameters of the device of Multiflexmeter.

Based on its modular design, more powerful functionalities are possible to access in the future. It follows robust, energy-efficient, and cheap principles(Figure 2), which makes it cost-effective.

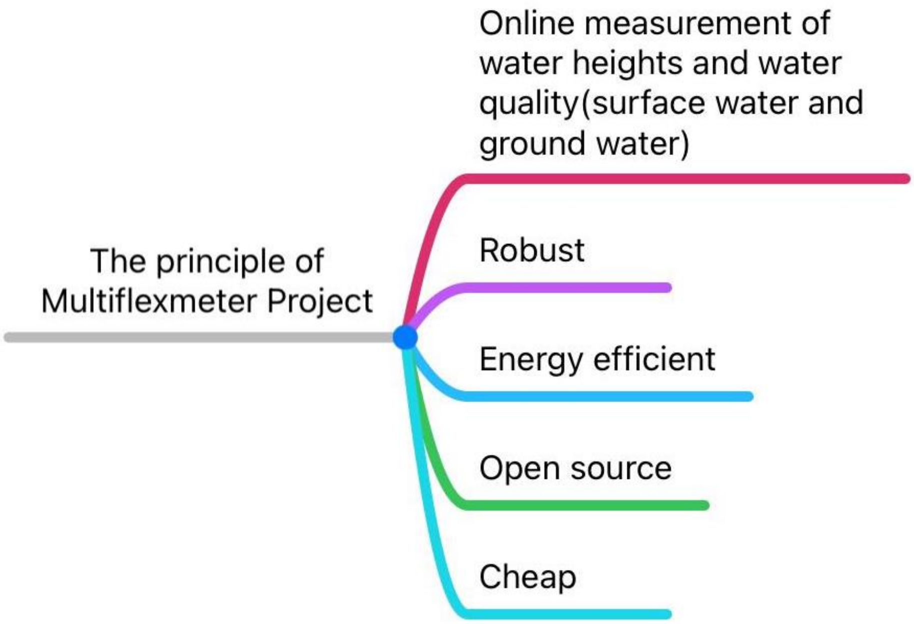


Figure 2 The principles of Multiflexmeter(MFM) Project

The birth of Multiflexmeter is based on the universal and accessible electronic platform "Arduino". Multiflexmeter is completely open-source, the design is freely available to everyone, and anyone can benefit from it. For more information, please visit *https://www.multiflexmeter.nl/*.

1.2 Problem analysis

1.2.1 Assignment background

Since most of the land in the Netherlands is below sea level, the ocean can easily pollute the quality of inland water and soil through salt intake. Thus, salinity is one of the most capital water quality parameters for Zeeland, which is derived from the measurement of the electrical conductivity(EC) of water typically.

Due to the specific topography of the Netherlands, it has an urgent usage of quality data enabled by a large-scale sensor network to monitor. MFM project is induced by the need of measuring levels and quality of water online in a cheap yet advanced way in Waterschap. In previous graduation assignments under MFM project, the students have done quite a lot of researches on developing cheap and robust online measurement methods. In 2018, this resulted in a measurement system that uses a Europlug coupled to a 555 timer circuit and a microcontroller. The measured data will be transmitted and received by using the Internet of Things(IoT).

Waterschap has already devised a 2-electrode system for the current MFM-EC so far(Figure 3). However, it only enables to measure relatively low salinity level which sets the maximum at 1000 mg chloride/liter, which is far from enough to measure the conductivity from demineralized water to seawater.

Figure 3 Close-up of 2-electrode sensor

At present, Waterschap intends to find a way to enhance the working range of the conductivity sensor they applied. Coincidently, the 4-electrode system that Waterschap has not yet used can provide a larger working range than their commercial 2-electrode sensors. To be more specific, 4-electrode will not produce a polarization effect as 2-electrode does which can affect the accuracy of conductive probes to restrict the measuring range. Duo to this character, the 4-electrode EC-sensor can measure within a larger salinity range theoretically. Luckily, the new generation of sensors provided by Interuniversity Microelectronics Centre(imec) Company is based on this technology.

Imec, which is one of the leading organizations working in the field of 'lab on a chip', supplies a new chip(Figure 4) in the latest EC-sensor but still needs further practical verification.

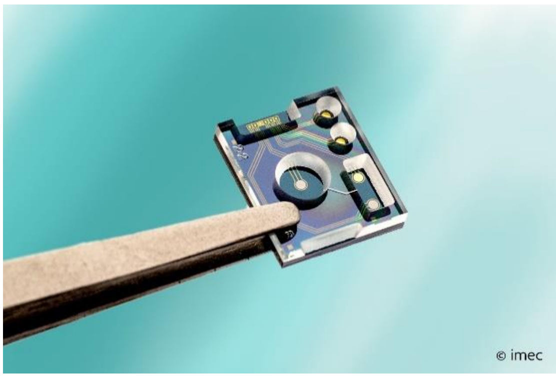


Figure 4 The new chip from imec

Although Waterschap has possessed a relatively commercial version of 2-electrode EC-sensor right now, 4-electrode sensor from imec has many interesting and potential possibilities, for instance, lower price, larger working range, which is worth trying.

1.2.2 Problem statement

Waterschap intends to investigate the performance(Figure 5) of this imec new generation 4-electrode EC-sensor and how to couple this EC-sensor to the microcontroller as preparation of future online measurement in MFM-system.

Figure 5 4-criteria of performance of EC-sensor to be measured

Figure 6 shows the dominating challenges of the project.

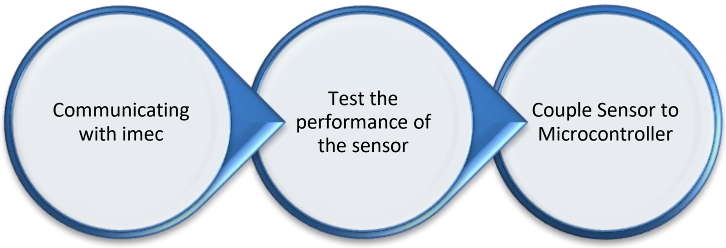


Figure 6 The dominating challenges

Figure 7 The USB-connected imec EC-sensor

For now, imec has worked out USB-connected for the latest EC-sensor(Figure 7). The student needs to do an amount of research and communication with imec to construct the cornerstones of performance inquiry and coupling system build-up. By utilizing the USB-connected device from imec, the performance of the sensor can be investigated first via RealTerm. If the sensor can work properly, it is also imperative to compare the performance of the sensor with that of the commercial EC-sensor.

After investigating the performance of the EC-sensor, the student shall discuss the possible interface methods for microcontroller connection with imec and build a design prototype. MFM projects generally use Arduino as the system's microcontroller, so the coupling with Arduino shall be investigated first. If it fails, the failure reasons and recommendations regarding the replacement microcontroller shall be stated.

In a word, the student is going to deliver the following deliverables:

- The performance of the new generation EC sensor.
- Designed prototype which aims to couple the new generation EC-sensor with Arduino.

1.2.3 Requirements

Table 2 illustrates the requirement list from the client, Jos Goossen. The priority has been split into three levels: 1,2 or 3. 3 possesses the highest priority(Table 1).

Table 1 The meaning of 1,2,3 priority

Priority	Meaning
3	The results that clients value most. These items should be investigated and guaranteed first.
2	Subordinate information that clients care. If time is limited, it can be optional.
1	Expected to reach, but not the focus of the project

Table 2 Requirement list(3 possesses the highest priority)

Requirement list			
Items	Aspects	Details	Priority
The entire system	Working	The whole system containing a microcontroller, connected part and output can work properly to test the conductivity of the water.	3
The connected part	Price	≤€ 100	1
Output	Sensitivity	Find out	2
	Accuracy	Find out	3
	Working range	Find out	3
	Stability	Find out	3

※The connected part: Excluding the price of the controller and sensor.

1.3 Research question

In this chapter, the main question and sub-questions will be defined.

1.3.1 Main question

The main question is derived from the problem analysis:

What is the performance of the new-generation 4-electrode conductivity sensor, and what is the coupling design on the premise that the cost of the coupling part is controlled within €100?

1.3.2 Sub questions

The sub-questions are derived from the main question and problem analysis:

Measurement stage:

a) What are the system description and the test plans for the measurement of the performance?
b) What are the test results regarding measurement?

Coupling stage:

c) What are the system descriptions and the test plans for the coupling, its sub-systems, and its components?
d) What are the test results regarding coupling for the components, the sub-systems, and the system?

1.4 Objectives

The following items are the main objectives extracted from current known requirements that should be achieved at the end of the project.

i. Working

At the end of the project, a designing prototype of the new 4-electrode EC-MFM sensor shall be shown as a proof of concept. To verify the function of the prototype, a demonstration will conduct eventually by video or a live experiment.

ii. The performance of EC-sensor

The performance of the new generation sensor especially the working range, stability, accuracy shall be found out.

iii. The price

The cost of the connection part shall lower than €100.

1.5 Boundaries

- ✧ The project will not take the networking function into account.
- ✧ The project will not conduct field experiments, just indoor tests.
- ✧ Optimizing the performance of the EC-sensor is out of the project's hands.
- ✧ The project will not take volume production into account.

Chapter 2 Theoretical framework

Chapter 2 is the theoretical framework of this project. The search plan can be found in >>Appendix 9: Search plan.

2.1 Arduino microcontroller

Due to the coupling task amidst the project, it is vital to consider the microcontroller. Since the Multiflexmeter(MFM) generally applies Arduino microcontroller, the project will test the compatibility by Arduino first. If it fails, Arduino will be replaced by another proper type of microcontroller.

In this chapter, a specific introduction of the Arduino microcontroller will be presented.

2.1.1 Overview

Arduino is such an open-source electronics platform constructed by easy-to-use hardware and software. It implies that everyone can manufacture the circuit boards and come to the website *https://www.arduino.cc* (Banzi, Arduino, 2021) and download the shared resources out of charge. This is a positive operating pattern to push the innovation into a brand-new step. It is widely used in many fields, from toys to satellite devices.

2.1.2 Hardware

The Arduino circuit boards are equipped with a set of digital and analog I/O pins that can be connected to various expansion boards or breadboards (shield boards) and other circuits.

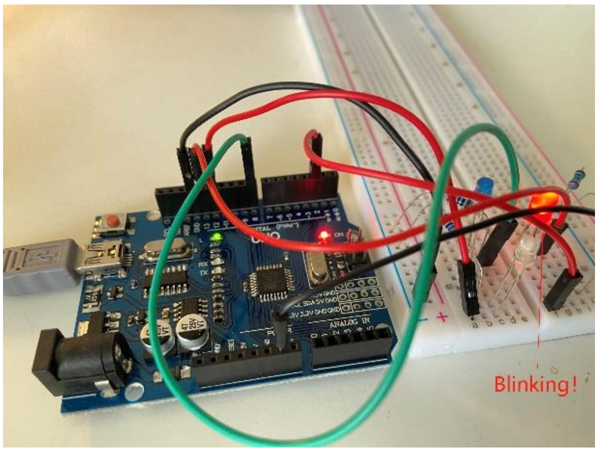


Figure 8 Blink test

As the leftward illustration(Figure 8), use breadboards, LED lights, resistances, and DuPont cables to form a simple circuit, transfer the written code to the circuit board via USB, then launch by the power supply, the function can be realized instantly.

2.1.2.1 Arduino main board

When it comes to the mainboard, the Uno(Figure 9) and the Nano(Figure 10) are two of the most classic and general editions.

Figure 10 Arduino Uno (Banzi, Arduino, 2021)

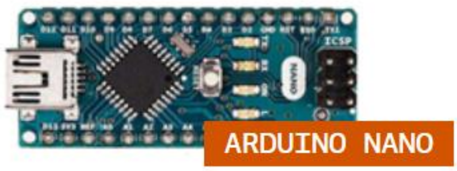


Figure 9 Arduino Nano (Banzi, Arduino, 2021)

It is worth mentioning that the Nano has the same functionality as the Uno more or less. It is cheaper and compact with two extra analog pins as shown in Table 3. That is the reason why the Nano is a better choice unless the user is a novice. However, on account of compatibility, the Nano is much less accessible with a lot more peripheral hardware and online support than the Uno.

Table 3 The specification of Arduino Uno & Nano

Specification	Arduino Uno	Arduino Nano
Dimension	6.9cm x 5.3cm	4.3cm x 1.7cm
Processor	ATmega328P	ATmega328P
Input Voltage	5V/7-12V	5V/7-12V
Speed of CPU	16MHz	16MHz
Analog I/O	6/0	8/0
Digital IO/PWM	14/6	14/6
EEPROM/Sram[kB]	½	½
Flash	32	32
USB	Regular	Mini
USART	1	1

Among a variety of pins on Arduino board, UART communication can be realized by pin "Rx0" and "Tx1". Tx is for sending the serial data, and Rx is for receiving the data(Figure 11).

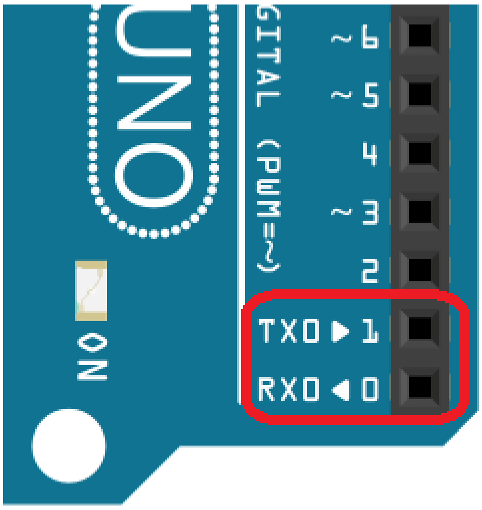


Figure 11 Arduino Uno TX/RX pins

2.1.2.2 Related hardware

i. LCD-I2C display

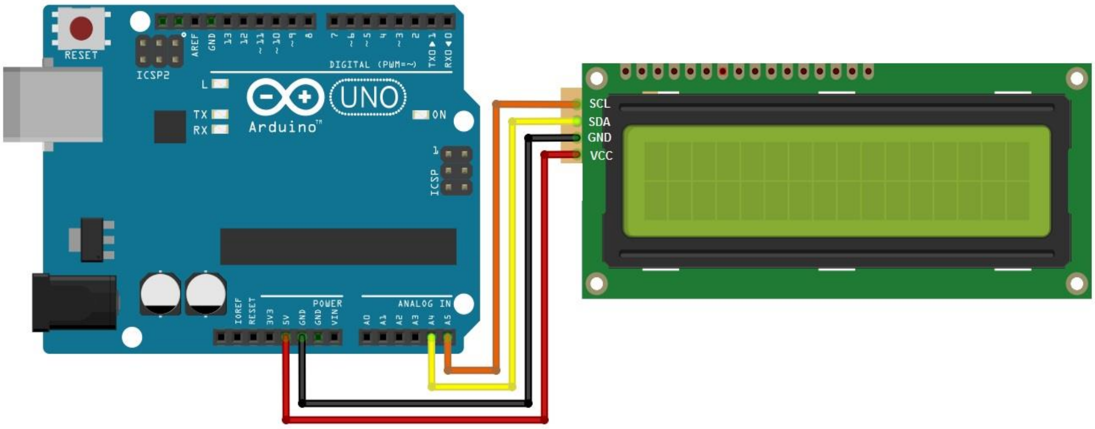


Figure 12 Wiring diagram of LCD-I2C example (Sharma, 2018)

Figure 12 is about the wiring diagram of LCD-I2C. Find the code in https://arduinogetstarted.com/tutorials/arduino-lcd-i2c (ArduinoGetStarted.com, 2021). Table 4 is about the unit’s display on LCD-I2C:

Table 4 Correspondence between character patterns and Character codes (HITACHI, 1998)

ii. BOB-11189

The imec EC-sensor can also be used without USB and directly with RS-232. The output is the same, so it can be parsed and processed (Boonen, The work instruction of Waterproof imec EC-sensor module, 2021).

Most controllers currently have built in UART protocol that can be used for receiving and transmitting data serially. So as Arduino. UART transmits one bit at a time at a specific data rate. And this approach of serial communication is sometimes mentioned as ‘TTL Serial’, also named ‘transistor-transistor logic’. Serial communication at a TTL level always holds between 0V and V_{cc}, normally 5V or 3.3V. A logic low is 0V, while logic high is expressed by V_{cc}. However, RS-232 standard logic high is from -3V~-15V, while logic low is from 3V~15V (jimblom, 2010). Figure 13 explain intuitively.

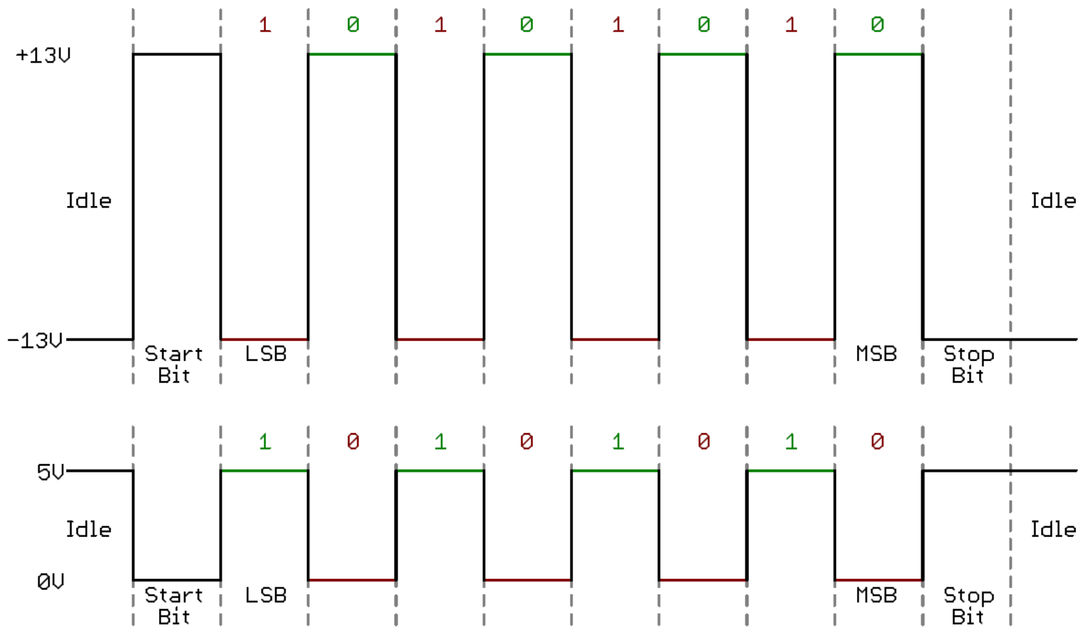


Figure 13 This timing diagram of both a TTL (bottom) and RS-232 signal sending 0b01010101 (jimblom, 2010)

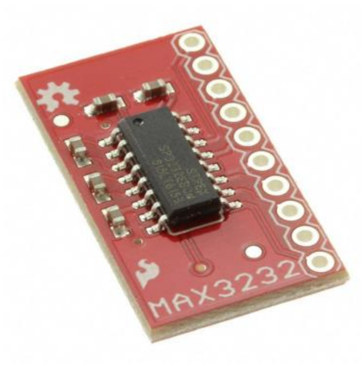


Figure 14 BOB-11189

To convert RS-232 standard into TTL level, BOB-11189(Figure 14) developed by SparkFun Electronics is a good choice (Digi-Key, 2021).

This is an RS232 converter IC that can run at 3V and communicate with 5V logic. This product uses the SOIC package MAX3232 and disconnects all pins required to set RS232 to TTL connection. In addition, the necessary 0.1uF charge pump capacitor is included. It is worth mentioning that because the operating voltage range of MAX3232 is larger than that of 232 (3-5.5V), 3.3V and 5V projects can both use it(Figure 15).

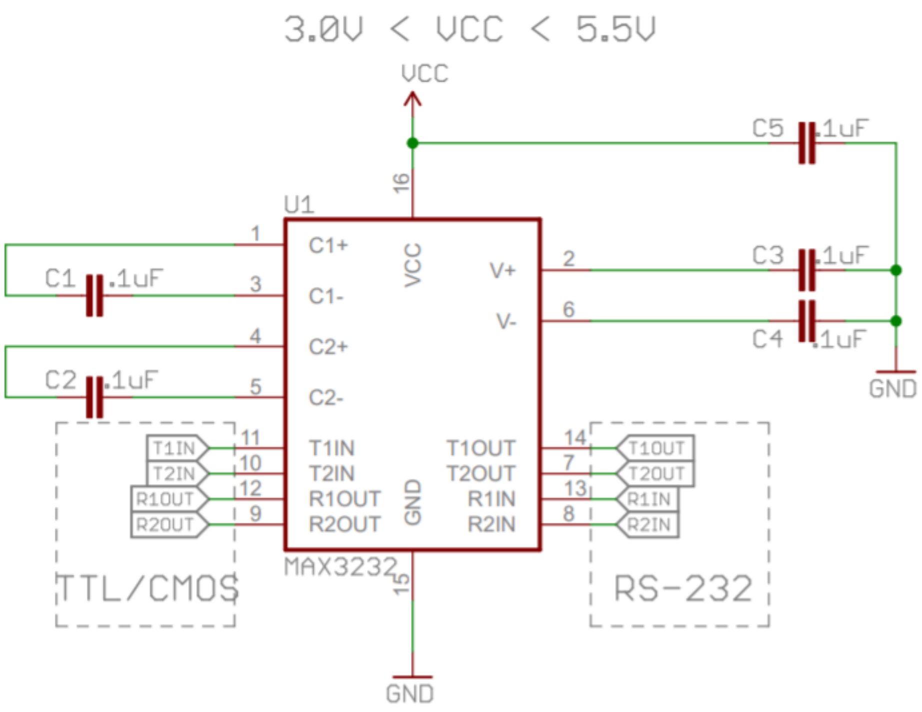


Figure 15 Principal diagram of BOB-11189

2.1.3 Arduino IDE

As shown in Figure 16, the Arduino integrated development environment (or Arduino IDE) operates can upload programs to the connected control board and communicate with the control board.

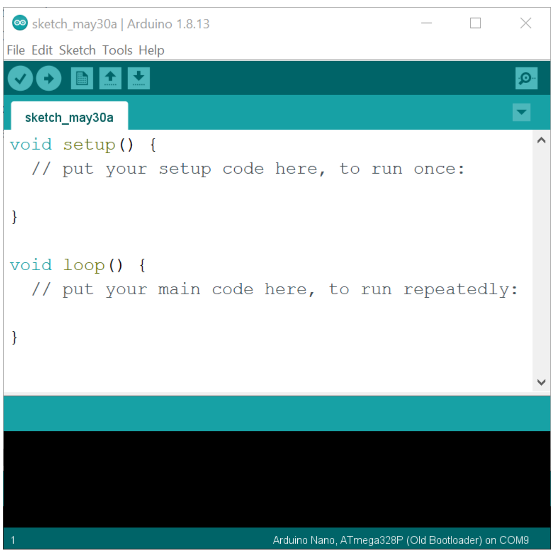


Figure 16 Arduino IDE interface

2.2 EC-sensor

The section will present specific information referring to the new generation EC-sensor supplied by imec.

2.2.1 The demo setup of the new EC-sensor

Figure 17 illustrates the entire sensor which points out different parts, respectively. The circuit board on the top is the readout device. The demo setup of the new EC-sensor can only go into the solution up to the “water line”. The readout processed the analog signals of the sensors and turns them into a digital output. The output is a csv string, and it can be guided into the laptop via RealTerm and processed in Excel. Find the information of data collection and processing in Appendix 2: Data collection and processing.

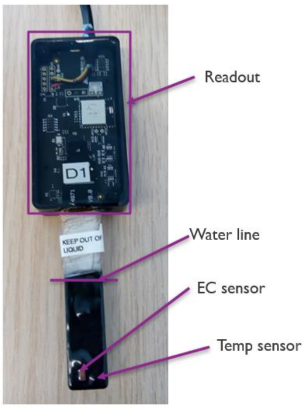


Figure 17 The new generation 4-electrode EC-sensor from imec

The EC sensor is the shiny part in Figure 18. It is forbidden to touch it with your fingers and wipe it dry with a paper towel. When not in use, the test tube must be put back on the sensor rod. The small bump next to the EC sensor is the temperature sensor, which is completely covered by black epoxy (Boonen, How to use the new generation conductivity sensor from imec, 2021).

Figure 18 The enlarged image includes EC sensor(the left shiny one) and temperature sensor(the right bump in red circle)

2.2.2 Improved version

Since the version mentioned in Chapter 2.2.1 The demo setup of the new EC-sensor was broken, the technical engineer from imec sent another more practical version(Figure 19), which is waterproof. Due to the similar structure and the same function, a detailed description will be omitted here.

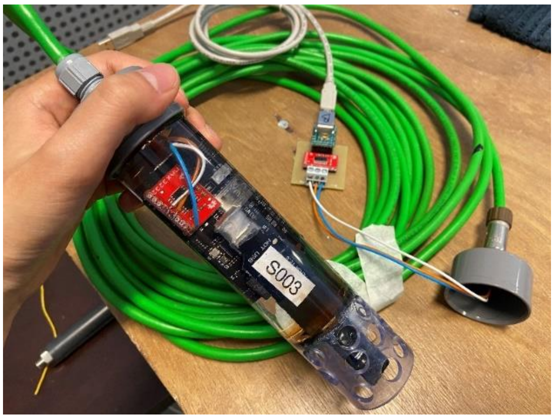


Figure 19 The waterproof version of EC sensor

As illustrated in Figure 20, the cable colors are (Boonen, The work instruction of Waterproof imec EC-sensor module, 2021):

- White is ground.
- Orange is 5 V.
- Blue is data out. (There is no communication to the readout)

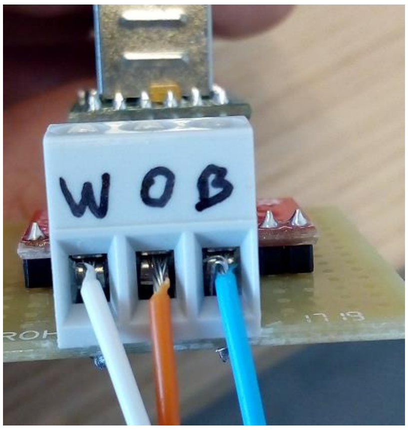


Figure 20 The sensor's cable

2.2.3 The specific part to be designed

Waterschap would like to replace the readout device with its own design. It implies that the ultimate goal in connecting to Arduino is to start at the red line(Figure 21). By inquiring the imec engineer, the design from the red line to the green line took immense efforts from a team of engineers in imec, it is impossible to improve and design it within a graduation bachelor project (Boonen, The work instruction of Waterproof imec EC-sensor module, 2021). On account of the advice of the imec engineer, the project will conduct the design from the green line.

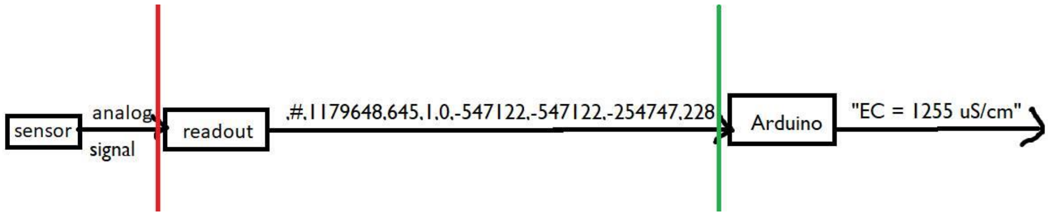


Figure 21 Data procedure inside of the imec EC-sensor

2.2.4 Electrical conductivity calculation

The output of the sensor looks like this:

1595007477,#,1179648,645,1,0,-547122,-547122,-254747,228,

1595007477 is the unix time stamp and # is the to indicate a new line. The information after # is important, which has been explained below (Boonen, How to use the new generation conductivity sensor from imec, 2021):

1	2	3	4	5	6	7	8
1179648	645	1	0	-547122	-547122	-254747	228

1. The ID of the readout (*not relevant*)
2. Raw resistance of the EC measurement in ohm
3. The phase of the EC measurement.
   The phase must be between:
   - Between -10 and 10
   - Between -190 and -170
   - Between 170 and 190

   If not, the measurement is invalid.
4. The ROD errors(ROD). If the error is not 0, the data is invalid. The actual error value in only relevant for troubleshooting by imec.
5. Voltage A in mV *(not relevant)*
6. Voltage B in mV (*not relevant)*
7. Voltage C in mV (*not relevant)*
8. Temperature in °C * 10. (So, in the example the temperature is 22.8 °C)

If the phase is in the right range and the error is 0, the EC can be calculated. If the KCell of the sensor is 0.81, to get EC (µS /cm)**:**

$$EC = 810000 \div the\ temp\ corrected\ impedance$$

Use a temperature correction of 2 %:

$$The\ temp\ corrected\ impedance = Imp + 0.02 \times Imp \times (Temp - 25)$$

Imp = Raw resistance of the EC measurement in ohm

Temp = Temperature in °C * 10

In the example:

The temp corrected impedance = *645 + 0.02 * 645 * (22.8 - 25) = 616*

The temp corrected EC = *810000/616=1314 µS /cm*

2.2.5 Conductivity measurement

2.2.5.1 The definition of conductivity

Conductivity is the ability of the solution to conduct electrical current. Ions’ solution such as dissolved acids or salts carries electrical current. In chemistry, it is common sense that ions lost electrons will become positive, and ions that have gained electrons are negative. The more ions in the solution, the more electrons will be transferred, furthermore, the more conductivity a solution is (Engg, 2017).

In a word, conductivity is used for measuring the volume of dissolved solids in a solution. It is directly proportional to the number and charge of ions in the solution. The conductivity unit is µS/cm.

2.2.5.2 The merit of 4-electrode conductivity sensor

A high ion concentration in the medium results in a mutual repulsion of the ions and leads to a reduction of the current, which is being called the polarization effect. It can make an effect on measuring the accuracy of conductive probes. 4-electrode sensors have two current-free electrodes, so they are not affected by polarization effects (Engg, 2017).

Figure 22, which was supplied by Endress+Hauser company, illustrates the promising working range of various EC-sensor, including 2-electrode conductive conductivity sensor, 4-electrode conductive conductivity sensor, and inductive conductivity sensor. 4-electrode conductive conductivity sensor provides the widest range for measurement among these three types of sensor.

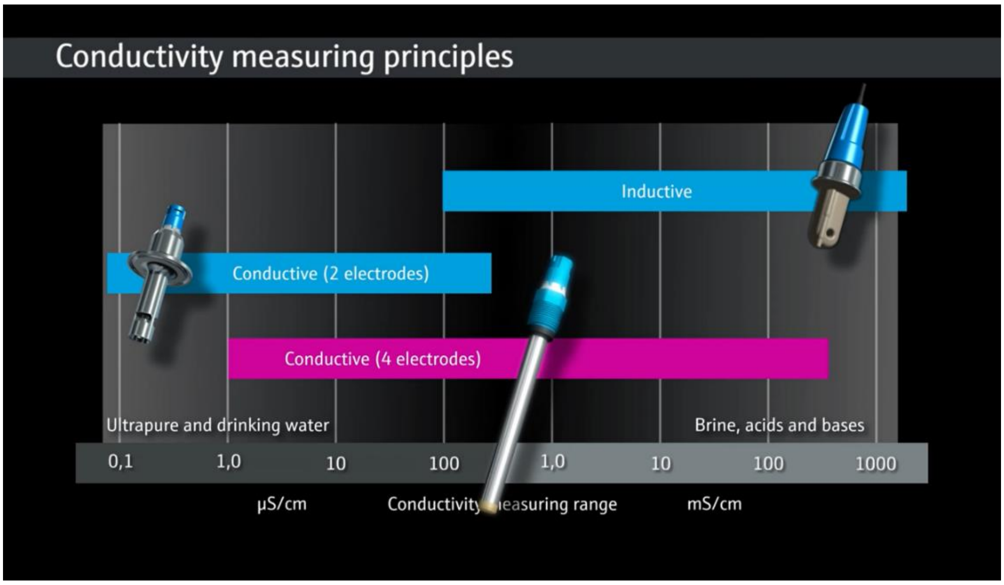


Figure 22 The working range of various conductivity sensors produced by Endress+Hauser Company (Endress+Hauser, 2016)

To sum up, 4-electrode EC-sensor has the following characteristics (Xi'an Kacise Optronics Co., 2021):

a. The current electrode is separated from the voltage electrode, and the current electrode is powered by a constant current source, effectively avoiding the influence of polarization impedance.
b. High sensitivity and strong anti-pollution ability
c. 4-electrode conductivity cell has ultra-microstructure, large diversion space, and short distance, which is suitable for long-term field measurement.

2.2.5.3 The principle of 4-electrode

As Figure 23 shows, the 4-electrode conductivity cell is composed of 2 current electrodes and 2 voltage electrodes. The voltage electrode and the current electrode are coaxial. During measurement, the liquid to be measured passes

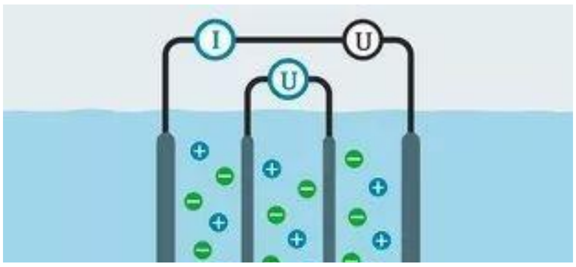


Figure 23 Schematic diagram of 4-electrode EC-sensor

through the gap between the two current electrodes. An AC signal is applied to both ends of the current electrode. Through the current, an electric field is established in the liquid medium, and the two voltage electrodes induce a voltage to keep the voltage across the two voltage electrodes constant. The current passing through the two current electrodes has a linear relationship with the conductivity of the liquid (Engg, 2017).

2.2.5.4 Conversion between conductivity and chloride ion

For EC values under about 2000 μ S/cm, the relation is (Baaren, 2015):

$$Cl(mg/l) = 360 \times EC(ms/cm) - 450$$

For EC values > 2ms/cm (Baaren, 2015):

$$Cl(mg/l) = EC(ms/cm)/3$$

2.2.5.5 Conversion between g/l NaCl and g/l chlorine (Cl^-)

M_{NaCl}=58.44g/mol

M_{Na}=23g/mol

M_{Cl}=35.453g/mol

(chemistry, 2021)

$$\frac{M_{NaCl}}{M_{Cl}} = \frac{\text{g/l Sodium chloride}}{\text{g/l Chlorine}^-} = \frac{58.44}{35.453}$$

M means molar mass here. The formula can be used when making the solutions with pure sodium chlorine and demineralized water.

2.3 Performance criteria

In this chapter, the 4 performance criteria of the sensor: working range, stability, accuracy, and sensitivity has been defined.

2.3.1 Working range

Every instrument that people used has a working range(WR). It has an upper limit and a lower working limit. Measurements outside the working range will not meet the desired criteria. It means that the working range depends on the criteria. Those criteria will lie on the desired information from the user. For example, sometimes the situation only intends to know if the salt concentration is low, moderate, high, or very high. In some other situations, it is expected to know the salt concentration with 1% accuracy (Goossen, The definition of Working Range, 2021).

2.3.2 Accuracy

Accuracy(ACC) is a vital index regarding the performance of the sensor. During the measurement, accuracy is a word to describe the proximity of the measurements to a specific value. In general, the specific value shall be defined as the true value essential (Anderson, 2021). In the project situation, the true value is going to refer to the measuring result from the laboratory.

The formula has shown below:

$$Accuracy = \pm \frac{MV - TV}{TV} \times 100\%$$

Thereinto, MV=Measured Value; TV=True Value.

2.3.3 Stability

Precision can represent the stability(Sb) of the sensor. It reflects on how consistent the sensor can get the result (Portable Spectral Services, 2021).

There are several steps to calculate the precision of a sensor:

1. Calculate the sample mean.

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \cdots + X_{n-1} + X_n}{n}$$

2. Calculate the sample standard deviation(S).

$$S = \sqrt{\frac{\sum(X_I - \bar{X})}{n-1}}$$

3. Calculate relative standard deviation(RSD).

$$RSD = \frac{S}{|\bar{X}|} \times 100\%$$

Therefore,

$$Stability = \bar{X} \pm RSD$$

2.3.4 Sensitivity

Sensitivity(ST) refers to the ratio of the output change of the sensor in the steady state to the input change, which is represented by Sn:

$$S_n = \frac{Amount\ of\ change\ in\ output}{Amount\ of\ change\ in\ input} = \frac{dy}{dx}$$

In the previous project, 2 electrode system polarization will occur around the electrodes. Usually, that results in a relatively higher sensor response for lower salt concentrations. That will also occur in the 4-electrode system, which has a variable sensitivity. Thus, the EC-sensor is a non-linear sensor as shown in Figure 24. For this reason, for general nonlinear sensors, some correction networks are often used to make the output and input have a linear relationship. At this time, the sensitivity of the sensor can be written as K = y / x (He, 2004).

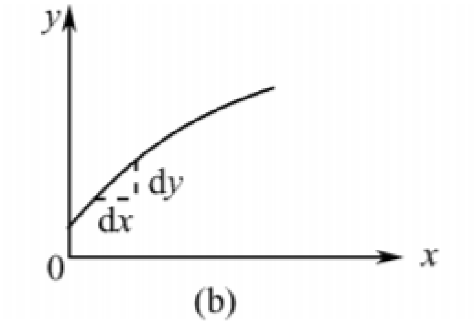


Figure 24 The sensitivity of the non-linear sensor (He, 2004)

Chapter 3 Methods

This chapter introduces the two design methodologies that have been learned, namely Oskam-design and V-model. Then the chapter states why V-model is the final choice, how the student plans to use V-model in the process according to local conditions, and what are the deliverables and activities of V-model.

3.1 Oskam-design method

In Oskam-method, it has been divided into 5 phases: orientation, analysis, design, detailing and realization. As the Figure 25 showed, the development covering from phase 1 to 4 occupies most of the process. It focuses on the study of design and feasibility. On the contrary, the realization playing the role of phase 5 which is emphasized in preparation production marketing and service accounts for a little.

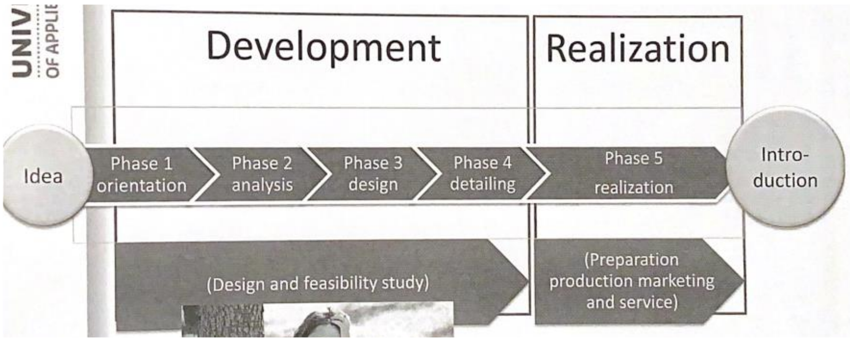


Figure 25 The structure of Oskam-design method (Mouw, 2018)

The results per phase have been demonstrated in Figure 26. The deliverables and activities of each Oskam-design phase has been presented in Appendix 1.

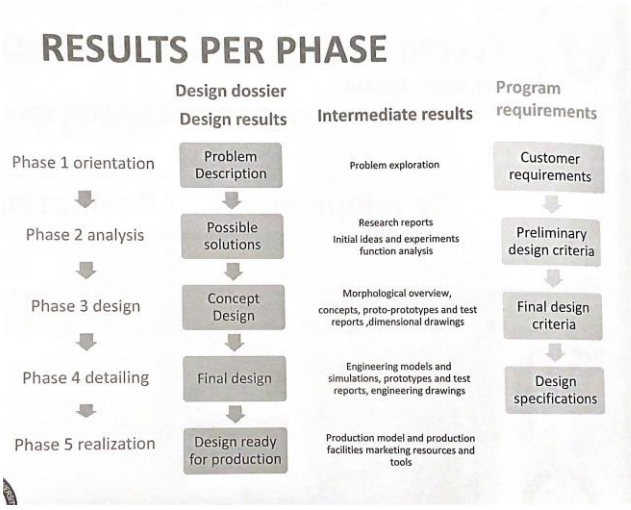


Figure 26 Results per phase of Oskam (Mouw, 2018)

3.2 V-model

V- model is occasioned in a thesis published in 1986 by Paul Rook. He used this method to design software by breaking it down into small pieces, programming individually to achieve the final product. Since its effectiveness, V-model remains to be one of the most efficient approaches for developing software.

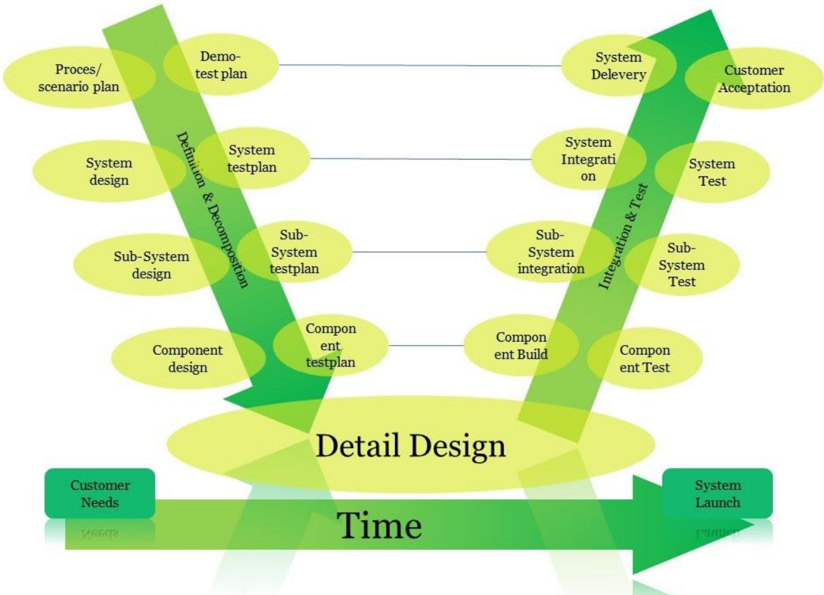


Figure 27 V-model structure (Haak, 2020)

As Figure 27 shows, V model has a characteristic structure that looks like “V”. It is a type of SDLC(System Development Life Cycle) model that works sequentially by the arrow. Each circle on the left of the arrow corresponds to the ones on the right. The process will go down into the next phase by passing the staged test. It implies if the designed results cannot pass the corresponding test, the projecting process should go back to the related design stage on the left side instantly and resume with the original direction until it is qualified so far.

By the iterative verification and validation, there is no need for the people using V model to persuade the clients or the stakeholders that the results are eligible.

3.3 Reason for applying V-model

Oskam-method focuses more on innovation, it takes a lot of work before realization to find out the best assembly design of products. It is more suitable for product design projects which gives the issue an open, full analysis and a way of thinking.

However, V-model emphasizes functional achievement. It needs several test plans which aim to verify and validate (Kwekkeboom, 2019). It is more applicable in realizing a specific aim or a clear task, such as system development and build-up. Not too much elasticity and innovation in it.

This project has two certain tasks:

1. Investigate the main performance of the new EC-sensor.
2. Couple the sensor with Arduino.

The focus is on how to implement the function, not on innovation. That is the reason for applying V-model instead of Oskam-design during the process.

3.4 Adjusted method

The measurement stage is so simple-structured that no need to break it into small pieces. As shown in Figure 28, the measurement stage will conduct in the system-level phase of V-model. During the coupling stage, V model is going to apply in depth.

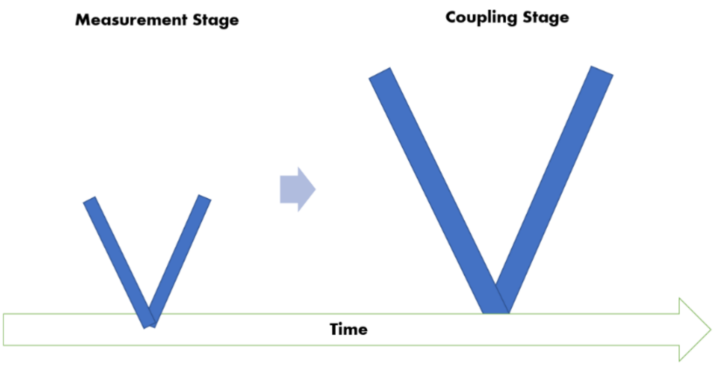


Figure 28 The specific application of V-model in this project

Due to the less content, as scheduled, the measurement step is expected to last four weeks. In terms of the coupling stage, since its complex, it is planned to be completed in 8 weeks,which is the rest of the time of the project.

3.5 Deliverables and activities of V-model

For V-model, there are 4 phases with corresponding activities and deliverables (Kwekkeboom, 2019). They are orientation phase, design phase, integration phase, and completion phase.

Phase 1: Orientation phase

Phase 1 is about the preparation before execution.

The deliverable of Phase 1:

1. Research proposal
   a) Assignment background
   b) Company background
   c) Theoretical framework

   d) Main question/ sub-questions
   e) Objectives
   f) Method selection
2. Planning

The activities of this phase have been shown in Figure 29.

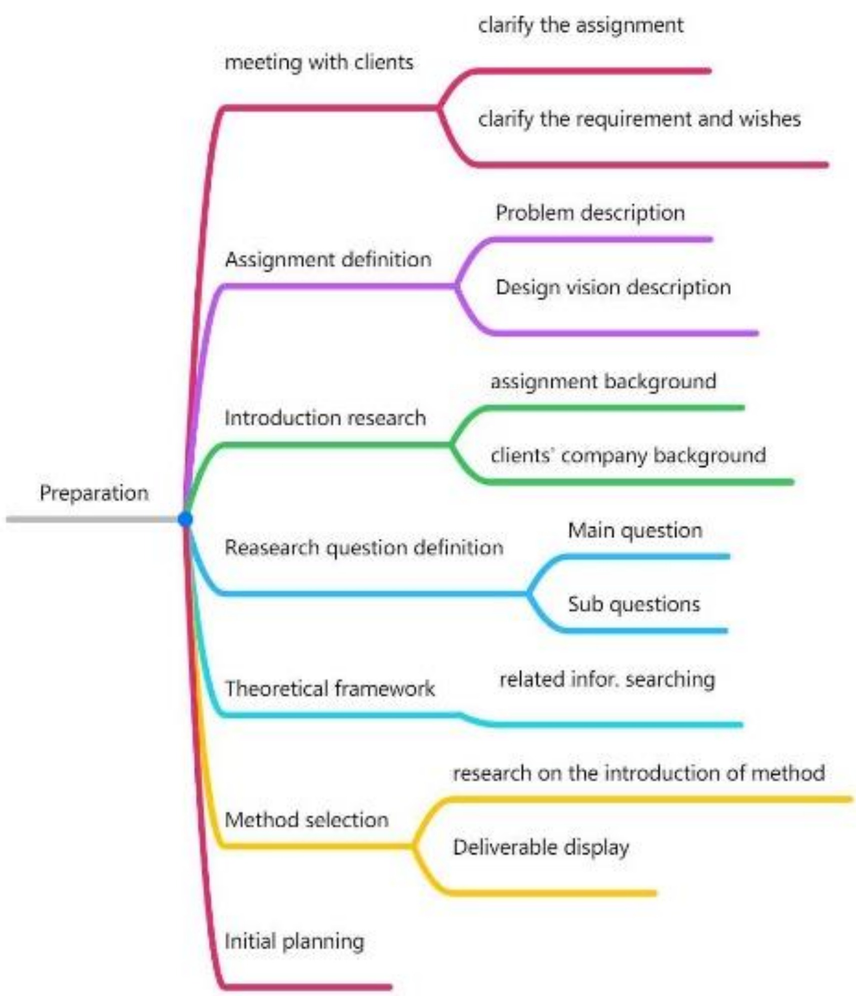


Figure 29 The activity of orientation phase of V-model

Phase 2: System/subsystem/sub-subsystem/component design phase

Phase 2 will start to respond to the client's requirements by describing the design and formulating the test plan for each level. How many levels are used to split the system design depends on the situation.

Figure 30 illustrates the deliverable of phase 2 after the formulation of demo test plan.

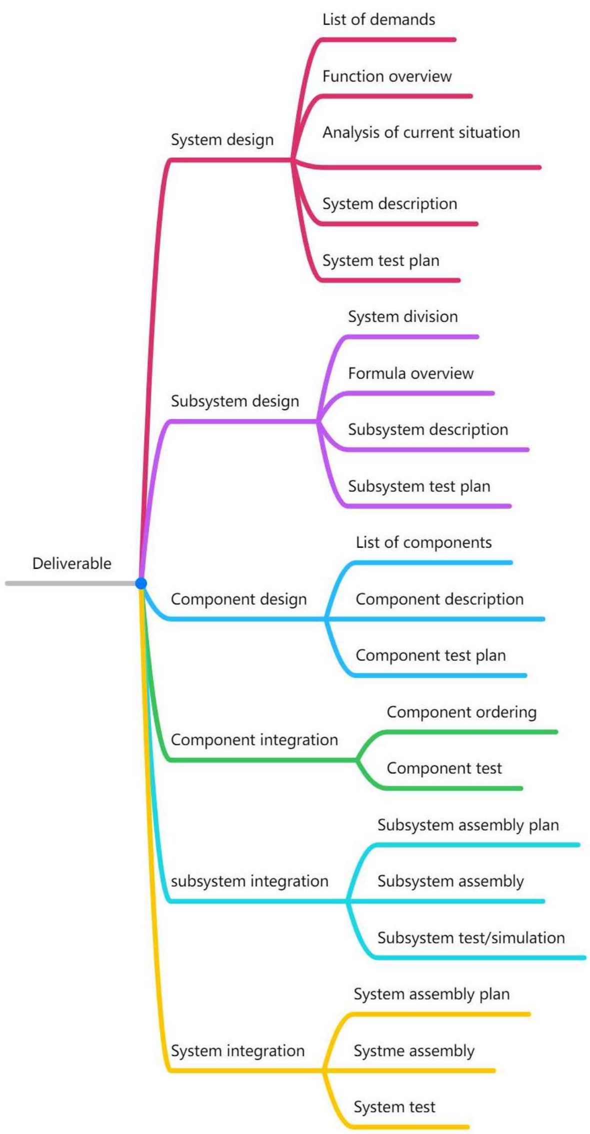


Figure 30 The deliverables of design phase and integration phase of V-model

The activities of this phase have been shown in Figure 31.

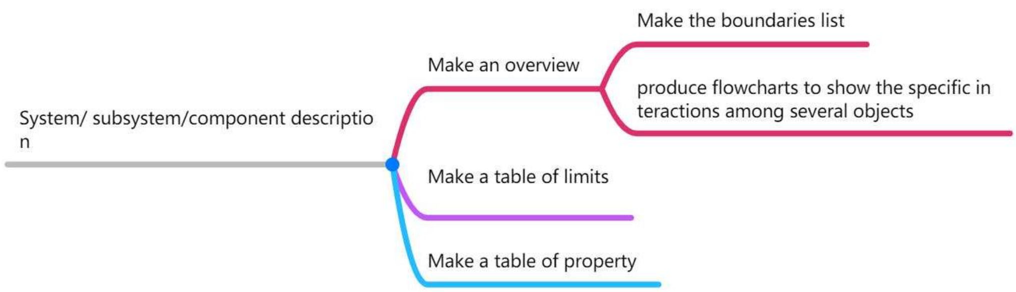


Figure 31 The activities of design phase of V-model

Phase 3: System/subsystem/sub-subsystem/component integration phase

Phase 3 will begin to execute the test plans formulated in Phase 2 and validate and verify the function of the (component, subsystem, sub-subsystem, etc.) system.

See the deliverables of Phase 3 in Figure 30.

The activity of Phase 3:

1. Formulate the component list for ordering.
2. Test by following the test plans.
3. Assembly

Phase 4: Completion phase

Phase 3 is time to demonstrate the designed prototype by following the demo test plan. Meanwhile, the conclusion and recommendations on the basis of the project will be given in the final report.

The deliverables of Phase 4:

1. Demo test
2. Final prototype
3. Thesis report
4. Portfolio

Chapter 4 Results

According to the client’s request, the results shall be split into two stages. The first one is measurement stage, which investigates 4 criteria as to the performance of the new EC sensor. The second one is coupling stage, which aims to couple the new EC sensor with Arduino.

4.1 Measurement stage

The design of measurement stage is a pure experimental design by following the steps of V-model.

4.1.1 System design

4.1.1.1 List of demand

Table 5 The list of demand of Measurement system

Nr.	Requirement	Demand	Wish
1	Investigate the working range of the new generation electronic conductivity sensor from imec.	✔	
2	Investigate accuracy of the new generation electronic conductivity sensor from imec.	✔	
3	Investigate stability of the new generation electronic conductivity sensor from imec.	✔	
4	Investigate sensitivity of the new generation electronic conductivity sensor from imec.	✔	
5	Make a list of test-wanted solutions with client’s approval	✔	
6	Make the solutions in the laboratory or gather them in real life.	✔	
7	The testing solutions are all water, but with different sodium chloride concentrations.	✔	
8	Take the solution analysis result measured in the laboratory as the true value.	✔	
9	Provide measurement suggestions for follow-up projects.	✔	
10	Dispose the testing solution eco-friendly.	✔	
11	Test the sensor in the water of 0-30℃ to prevent damage.	✔	
12	No additional costs in the use of software		✔

13	If the sensor is in good condition, compare it with Waterschap 2-electrode commercial EC-sensor		✔

4.1.1.2 Function overview

Based on the requirements, the main function of the measurement system design is to investigate the performance of new generation conductivity sensor from imec. As illustrated in Figure 32, it includes four sub functions.

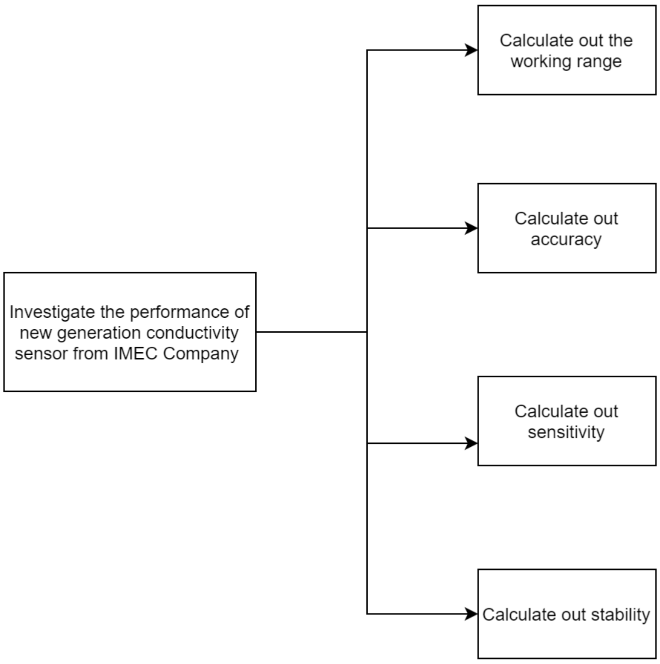


Figure 32 The function overview of simulation system (function-based)

4.1.1.3 Input and output diagram

Figure 33 depicts the input and output diagram of the measurement system. It contains both sensor-tested processes and data processing in Microsoft Excel. Thus, the middle block not only acts as outputs to the left block, but also inputs to the right block.

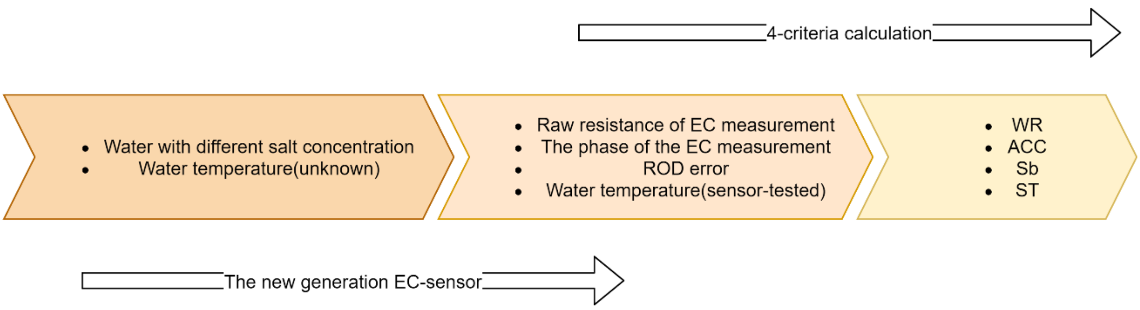


Figure 33 Input and output diagram

Some explanations about the upper diagram:

1. Water temperature(unknown): The temperature is still unscanned.
2. Water temperature(sensor-tested): The temperature has been scanned.
3. The upper 4 items in the middle block are the outputs from the new generation EC sensor, they directly display on the 'RealTerm' interface and record in the file. See Chapter 2.2.4 Electrical conductivity calculation.

4.1.1.4 System description

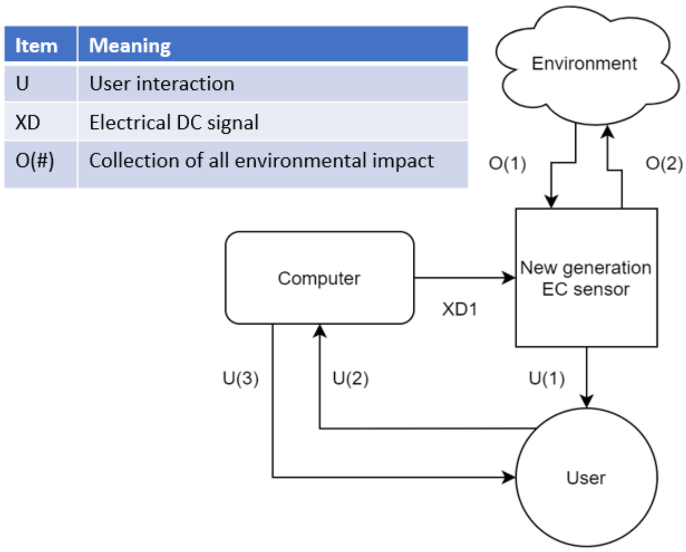


Figure 34 Flowchart with unique identifiers of new generation

Table 6 The limits of the measurement system

INTERACTION	SYMBOL	MINIMUM	MAXIMUM	UNIT
->0(#)->				
Environmental impacts				
Water temperature (unknown)	T_u	0	30	℃
Water with different salt concentrations	WC	0	80000	μ S/cm
U1->	(Boonen, How to use the new generation conductivity sensor from imec, 2021)			
sensor output				
Raw resistance of the EC measurement	Imp	1.33	80000	Ω
The phase of the EC measurement	The phase must between these three scopes, otherwise the measurement is invalid. (Boonen, How to use the new generation conductivity sensor from imec, 2021)			

	P_{EC}	-10	10	/
		-190	-170	/
		170	190	/
ROD error	ROD	If the value is not 0, the data is invalid.		/
Water temperature (sensor-tested)	T_{st}	0	30	℃
-> U2	The user gives the formulas to the computer to process the data. (Boonen, How to use the new generation conductivity sensor from imec, 2021)			
User Iutput				
	Cond.	Cond.=810000/Imp		
	Temp cond.	Temp cond.= Imp + 0.02 * imp * (temp - 25)		
U3->				
User output				
Working range	WR	-		μ S/cm
Stability	Sb	-	-	-
Accuracy	ACC	-	-	-
Sensitivity	ST	-	-	-
->XD1	(Brown, 2020)			
Power from computer				
Power	P	0	30	kW
Voltage	U	0	5	VDC
Current	I	0	30	A

4.1.2 System test plan and test results

Test plan: The test plan of the measurement system has been presented in >>Appendix 5 Measurement System Validation Test Plan.

Test analysis: What has been tested in measurement system is a waterproof version sent in the second time. 15 solutions were made for the tests with client's approval, meanwhile, they were sent to laboratory to obtain the true value.

The experiment used RealTerm as the measurement software, saved the data in the form of a csv file, and processed the data in Excel to obtain 4-criteria of working performance. Table 7 shows 4-criteria gained in the test and the performance of imec EC-sensor.

Table 7 The results of 4-criteria

Criteria	4-criteria gained in the test	The performance of imec EC-sensor
Working range	270-13000μS/cm	40-60000 μ S/cm
Accuracy	10%-30%	5%-10%
Stability	<3%	<5%
Sensitivity	Too few available data points to draw a sensitivity curve for the sensor.	/

※ *270μS/cm: drinking water*
※ *13ms/cm: a bit higher than wastewater effluent*
※ *9ms/cm: upper limit of wastewater effluent*
※ *60ms/cm: sea water*
※ *40μS/cm: higher than demineralized water while lower than drinking water*
※ *More conductivity of different solutions, see Appendix 4: The conductivity range of various liquids.*

The sensor can output valid data just in 50-13000 μ S/cm(Solution 2-6). Thereinto, only 270-13000 can meet the sufficient accuracy(<30%) and stability(<3%). The results express that the sensor being tested does not match the performance. It is suspected that the sensor has been damaged to some extent. See the detailed values for each valid sample in Table 8.

Table 8 The detailed values for each valid sample

Sample	Cond.	Accuracy	Accuracy Status	RSD	Stability Status
2	47	35.9%	Bad	0.6%	Very good
3	480	61.6%	Very bad	2.1%	Good
4	270	9.6%	Very Good	0.5%	Very good
5	5500	8.8%	Very Good	2.3%	Good
6	13000	28.8%	Good	2.3%	Good

Accuracy a	Status	RSD b	Stability Status
a⩽10%	Very good	b⩽1%	Very good
10%<a<30%	Good	1%<b<3%	Good
30%⩽a⩽50%	Bad	3%⩽b⩽5%	Bad
a>50%	Very bad	a>5%	Very bad

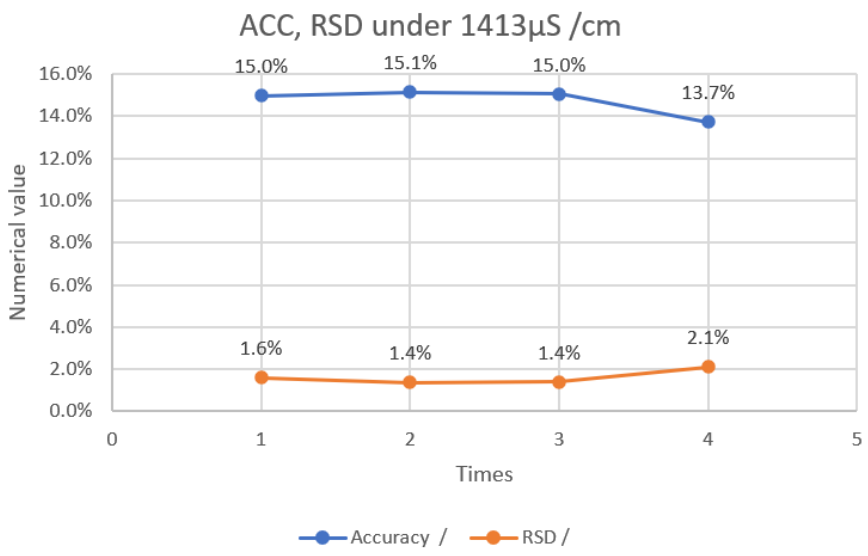


Figure 35 The accuracy and the stability of the sensor under 1413 μS/cm calibration solution

By experimenting with the sensor four times in calibration solution(1413 μ S/cm), the sensor has good working stability when measuring the same solution multiple times(Figure 35).

Judging from the sensors received twice, it is recommended that imec should further improve the robustness and reliability of the 4-electrode EC-sensor.

To help the future related project, here are some tips for the measurement of this type of EC-sensor based on student's experience and imec expert's test in Table 9.

Table 9 Tips for the measurement of imec EC-sensor

Nr.	Contents	Keyword
Based on student's experience		
1	Since the sensor is still not a commercial product, pretest EC-chip and Temp-chip before long-term test to save time.	Pretest;
2	Employ the thermometer to check if the temperature of the solution is within 0-30℃ first in each test. Excessive temperature may damage the sensor.	Prevent temperature damage;
3	The higher conductivity the solution has, the longer period of measuring a set of data is. To ensure that each solution has enough data to analyze, increase the sampling time as the concentration of the solution increases. For instance, there are roughly 270-330 data sets outputted when the conductivity of the solution is below 5500µS/cm in 10 mins, however, only about 150 data sets outputted as the conductivity rose higher than 5500µS/cm.	Test duration;

4	To prevent the solution from pollution, remember to wash the probes(chip) with demineralized water between test and test. Dry the sensor by a towel(or tissue) except EC-chip.	Prevention of solution contamination;
5	When the day's experiment is over, clean the sensor with demineralized water to prevent the residual sodium chloride crystals from eroding the chip after the water evaporates.	Prevent chip erosion;
Based on expert's test		
6	Be careful when putting the sensor in bottles and test tubes, otherwise, the sensor's chip is easy to be damaged.	Protect EC-sensor;
7	When the sensor is plugged into the computer, it can affect it if the wiring in the house is very noisy. The problem tends to go away by an employing battery as a power supply. It will be solved in the next generation of EC-sensor.	Noise disturbance;
8	As for the two broken sensors, the reasons have been reviewed in Appendix 7: The received imec EC-Sensors.	Cause of sensor failure

The test result of the measurement system has been presented in >>Appendix 6 Measurement System Test Results.

4.2 Coupling stage

The design of the coupling stage is the software and hardware design through the steps of the V model.

4.2.1 System design

4.2.1.1 List of demands

Table 10 The list of demand of Coupling system

Nr.	Requirement	Demand	Wish
1	The designed prototype can work properly.	✔	
2	The cost of the connection part(Arduino, new generation EC-sensor are not included)is expected to be lower than €100.	✔	
3	Open-source hardware and software.	✔	
4	Compatible with the Arduino Nano board.	✔	
5	Display all the measured data of the sensor via the serial monitor of Arduino IDE timely.	✔	

6	Demonstrate the conductivity and temperature of water via LCD display when the outputs are valid.	✔	
7	The design can show error status on the LCD display when the sensor outputs invalid values.	✔	
8	The system can judge the validity of the sensor's outputs.	✔	
9	Use the sensor that in good condition to build a designed prototype.	✔	
10	Open-source hardware and software.	✔	
11	The design is eco-friendly which will not generate harmless gas or substances.		✔
12	Easy to install		✔

4.2.1.2 Function overview

Based on the requirement, the main function of the coupling system design is to visualize the value of conductivity. It covers 5 sub functions:

- Sub function 1: Read out all the measured values.
- Sub function 2: Judge the validity of data.
- Sub function 3: Calculate the temper corrected conductivity.
- Sub function 4: Display the results on the LCD display.
- Sub function 5: Check if the applied sensor can work properly.

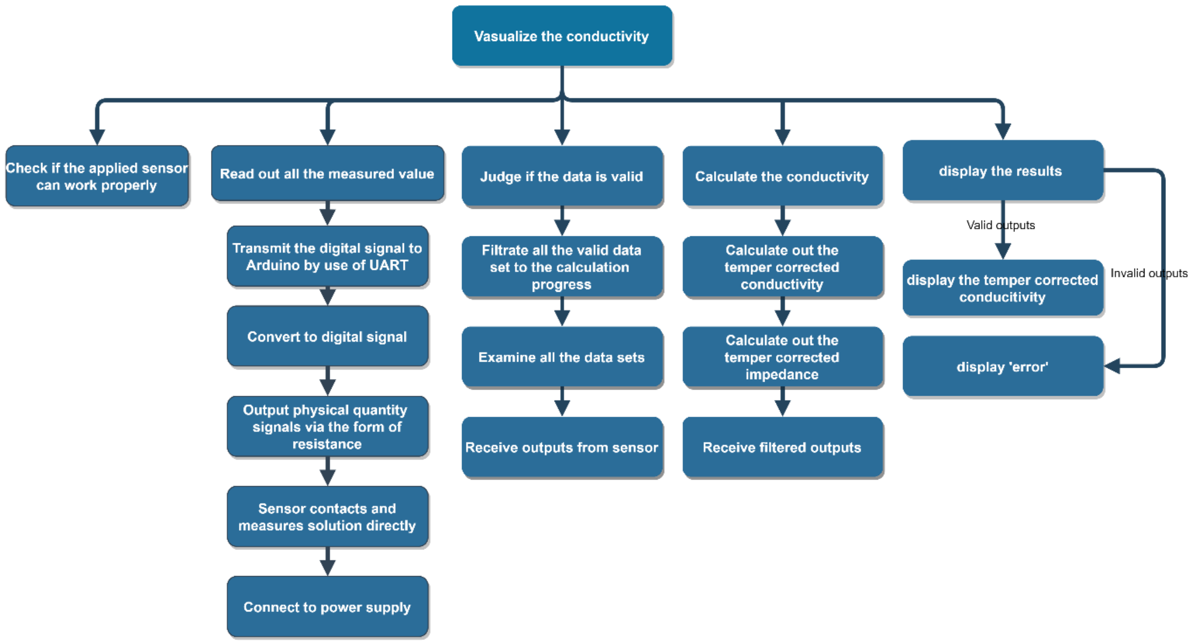


Figure 36 The function overview of coupling system (function-based)

4.2.1.3 Input and output diagram

The input and output diagram of coupling system has been shown in Figure 37 , which provides a clear view.

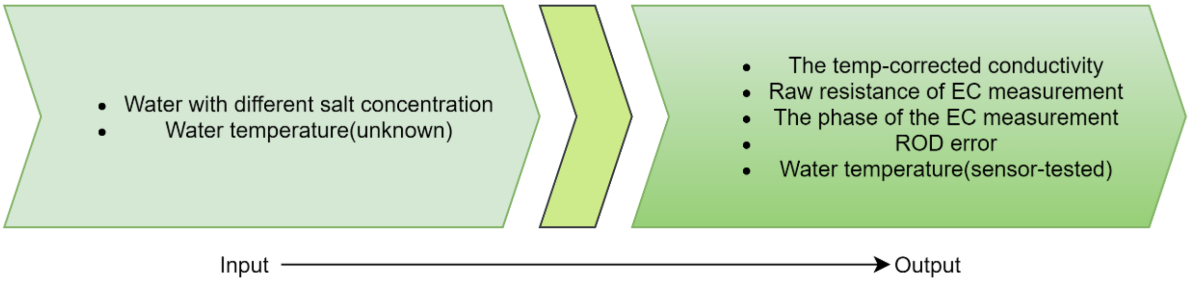
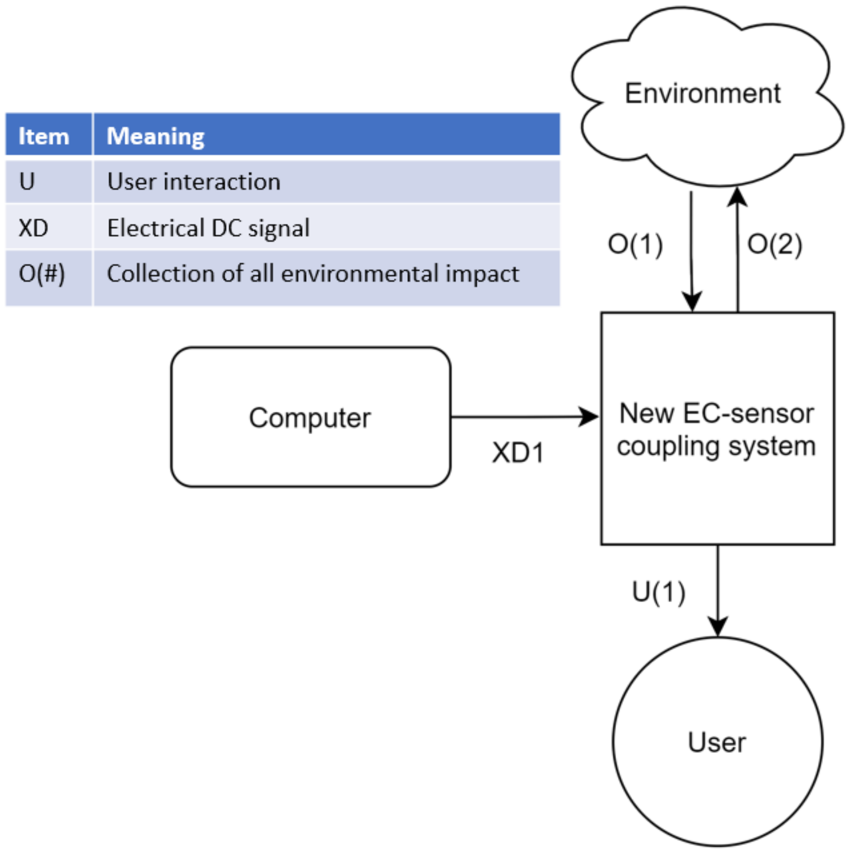


Figure 37 Input and output diagram---Coupling system

4.2.1.4 System overview



Item	Meaning
U	User interaction
XD	Electrical DC signal
O(#)	Collection of all environmental impact

Figure 38 Flowchart with unique identifiers of new EC-sensor coupling system.

Table 11 Table of limits

INTERACTION	SYMBOL	MINIMUM	MAXIMUM	UNIT
->O(#)->				
Environmental impacts				
Water temperature (unknown)	T_u	0	30	℃
Water with different salt concentrations	WC	0	80000	µ S/cm
U1->				
system output	(Boonen, How to use the new generation conductivity sensor from imec, 2021)			
Raw resistance of the EC measurement	Imp	1.33	80000	Ω
The phase of the EC measurement	The phase must between these three scopes, otherwise the measurement is invalid. (Boonen, How to use the new generation conductivity sensor from imec, 2021)			
	P_{EC}	-10	10	/
		-190	-170	/
		170	190	/
ROD error	ROD	If the value is not 0, the data is invalid.		/
Water temperature (sensor-tested)	T_{st}	0	30	℃
The temper corrected conductivity	Temp cond.	40	60000	µ S/cm
->XD1				
Power from computer	(Brown, 2020)			
Power	P	0	30	kW
Voltage	U	0	5	VDC
Current	I	0	30	A

4.2.2 Sub-system design

4.2.2.1 System division

As shown in Figure 39, the new EC-sensor coupling system has been divided into three sub-systems: EC-sensor sub-system, Arduino sub-system, Display sub-system.

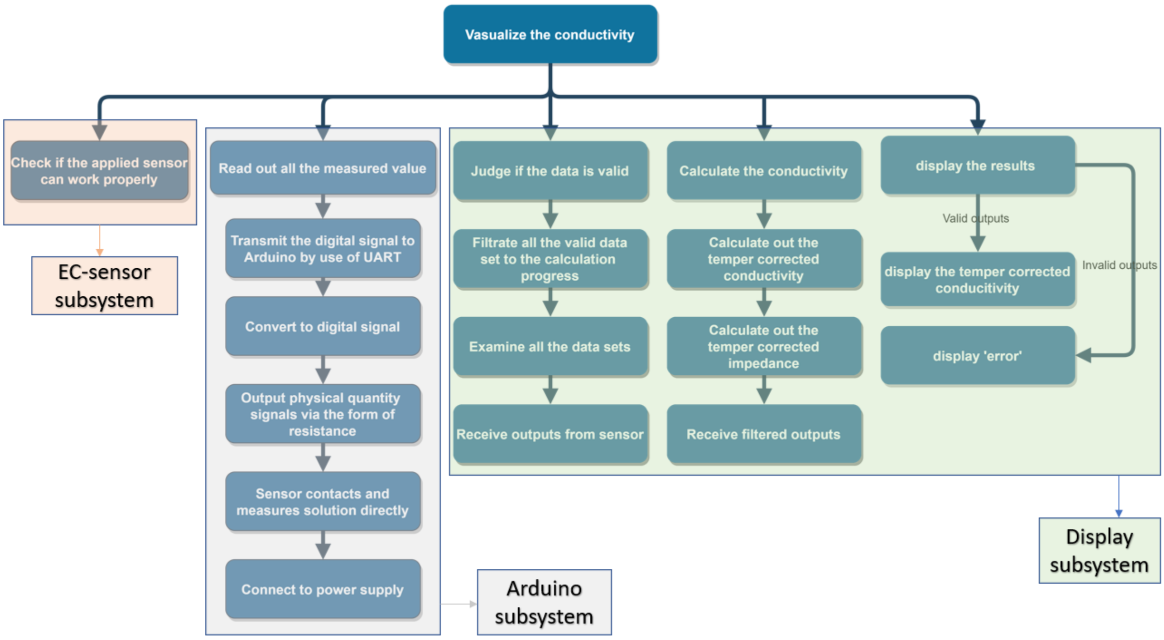


Figure 39 Coupling system division

4.2.2.1 Subsystem overview

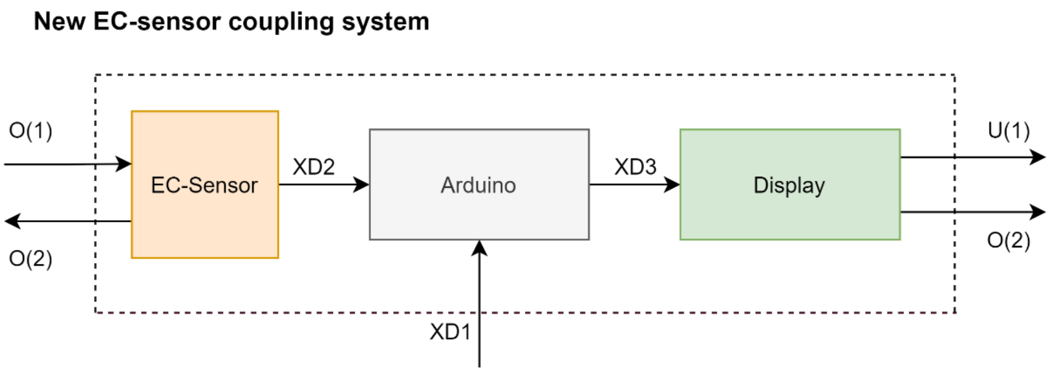


Figure 40 The new EC-sensor coupling system

Table 12 The limit of coupling subsystems

INTERACTION	SYMBOL	MINIMUM	MAXIMUM	UNIT
->O(#)				
Environmental input				
Water temperature (unknown)	T_u	0	30	℃
Water with different salt concentrations	WC	0	60000	µ S/cm
XD2->				
Voltage from sensor	(Brown, 2020)			

Voltage	U_{sensor}	0	5	VDC
XD1->				
Power from computer	(Brown, 2020)			
Power	P	0	30	kW
Voltage	U	0	5	VDC
Current	I	0	30	A
->XD3				
Voltage from Arduino				
Voltage	$U_{Arduino}$	0	5	VDC
U(1)->				
User Output				
Power	P	0	30	kW

4.2.3 Sub-system test plans and test results

4.2.3.1 EC-sensor test plan and test results

Test plan: The test plan of the measurement system has been presented in >>Appendix 5 EC-sensor Subsystem Validation Test Plan.

Test analysis: Imec sent a brand-new EC-sensor in the third time. Table 13 shows that this EC-sensor can work properly in demineralized water, tap water and calibration 1413 μ S/cm solution during the subsystem test. It implies that the EC-sensor can be used in the system test.

Table 13 The results of the new-gained EC-sensor testing in three types of solutions

The type of the solution	Conductivity range	Test results	Good/Bad
Demineralized water	<0.1μS/cm	Invalid outputs	Good
Tap water	150-800μS/cm	457μS/cm	Good
Calibration water	Around 1413μS/cm	1456μS/cm	Good

The test result of the measurement system has been presented in >>Appendix 6 EC-sensor Subsystem Test Results.

4.2.3.2 Arduino test plan and test results

Test plan: The test plan of the measurement system has been presented in >>Appendix 5 Arduino Subsystem Validation Test Plan.

Test analysis: The subsystem uses BOB-11189 to realize level-translation and outputs real-time data sets line by line via serial monitor through serial syntax and indexing hash key. Figure 41 indicates the success of coupling between EC-sensor and Arduino.

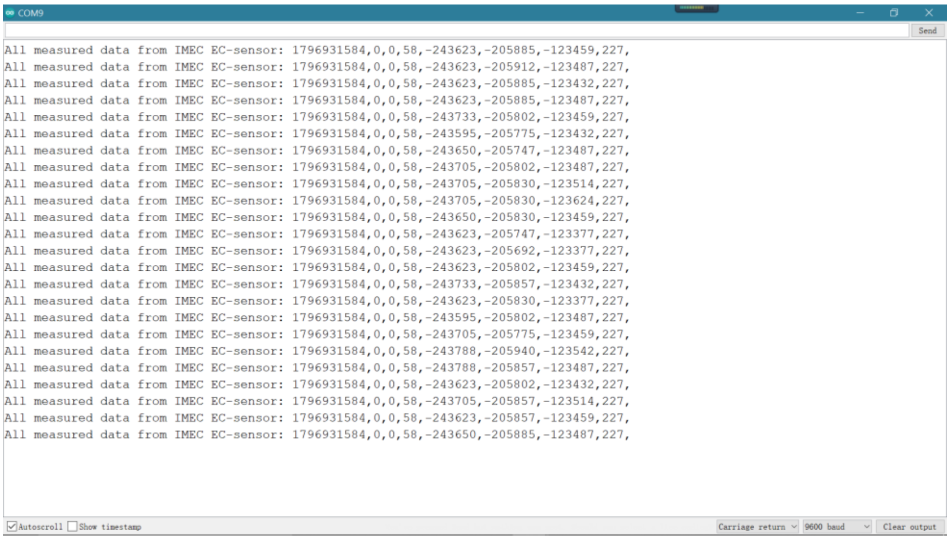


Figure 41 The sensor readout in the serial monitor of Arduino IDE

The test result of the measurement system has been presented in >>Appendix 6 Arduino Subsystem Test Results.

4.2.3.3 Display test plan and test results

Test plan: The test plan of the measurement system has been presented in >>Appendix 5 Display Subsystem Validation Test Plan.

Test analysis: Based on Arduino subsystem, display subsystem used commas to locate the value that wanted to be extracted, employed toInt() to convert string to integer, then "if" syntax carried out the function of judgement, and finally lcd syntax realized the display. The wiring of LCD refers to theoretical framework.

Accordingly, LCD can display correct status in different ranges. To take a closer look, Table 14 shows the results of judgement test and calculation test, which are all correct.

Table 14 The results of judgement and calculation test

Judge-calculation test	Valid sample1	Valid sample2	Valid sample3	Invalid sample1	Invalid sample2	Invalid sample3
Temperature*10	205	220	230	210	220	230
Raw resistance	562	600	600	600	600	600
ROD error	0	0	0	1	0	1
The phase of EC-measurement	1	-190	190	-190	-191	169
If the judgement is correct?	YES	YES	YES	YES	YES	YES
If the calculation is correct?	YES	YES	YES	/	/	/

To prove LCD can work properly, Figure 42 presents the display when testing out the invalid data set, and Figure 43 demonstrates the display when testing out the valid data set.

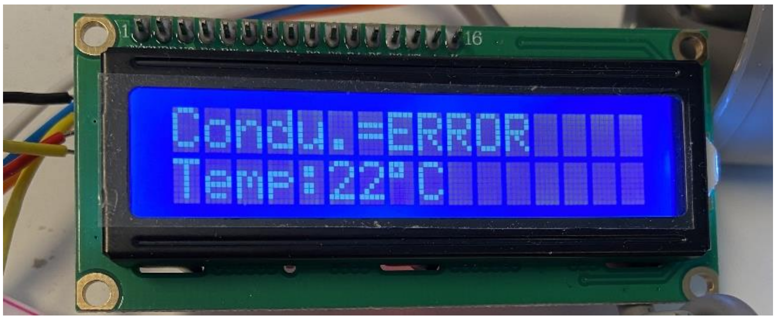


Figure 42 When LCD displays invalid data set

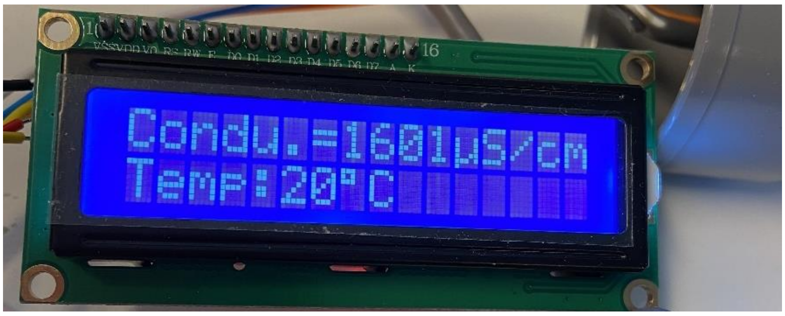


Figure 43 When LCD displays valid data set

The test result of the measurement system has been presented in >>Appendix 6 Display Subsystem Test Results.

4.2.4 System test plan and test results

Test plan: The test plan of the measurement system has been presented in >>Appendix 5 Coupling System Validation Test Plan.

Test analysis: To avoid calculation error caused by using floats in Arduino, code responsible for calculation has been altered to make the results more precise. The design also specially defined a constant to facilitate users to modify the KCELL in time according to their own sensors.

The result is that the designed prototype of the new EC-sensor coupling system can work properly. In Figure 44, it can output all the measured data from imec sensor via serial monitor.

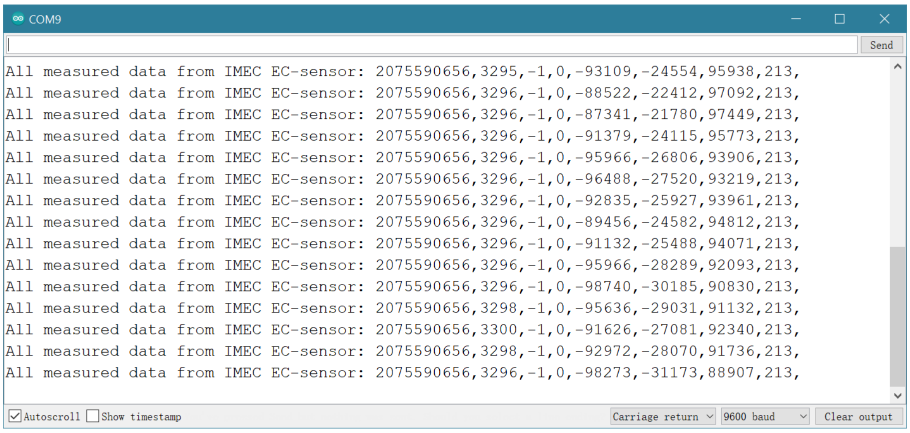


Figure 44 The serial monitor during Coupling system test

Furthermore, through LCD display, user can directly observe the conductivity and the temperature of the soltuion. In Figure 45, the tap water has been tested.

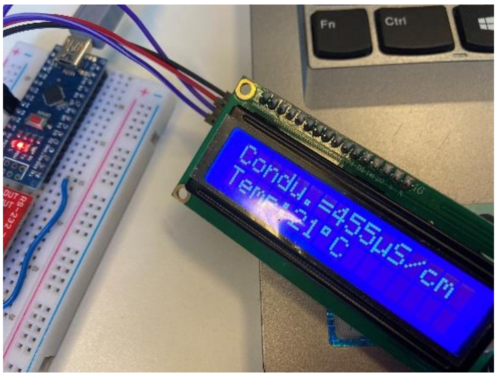


Figure 45 The LCD display in Coupling system test

The test result of the measurement system has been presented in >>Appendix 6 Coupling System Test Results.

4.2.5 Cost control

Based on the subsystems design, the required components have been collected as a list, it can be found in Appendix 8: Component list.

In Table 15, the cost of the coupling part is € 18, which is far less than acceptable maximum cost. The cost meets the request from the client.

Table 15 Cost control

Item	Amount	Satisfaction
The cost of the coupling part	€ 18	✓
Acceptable maximum cost of the coupling part	€ 100	

Chapter 5 Discussion

In this chapter, the unexpected issues during the time when measuring the performance and developing the coupling system, the answers to the sub-questions, and evaluation about the applied method have been stated.

5.1 Issue analysis

Issue: When testing with online exampled code collected in theoretical framework, the LCD display cannot work properly.

Analysis: To ensure that it is not a problem with the LCD itself, three displays of the same model were tested with the same code. The result is that none of the three LCDs can display properly. This implies the code is wrong. After checking the code line by line, the address ‘0x27’ is suspicious(Figure 46).

```
LiquidCrystal_I2C lcd(0x27,20,4);  // set the LCD address to 0x27
```

Figure 46 The suspicious code

By researching, the address of the LCD with the PCF8574 chip of NXP Semiconductors(0x3F) is different from the address of the LCD with the PCF8574 chip of Texas Instruments(0x27). After changing the address to 0x3F, LCD can work in great harmony (ENGINEERS, 2021).

Issue: When building up Arduino subsystem, it always failed to upload the code to Arduino and occurred the error in Figure 47.

```
An error occurred while uploading the sketch
avrdude: stk500_getsync() attempt 8 of 10: not in sync: resp=0xe0
avrdude: stk500_getsync() attempt 9 of 10: not in sync: resp=0xe0
avrdude: stk500_getsync() attempt 10 of 10: not in sync: resp=0x00
```

Figure 47 The error occurred while uploading the sketch

Analysis: Arduino is in good condition by testing with blink example. The wires are all good. After constant attempts, disconnecting the wire from R1OUT to Arduino-Rx when uploading can eliminate this error(Figure 48).

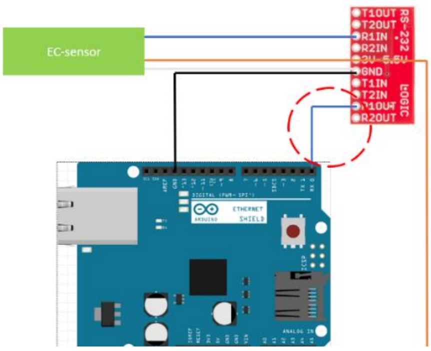


Figure 48 The wire that occurs the error

5.2 Answers to sub-questions

The answers to the sub-questions have been shown below.

Table 16 The answer to the sub-questions

The answer to the sub-questions
Measurement stage
Q1:What is the system description and the test plans for the measurement of the performance?
A: Based on V-model, the system description of measurement of the performance can be found in Chapter 4 Results >>4.1.1 System design. The corresponding system test plan is in Appendix 5 Test plan>>Measurement stage.
Q2: What are the test results regarding measurement?
A: Based on V-model, the test results of measurement have been presented in Chapter 4 Results >>4.1.2 System test plan and test results briefly. The full edition can be discovered in Appendix 6 Test results>>Measurement System Test Results.
Coupling stage
Q3: What are the system descriptions and the test plans for the coupling, its sub-systems, and its components?
A: Based on V-model, the system description of measurement of the performance can be found in Chapter 4 Results >>4.2.1 System design. The corresponding coupling system test plan is in Appendix 5 Test plan>> Coupling stage.
Q4: What are the test results regarding coupling for the components, the sub-systems, and the system?
A: Based on V-model, the test results of measurement have been presented in Chapter 4 Results >>4.2.3 Sub-system test plans and test results and 4.2.4 System test plan and test results concisely. The full edition can be discovered in Appendix 6 Test results>> Coupling stage.

5.3 Method evaluation

V-model, as a guideline of the project, acted as a great role during the designing, validating, and verifying process. The structure of the design phase of V-model helped clarify the requirements from the clients, define the function, the limits, and property of the system, etc. to smooth the validation process. By increasing or decreasing the level of division(system, subsystem, sub-subsystem, etc.) according to the specific situation, while spending more time on more important phases, the process of the system development became more systematical and methodical.

Chapter 6 Conclusion and recommendations

6.1 Conclusion

This project aimed to investigate the performance of the new generation electrical conductivity sensor devised by Interuniversity Microelectronics Centre and try to connect this sensor with Arduino under the premise that the cost of the coupling part is within € 100. By the guidance of V-model, it can be concluded that the obtained sensor tested in the performance investigation was damaged which could not reach the performance criterion, meanwhile, the sensor can couple with Arduino successfully by the cost of €18. The results clearly indicate that the robustness of this new generation EC-sensor still needs further improvement, and the sensor can be applied in Multiflexmeter system for continuous online measurement going with Arduino in the future project.

6.2 Recommendation

Based on these conclusions, here some recommendations for further developments.

- Practitioners should consider conducting new tests on the investigation of the performance of a healthy sensor.
  - Refer to the tips of measurement provided in chapter 4.1.2.
  - Regarding the sensitivity, clients are more concerned about the change of the sensor when testing two solutions with similar conductivities. Accordingly, as the conductivity of the measured solution increases, how the sensitivity changes are recommended to investigate.
  - Compare it with the performance of Waterschap commercial 2-electrode conductivity sensor.
- Given that the designed coupling prototype is not the final product, practitioners should also consider how to incorporate the sensor into the Multiflexmeter system.
  - Develop the sensor on measuring the conductivity of the solution online.
  - The sensor will be applied in the wildness. To be practical, integrate the designed circuit into a waterproof box or another kind of protector is recommended to adapt to outdoor weather.

References

Anderson, P. (2021). *Accuracy and Precision*. Retrieved from https://www.sophia.org/tutorials/accuracy-and-precision--3.

ArduinoGetStarted.com. (2021, 5). *Arduino-LCD I2C*. Retrieved from https://arduinogetstarted.com/tutorials/arduino-lcd-i2c.

Baaren, E. v. (2015, 02 20). Retrieved from https://publicwiki.deltares.nl/display/ZOETZOUT/Conversion+EC+to+Chloride#page-metadata-start.

Banzi, M. (2012, 6 27). *How Arduino motivate our open-source imagination.* (M. Banzi, Performer) TED presentation.

Banzi, M. (2021). *Arduino*. Retrieved from https://www.arduino.cc.

Boonen, T. (2021, 2 10). How to use the new generation conductivity sensor from imec. (F. Du, Interviewer)

Boonen, T. (2021, 3 19). The work instruction of Waterproof imec EC-sensor module. (F. Du, Interviewer)

Brown, G. (2020). *How PC Power Supplies Work*. Retrieved from https://computer.howstuffworks.com/power-supply.htm.

chemistry, P. a. (2021). *Chemistry*. Retrieved from http://www.physics-chemistry-class.com/chemistry/molar-mass.html.

Digi-Key. (2021). *BOB-11189.* Retrieved from https://www.digikey.nl/product-detail/nl/sparkfun-electronics/BOB-11189/1568-1193-ND/5673779.

Endress+Hauser (Director). (2016). *Four-electrode conductivity measurement* [Motion Picture].

Engg, I. (2017, 7 21). *What is conductivity and techniques used for measuring*. Retrieved from https://www.youtube.com/watch?v=6LSQdFzNtXg.

ENGINEERS, L. M. (2021). *Interface an I2C LCD with Arduino*. Retrieved from https://lastminuteengineers.com/i2c-lcd-arduino-tutorial/.

Goossen, J. (2021, 2). The conductivity range of various liquids. The Netherlands.

Goossen, J. (2021). The definition of Working Range. (F. Du, Interviewer)

Haak, W. (2020). Design methodology lectures Powerpoint. Vlissingen, Zeeland, Nederland.

He, D. (2004). *Sensors and sensor technology*. Beijing: Science Press.

HITACHI. (1998). HD44780U (LCD-II). Tokyo, Japan.

jimblom. (2010, 11 23). *RS-232 vs. TTL Serial Communication.* Retrieved from https://www.sparkfun.com/tutorials/215.

Kahle, B. (2010, 1 21). *WAYBACKMACHINE*. Retrieved from https://web.archive.org/web/20100121200614/http://changingminds.org/disciplines/hr/performance_management/smart_objectives.htm.

Kwekkeboom, G. (2019). *The engineer's guide to the V-model.* Driewegen.

Minitab. (2021). *What is measurement stability?* Retrieved from https://support.minitab.com/en-us/minitab/18/help-and-how-to/quality-and-process-improvement/measurement-system-analysis/supporting-topics/other-gage-studies-and-measures/what-is-measurement-stability/.

Mouw, E. (2018, 4). EDM Lecture Summary. Shanghai, China.

multiflexmeter. (n.d.). Retrieved from https://www.multiflexmeter.nl/.

Oskam, I. (2020). *Inge Oskam personal website*. Retrieved from http://www.ingeoskam.nl/io/Welkom.html.

Portable Spectral Services. (2021). *Precision and Accuracy*. Retrieved from https://www.portaspecs.com/precision-and-accuracy/.

Scheldestromen, W. (2020). *Watershcap Scheldestromen*. Retrieved from https://scheldestromen.nl/.

Sharma, A. (2018, 12 5). *LCD I2C Tutorial*. Retrieved from https://create.arduino.cc/projecthub/Arnov_Sharma_makes/lcd-i2c-tutorial-664e5a.

Xi'an Kacise Optronics Co., L. (2021). Electrode Conductivity Online Conductivity Sensor POM Material. Shanxi Province, China.

Xueping Quan, Zhibing Fu, Lei Yuan. (2017). Capacitive deionization of NaCl solutions with ambient pressure dried carbon aerogel microsphere electrodes. *Royal Society of Chemistry*.

Appendix 1: Deliverables & Activities of two methods

1. Oskam-Design Method

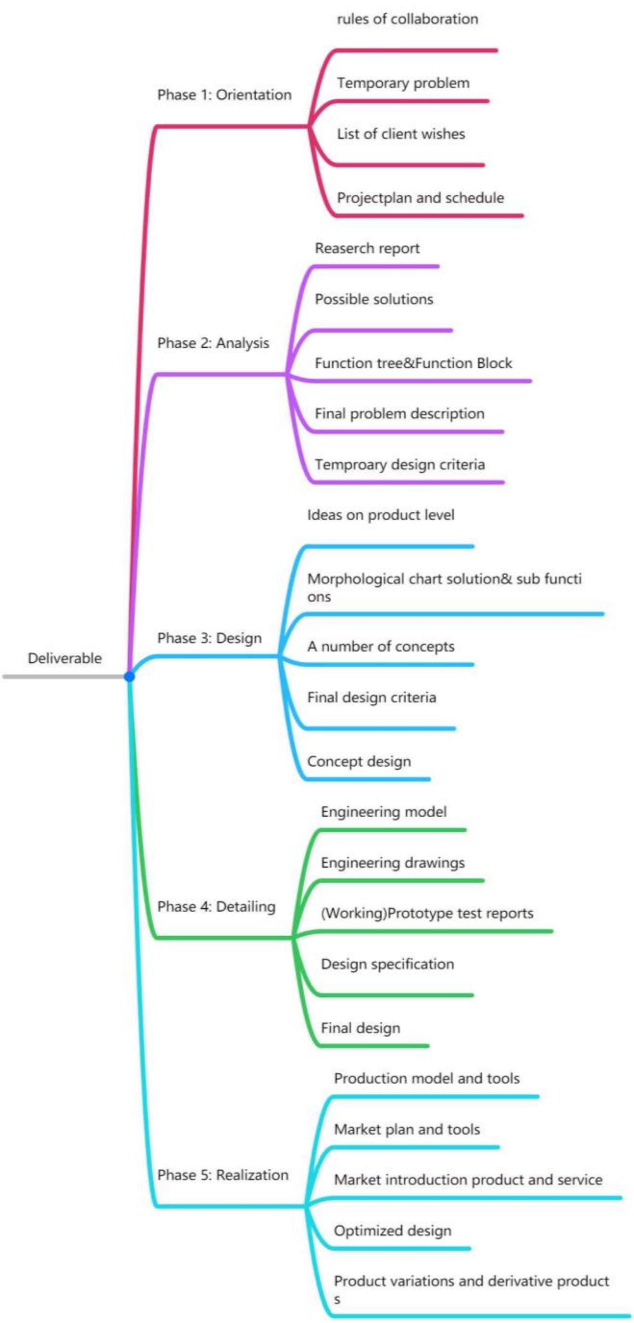


Figure 49 Deliverables in each Oskam-design phase

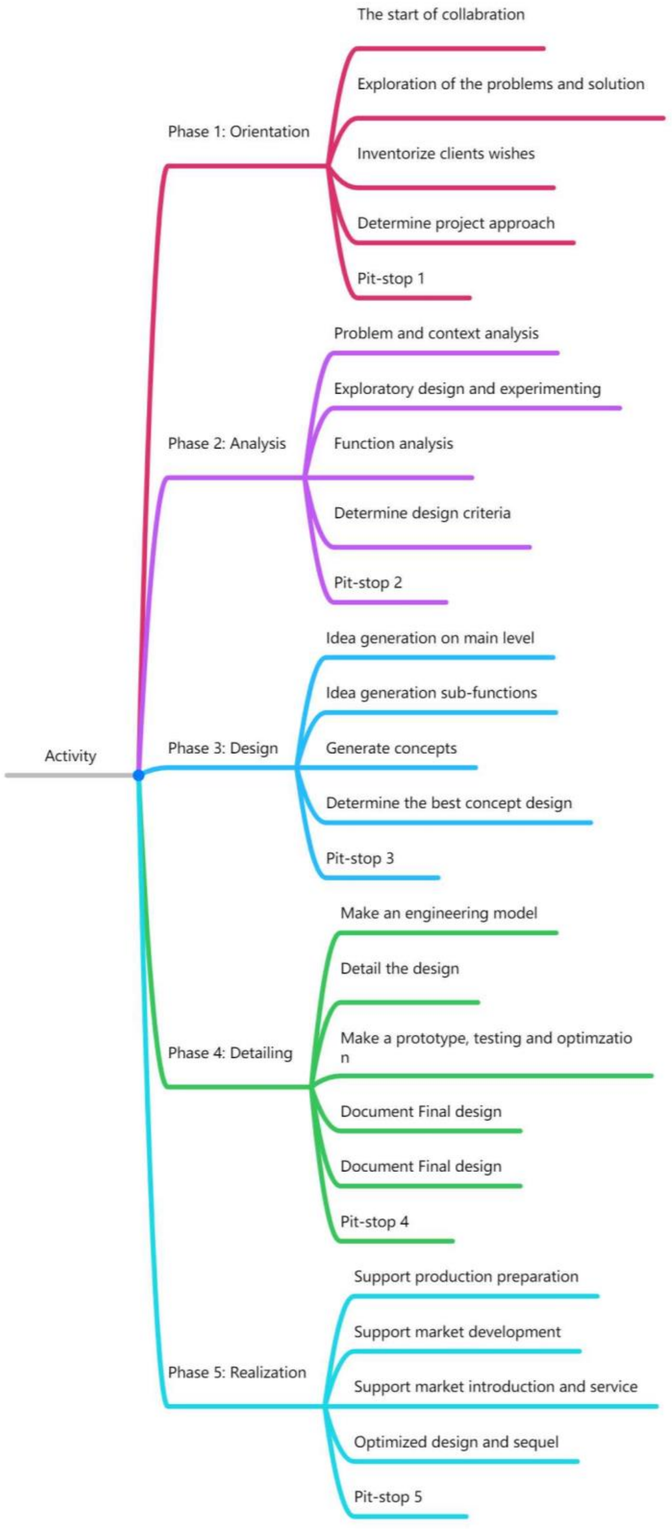


Figure 50 Activities in each Oskam-design phase

2. V-Method

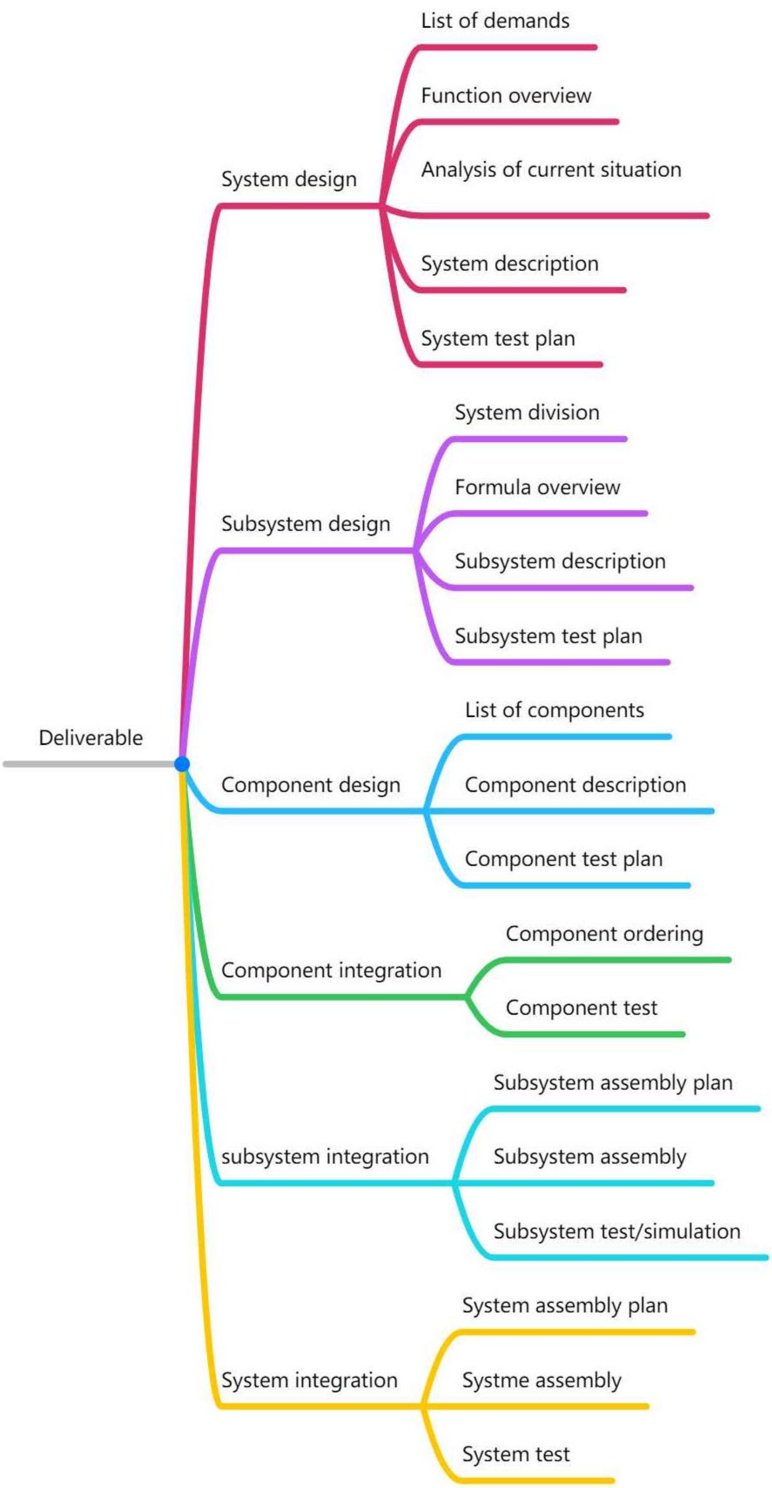


Figure 51 Deliverables in different phases

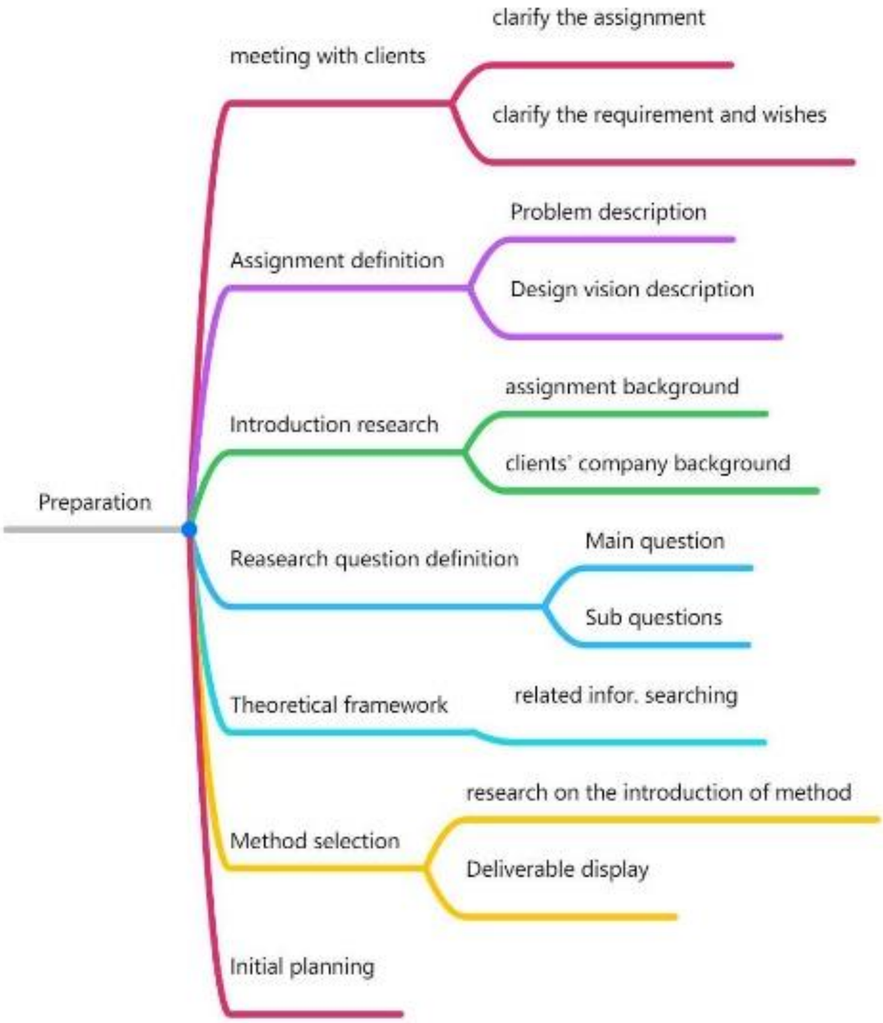


Figure 52 Stepwise activities whilst preparation

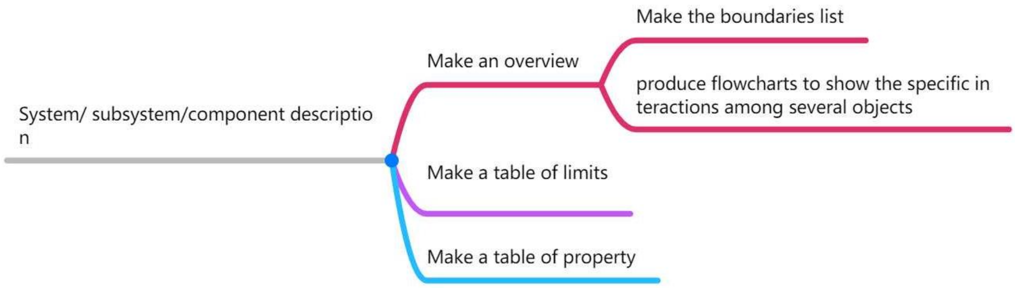


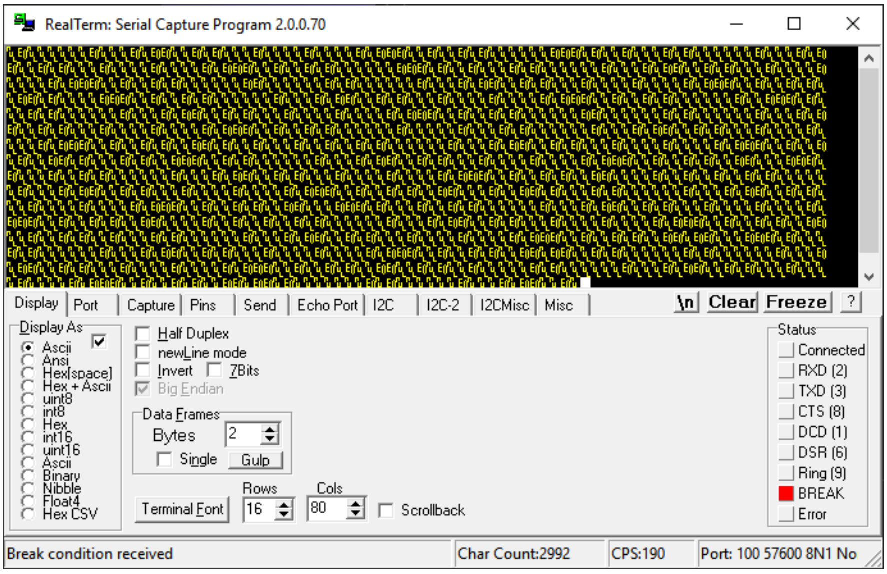
Figure 53 Allied activities of various V-model phases

Appendix 2: Data collection and processing

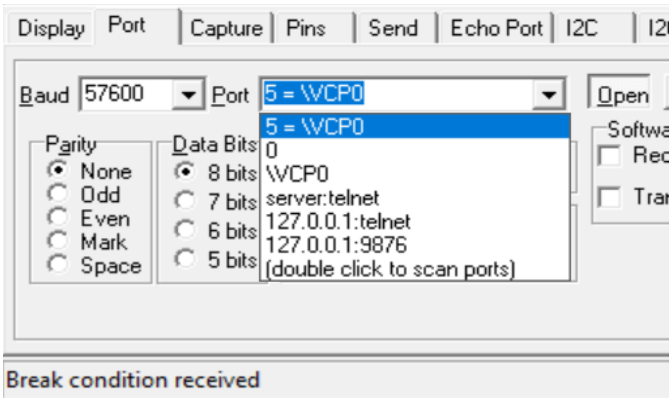
The EC sensor from imec can operate via RealTerm. The data can be viewed and logged in csv files with RealTerm. Then that csv file can be processed with applications like Excel, MATLAB, Python, etc.

The following steps will provide a clearer view of how to collect and process the data:

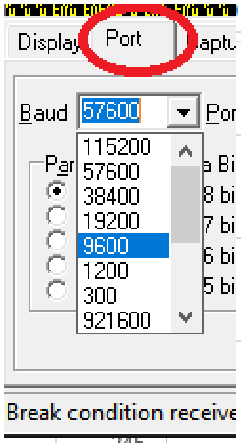
1. Download and install the application https://sourceforge.net/projects/realterm/files/latest/download
2. Plug the device into the USB port first.
3. Open RealTerm
4. It is possible the port is already open, then the random data will be seen. If so, skip to step 6.



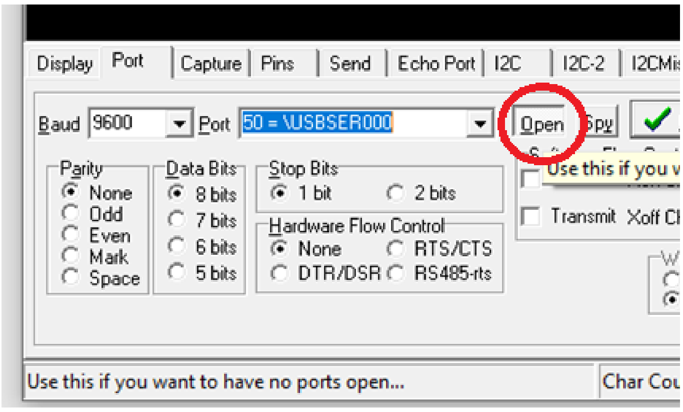
5. Open the "port" dropdown in the "port" tab. a device like "\VPCxx" should be observed. If not, double click on "double click to scan ports". If it is still not there, try to restart RealTerm. It can also take a couple of minutes for the device to be installed by windows, the first time plugging it in. Yet in rare cases, windows cannot automatically install the device.



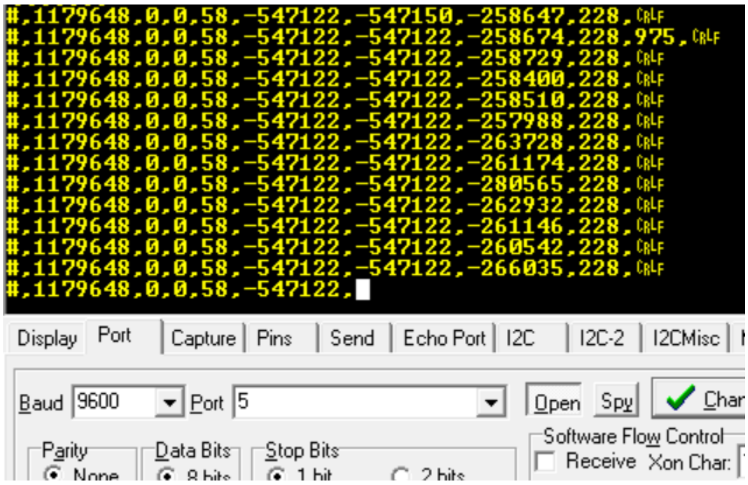
6. Go to the Port tab and select **9600** in the Baud dropdown for the EC readout. The ORP readout is set to the correct baud rate.



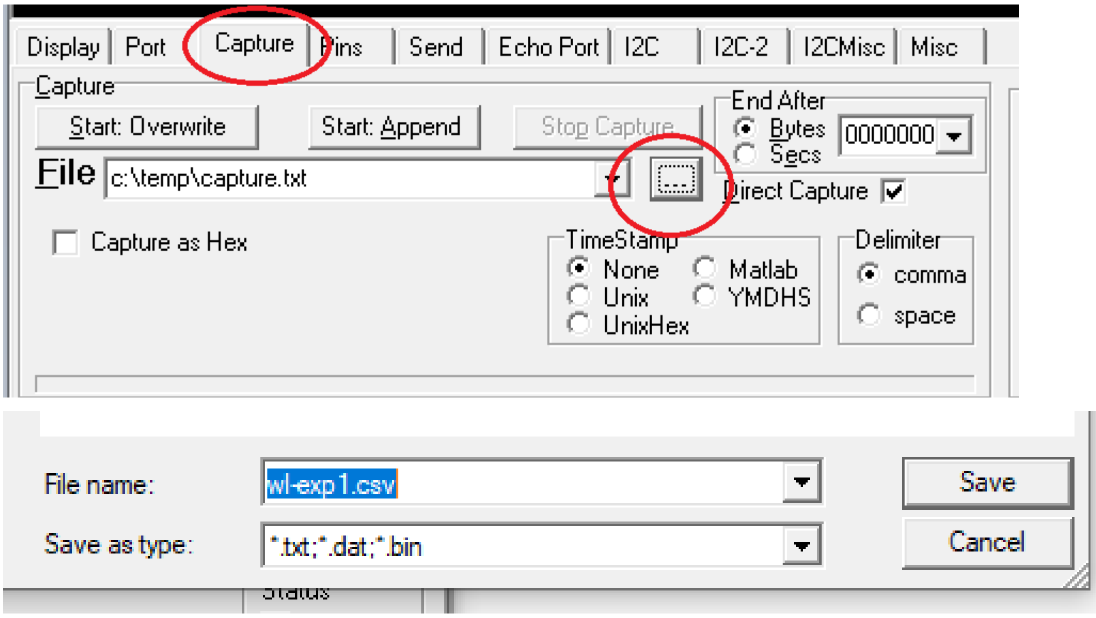
7. Now click on Open. If the device was already sending data, click open twice.



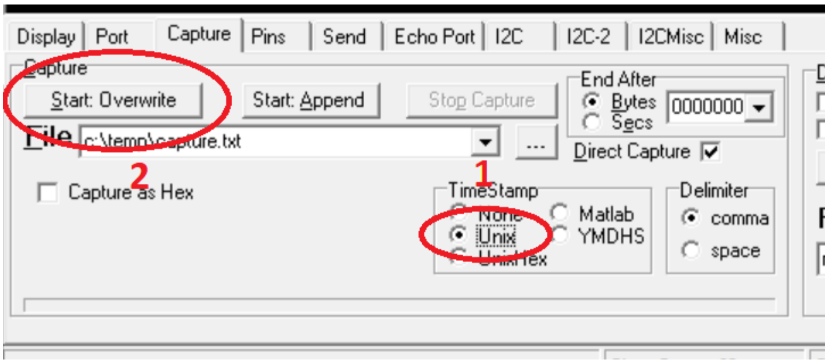
8. Now it should be seen a message like this every couple of seconds.



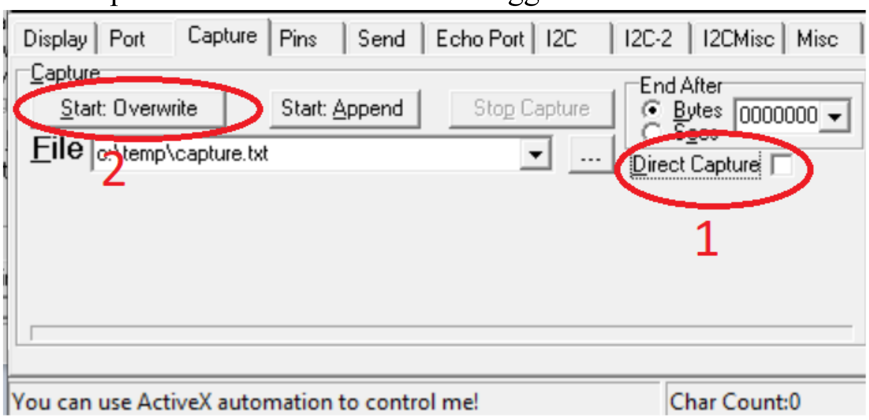
9. The data can also be stored in a file. Go to the capture tab and select a file location. The default location is C:\temp. Do not use this location, because the data can be lost when the device is turned off! End the filename with .csv. For example *exp1.csv*.



10. If you want a Timestamp on your data, select Unix (not UnixHex!). and click on “start overwrite”.
The output will no longer be visible in RealTerm, so you have to open and re-open the csv file in excel to see the new data.



If you do not care about a timestamp and just want to log data, you can uncheck “direct capture”. Then the data is both logged to file and visible in RealTerm.



11. The data can now be processed and plotted in Excel (or some other way). It is possible that Excel does not split the data on the commas.

A1 1612188229,#,1179648,0,0,58,-547122,-547122,-260405,229,

```
1612188229,#,1179648,0,0,58,-547122,-547122,-260405,229,
1612188231,#,1179648,0,0,58,-547122,-547122,-260075,229,
1612188232,#,1179648,0,0,58,-547122,-547122,-260240,229,
1612188234,#,1179648,0,0,58,-547122,-547122,-260157,229,
1612188235,#,1179648,0,0,58,-547122,-547122,-264387,229,
1612188237,#,1179648,0,0,58,-547122,-547122,-262602,229,
```

If this happens, open the csv file in notepad and add sep=, as the first line. Save the file and reopen in Excel.

*capture.csv - Notepad

File Edit Format View Help

```
sep=,
1612188229,#,1179648,0,0,58,-547122,-547122,-260405,229,
1612188231,#,1179648,0,0,58,-547122,-547122,-260075,229,
1612188232,#,1179648,0,0,58,-547122,-547122,-260240,229,
1612188234,#,1179648,0,0,58,-547122,-547122,-260157,229,
1612188235,#,1179648,0,0,58,-547122,-547122,-264387,229,
1612188237,#,1179648,0,0,58,-547122,-547122,-262602,229,
1612188238,#,1179648,0,0,58,-547122,-547122,-261915,229,
1612188240,#,1179648,0,0,58,-547122,-547122,-261943,229,
1612188241,#,1179648,0,0,58,-547122,-547122,-261558,229,
1612188243,#,1179648,0,0,58,-547122,-547122,-261338,229,
1612188244,#,1179648,0,0,58,-547122,-547122,-263179,229,
1612188246,#,1179648,0,0,58,-547122,-547122,-261476,229,
```

Now it will have columns.

A1 1612188229

	A	B	C	D	E	F	G	H	I	J	K	L
1	1.61E+09	#	1179648	0	0	58	-547122	-547122	-260405	229		
2	1.61E+09	#	1179648	0	0	58	-547122	-547122	-260075	229		
3	1.61E+09	#	1179648	0	0	58	-547122	-547122	-260240	229		
4	1.61E+09	#	1179648	0	0	58	-547122	-547122	-260157	229		
5	1.61E+09	#	1179648	0	0	58	-547122	-547122	-264387	229		
6	1.61E+09	#	1179648	0	0	58	-547122	-547122	-262602	229		
7	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261915	229		
8	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261943	229		
9	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261558	229		
10	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261338	229		
11	1.61E+09	#	1179648	0	0	58	-547122	-547122	-263179	229		
12	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261476	229		
13	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261476	229		
14	1.61E+09	#	1179648	0	0	58	-547122	-547122	-261256	229		
15	1.61E+09	#	1179648	0	0	58	-547122	-547122	-260377	229		

12. Because using unix timestamps, the data first must be converted. So, insert a column after column A and enter the following formula:

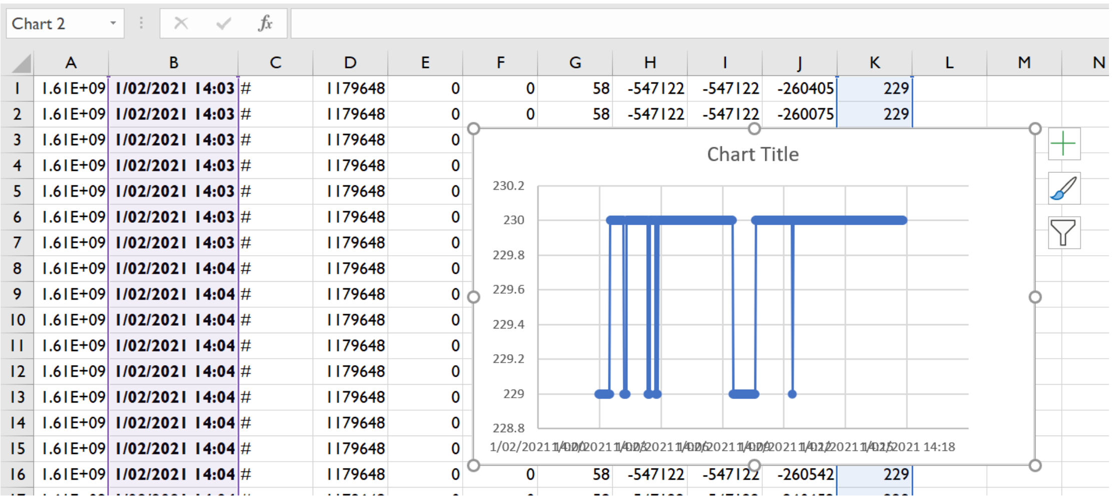
=(((A1/60)/60)/24)+DATE(1970,1,1)

and apply that to the whole column.

B1 =(((A1/60)/60)/24)+DATE(1970,1,1)

	A	B	C	D	E	F	G	H	I	J	K
1	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-260405	229
2	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-260075	229
3	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-260240	229
4	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-260157	229
5	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-264387	229
6	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-262602	229
7	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-261915	229
8	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-261943	229
9	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-261558	229
10	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-261338	229
11	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-263179	229
12	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-261476	229
13	1.61E+09	**44228.6**	#	1179648	0	0	58	-547122	-547122	-261476	229

13. The date can now be formatted as date or time and plotted.



Appendix 3: Embedded chip of new EC sensor

The new chip is embedded in the new generation EC-sensor to achieve the function of measuring a variety of parameters. The details of the new chip from imec have shown in Picture 6. The dimension of the chip is 8mm*9.5mm. The EC-meter is not ion-selective, but measures the conductance affected by the total ion concentration.

In terms of conductivity, it has the range from 5 to 100000 µS/cm within ±0.1 accuracy

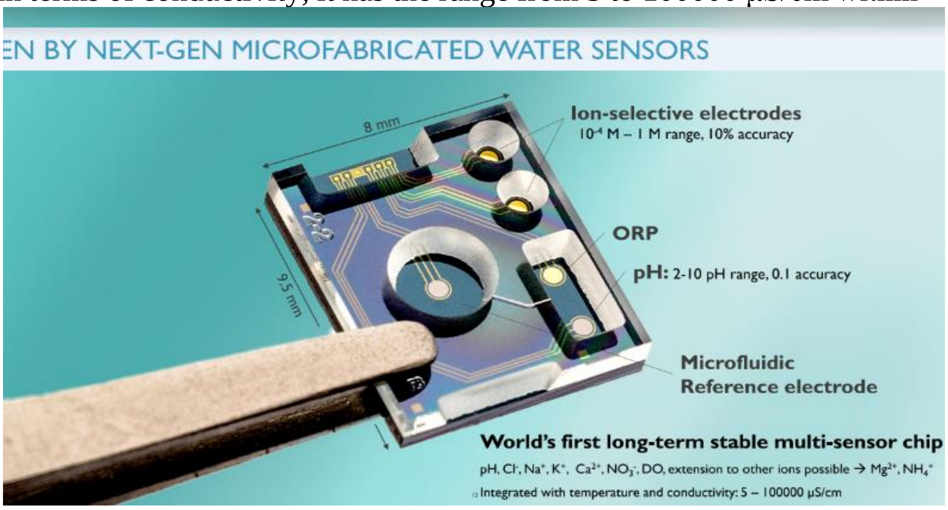


Figure 54 The configuration of the new generation chip

as well by applying interdigitated electrodes as a sensing mechanism and impedimetric readout. Its sensitivity is adjustable. Meanwhile, the TRL with level 7 implies a mature usage of the technology. Although other parameters of the sensor are not in the case of the project, Picture 7 gives a clear browse as an extra knowledge.

Parameter	Sensing mechanism	Readout	Range	Accuracy	Sensitivity	TRL
Reference electrode	Microfluidic channel + reservoir	Potentiometric	-	Drift < 0.1 mV/day	-	7
pH	Metal oxide electrode	Potentiometric	2-10	0.02 pH point	>59 mV/pH	7
Conductivity	Interdigitated electrodes	Impedimetric	5 – 100000 µS/cm	<10% of reading	adjustable	7
ORP	Pt electrode	Potentiometric	-1 V - +1 V	10 mV	-	7
Chloride	AgCl electrodes	Potentiometric	10^{-4} – 1 M	<10% of reading	50-59 mV/dec	7
Sodium	Ion-selective membrane	Potentiometric	10^{-4} – 1 M	<10% of reading	50-59 mV/dec	5
Potassium	Ion-selective membrane	Potentiometric	10^{-4} – 1 M	<10% of reading	50-59 mV/dec	5
Nitrate	Ion-selective membrane	Potentiometric	10^{-4} – 1 M	<10% of reading	50-59 mV/dec	5
Calcium	Ion-selective membrane	Potentiometric	10^{-4} – 1 M	<10% of reading	23-26 mV/dec	3
Dissolved oxygen	Direct oxidation	Amperometric	0 – 9 mg/L	50 ppb	120 – 130 nA/mg/L	3

Figure 55 Various parameters of the sensor

Appendix 4: The conductivity range of various liquids

Table 17 The conductivity range of various liquids (Goossen, The conductivity range of various liquids, 2021)

Solution	Conductivity Range	Optimum Cell Constant
Ultra-pure water	0.05 µS/cm	0.01
Power plant or boiler water	0.05-1 µS/cm	0.01 or 0.1
Drinking water	150-800 µS/cm	1.0
Cooling tower water	0-5mS/cm	1.0
Wastewater effluent	0.9-9 mS/cm	1.0
Ocean water	53 mS/cm	10 (consider toroidal measurement)
29% Nitric Acid	865 mS/cm	100 (consider toroidal measurement)

Appendix 5: Test plan

All the test plans will be split into two stages, measurement stage and coupling stage. Each stage will have their own demo test plan to go with signature from clients.

In every test plan , there are 6 parts to state:

1. Aim: the purpose of the experiment/test
2. Hypothesis: expected scenario of the results
3. Variables: The variables of the system
4. Tools: The tools that will applied during the test
5. Method: The steps for executing the test
6. Expected results: ideal and expected scenario.

1. Measurement stage

Measurement Demo Test Plan

1. Aim

The new generation conductivity sensor is provided by imec. The demo test plan aims to prove that the experiments can measure and dispose the data of main performance correctly, including working range, accuracy, stability, and sensitivity.

2. Hypothesis

The experiments enable to figure out the main performance of the new generation electronic conductivity sensor, regarding stability, working range, accuracy, and sensitivity.

3. Variables

3.1 Input & Output

The initial inputs and outputs of the measurement system are shown.

Table 18 Input of the measurement system

Nr.	Input	Unit
1	Water with different salt concentrations	µ S/cm

Table 19 Output of the measurement system

Nr.	Output	Unit
1	Working range	µ S/cm
2	Stability	/

3	Accuracy	/
4	Sensitivity	/

3.2 Limit & Property

The limit and property mentioned below illustrate the variables that the tester is going to keep constant and going to vary and/or measure, respectively.

Each limit will be defined as an exact value to eliminate potential bad conditions during the test execution.

Table 20 Limit of the measurement system

Nr.	Limit	Keep constant within..
1	Water temperature	Lower limit at 0°C, Upper limit at 30°C

The properties are the variables which researchers are going to vary and/or measure. And to vary certain properties, researchers will vary certain limits as well.

Table 21 Property of the measurement system

Nr.	Property	Unit	Vary/ or measure?	Limit of property
1	Water with different salt concentration	µ S/cm	Vary	0.05 µ S/cm-80000 µ S/cm
2	Working range	µ S/cm	Measure	/
3	Stability	/	Measure	/
4	Accuracy	/	Measure	/
5	Sensitivity	/	Measure	/

4. Tools

- Stirring rod
- EC-Sensor with USB-connected readout device
- Laptop
  - RealTerm software: get the data from the sensor
  - Excel: dispose the data
  - Charge the sensor as a battery
- Water
  - With Known-proportional concentrations.
  - With unknown concentrations (can be sent to laboratory and measured accurately)
- Demineralized water
  - To wash the probes between the tests.

- To make other unknown solutions
- The waterproof thermometer
    - To double check the temperature of the water

5. Method

This phase mainly introduces how clients can verify the results. It is composed of a humorous comic strip form and a clear text form. The step numbers in the comic correspond to those in the text table.

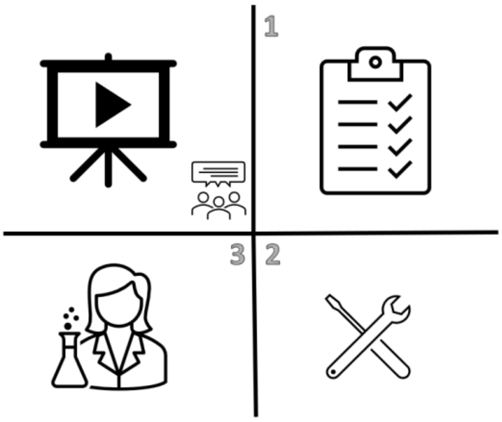


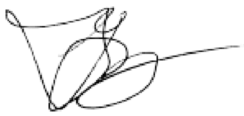
Figure 56 Comic on verifying the results of the measurement stage

Clear text on verifying the results of the measurement stage	
Synopsis: giving a presentation regarding the measurement experiments	
1	Declare the performance items that have been investigated during the project period and throw out their values.
2	Present the used tools and the related references.
3	Explain how the value comes out and how to conduct each experiment in a brief yet essential way.

6. Expected Results

The EC-sensor can transfer the data to the laptop successfully. The performance of the sensor as to the working range, stability, accuracy, and sensitivity can be worked out via Excel.

Clients signature:



Date: 2021-3-16

Measurement System Validation Test Plan

1. Aim

The new generation conductivity sensor is provided by imec. The purpose of this test is to use the sensor's accuracy in measuring solutions of different concentrations to provide users with a reference for the definition of the working range. The user can specify the working range of the sensor according to the accuracy required by the test. In other words, the working range is floatable to match the demand. Meanwhile, the sensitivity and stability of the new sensor will be investigated during the test.

2. Hypothesis

The working range, stability, accuracy, and stability of the new generation conductivity sensor have been measured with some reliable results coming out. The results show by numerical values and graphs.

3. Variables

The limit and property mentioned below illustrate the variables that the tester will keep constant and vary and/or measure.

Each limit will be defined as an exact value to eliminate potential bad conditions during the test execution.

Table 22 Limit of the measurement system

Nr.	Limit	Keep constant within..
1	Water temperature(unknown)	Lower limit at 0°C, Upper limit at 30°C

Table 23 Property of the measurement system

Nr.	Property	Unit	Vary/ or measure?	Limit of property
1	Raw resistance of the EC measurement	Ω	Measure	1.33 ~ 80000
2	The phase of the EC measurement	/	Measure	-10~10
				-190~-170
				170~190
				The number out of these three scopes means the measurement is invalid.

3	ROD error	/	Measure	If the value is not 0, the data is invalid.
4	Water temperature (sensor-tested)	℃	Measure	0-30
5	Water with different salt concentration			From demineralized water to sea water.

Table 24 the process of 4-criteria

Nr.	4-criteria	Unit	Process/directly output
1	Working range	μ S/cm	Process
2	Stability	/	Process
3	Accuracy	/	Process
4	Sensitivity	/	Process

4. Tools

- Stirring rod
- EC-Sensor with USB-connected readout device
- Laptop
  - RealTerm software: get the data from the sensor
  - Excel: dispose the data
  - Charge the sensor as a battery
- Water
  - With Known-proportional concentrations.
  - With unknown concentrations (can be sent to laboratory and measured accurately)
- Demineralized water
  - To wash the probes between the tests.
  - To make other unknown solutions
- The waterproof thermometer
  - To double check the temperature of the water

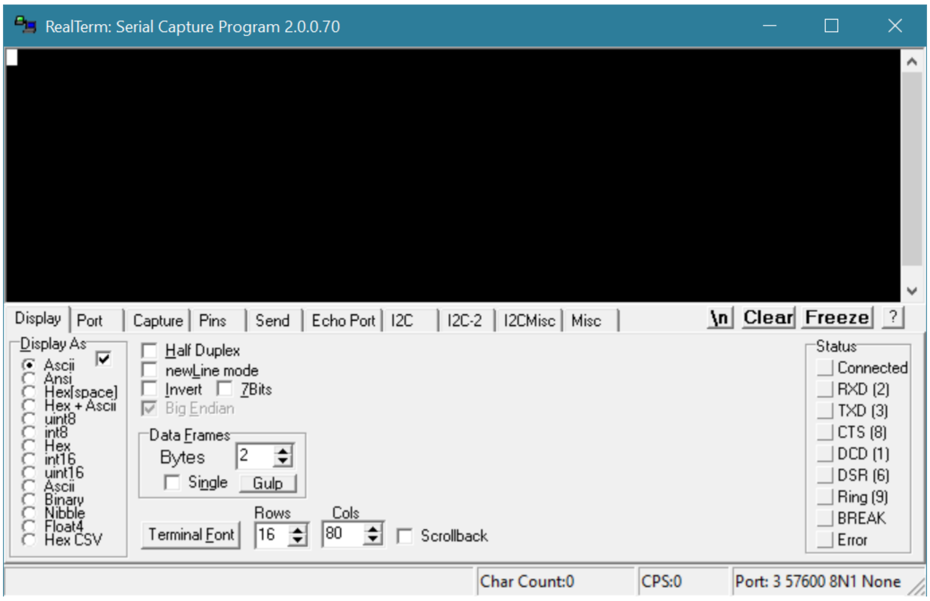
5. Method

Here are the steps that is going to be applied in the test:

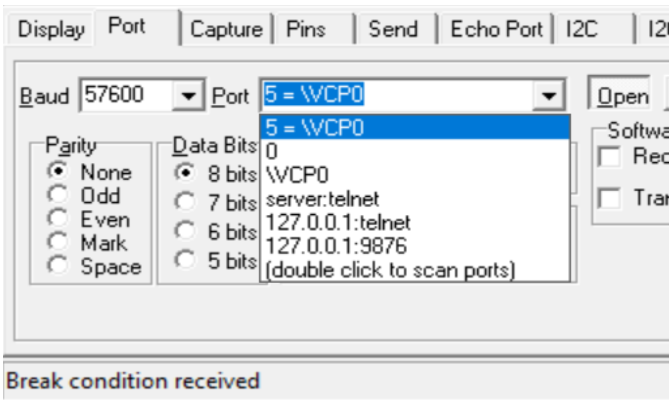
Preparation before the test:

1. Select 10-15 samples with different salt concentrations to be the test objectives and make a list.
2. Go to the lab, prepare the solutions by adding accurate weight of salt to the demineralized water.
3. Pour them over into different bottles with corresponding sample& concentration labels.

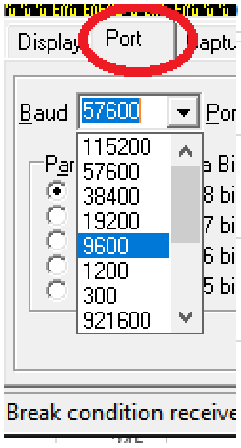
4. Plug the device into the USB port.
5. Open the RealTerm software.



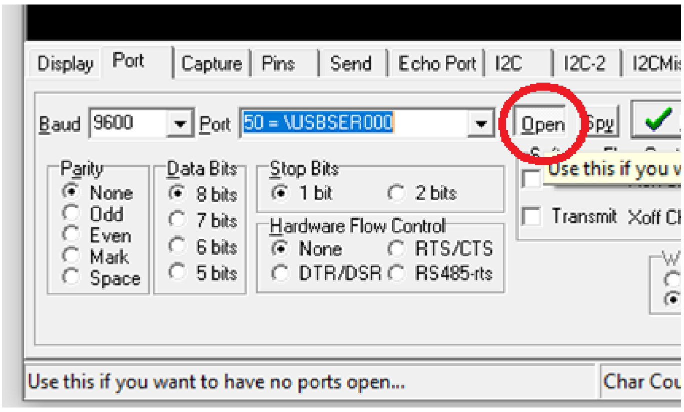
6. It is possible that the port is already open. The random data has been seen. If so, skip into step 5.
7. Open the “port” dropdown in the “port” tab. a device like “\VPCxx” should be observed. If not, double click on “double click to scan ports”. If it is still not there, try to restart RealTerm. It can also take a couple of minutes for the device to be installed by windows, the first time plugging it in. Yet in rare cases, windows cannot automatically install the device.



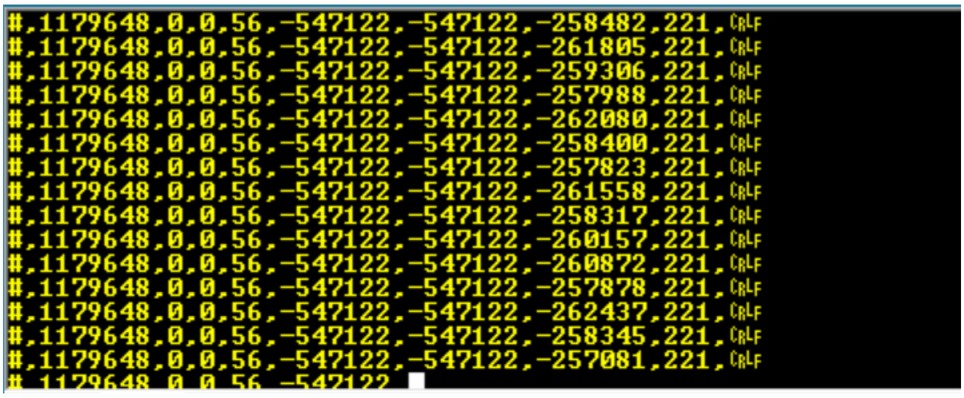
8. Go to the Port tab and select **9600** in the Baud dropdown for the EC readout. The ORP readout is set to the correct baud rate.



9. Now click on Open. If the device was already sending data, click open twice.



10. Now it should be seen a message like this every couple of seconds. The software is ready.



Officially start the test:

i. Regarding working range, accuracy:

11. Measure the temperature of the testing solution by waterproof thermometer.
12. Put the sensor in the test-wanted solution.
13. Go to Capture tab.
14. Click '…' button to create a saving path. Remember change the file type end by csv.

15. Uncheck the button ‘Direct Capture’.
16. Click ‘Start: Overwrite’
17. Test for until the data is stable.
18. Click ‘Stop capture’
19. Take out the sensor and put it in the demineralized water to clean the probes.
20. Unfold the csv document.
21. Outliers removed.
22. Work out the temper corrected impedance.
23. Highlight all the data in a relative stable condition, calculate out the average value of these data.
24. Record the average value in the table of each corresponding concentration.
25. Repeat step 11-24 until all the solutions have been measured.
26. Click ‘Stop capture’
27. Deliver all the tested solutions to the lab for the accurate values under salt concentration and conductivity, record them in table 1 as well.
28. Calculate out the accuracy of samples and record it in the table 2.
    Accuracy formula is set below:

$$Accuracy = \frac{|Measured\ value - Referenced\ value|}{Referenced\ value}$$

Sample	Lab Sodium chloride(g/l)	Measured conductivity result(μ S/cm)	Lab conductivity result(μ S/cm)	Accuracy
1				
n				

ii. Regarding the stability

29. Select one of the self-regulating solutions(or using well-proportional solutions) which has known conductivity(proved by reliable institution).
30. Put the sensor in the test-wanted solution.
31. Go to Capture tab.
32. Click ‘…’ button to create a saving path. Remember change the file type end by csv.
33. Uncheck the button ‘Direct Capture’.
34. Click ‘Start: Overwrite’
35. Test for until the data is stable.
36. Click ‘Stop capture’
37. Take out the sensor and put it in the demineralized water to clean the probes.
38. Unfold the csv document.
39. Outliers removed.
40. Work out the temper corrected impedance.
41. Calculate out the RSD.

iii. Regarding the sensitivity

42. Exhibit the list of salt concentration and measured conductivity of all sample solutions from **i: Regarding the working range and accuracy**.
43. Take measured conductivity value(μS/cm) as x axis and lab conductivity value(μS/cm) as y axis to work out Sn.

6. Expected Results

The test can find out the accuracy value of solutions which have different salt concentrations from 40 μS/cm to 60000 μS/cm, respectively. Moreover, the accuracy is expected to be in a reasonable range, which means the specification of EC-sensor provided by imec is exact. The new EC-sensor is qualified. The stability and the sensitivity of new sensor are expected to be investigated out.

2. Coupling stage

Coupling Demo test plan

1. Aim

The new generation conductivity sensor is provided by imec. The test aims to prove that the new EC-sensor coupling system can work properly.

2. Hypothesis

If the LCD display can show the temp corrected impedance or error status computed by the outputs of the new EC sensor, and display all measured values via serial monitor, then the new EC-sensor coupling system works properly.

3. Variables

The initial input and output will show below:

Table 25 The input of coupling system(demo)

Nr.	Input	Unit
1	Water temperature(unknown)	℃
2	Water with different salt concentration	μS/cm
3	Raw resistance of the EC measurement	Ω
4	The phase of the EC measurement	/
5	ROD error	/
6	Water temperature (sensor-tested)	℃
7	The temp corrected impedance	Ω

N.B. 1. Water temperature(unknown): the temperature is still unscanned, but to prevent too low or too high temperature will damage the sensor, the temperature should be firstly controlled in a proper scope.

2. Water temperature(sensor-tested): the temperature has been scanned by EC sensor.

3. The upper 3-6 items are the outputs from new generation EC sensor, they directly display on the 'RealTerm' interface and record in the file.

Table 26 The output of coupling system(demo)

Nr.	Output	Unit
1	The temp corrected conductivity	μ S/cm

The limit and property mentioned in Table 26 illustrate the variables that the tester will keep constant and vary and/or measure.

Each limit will be defined as an exact value to eliminate potential bad conditions during the test execution.

Table 27 Limit of the coupling system(demo)

Nr.	Limit	Keep constant within..
1	Water temperature(unknown)	Lower limit at 0℃, Upper limit at 30℃

Table 28 Property of the coupling system(demo)

Nr.	Property	Unit	Vary/ or measure?	Limit of property
1	Raw resistance of the EC measurement	Ω	Measure	1.33 ~ 80000
2	The phase of the EC measurement	/	Measure	-10~10 -190~-170 170~190 The number out of these three scopes means the measurement is invalid.
3	ROD error	/	Measure	If the value is not 0, the data is invalid.
4	Water temperature (sensor-tested)	℃	Measure	0-30

5	Water with different salt concentration	μS/cm	Vary	From demineralized water to sea water.
6	The temp corrected impedance	Ω	Measure	/
7	The temp corrected conductivity	μS/cm	Measure	/

4. Tools

- imec EC-sensor coupling system prototype
- BOB-11189 by Sparkfun
- Laptop with USB port
- 5V battery pack
- Calibration solution: 1413μS/cm
- Demineralized water
  - To wash the probes between the tests.
- The waterproof thermometer
  - To check the temperature of the water before testing

5. Method

i. Use waterproof thermometer to check
ii. Turn on the device via 5V battery pack/ USB port of laptop.
iii. Set the probe of the EC-sensor into the calibration solution.
iv. Observe if the LCD display shows the temp corrected conductivity.
v. Open the serial monitor in Arduino IDE and observe if it shows all the measured values timely.
vi. Record the error and present it to the client.

6. Expected results

If the temp corrected conductivity can display on LCD display timely, meanwhile, all the measured values can show via serial monitor , it proves that the new EC-sensor coupling system can work properly.

Client's signature:

Date: April 14th 2021

Coupling System Validation Test Plan

1. Aim

The new generation conductivity sensor is provided by imec. The test aims to prove that the new EC-sensor coupling system can work properly.

2. Hypothesis

If the LCD display can show the temp corrected impedance or error status computed by the outputs of the new EC sensor, and display all measured values via serial monitor, then the new EC-sensor coupling system works properly.

3. Variables

The input and output will show below:

Table 29 The input of coupling system

Nr.	Input	Unit
1	Water temperature(unknown)	℃
2	Water with different salt concentration	μ S/cm
3	Raw resistance of the EC measurement	Ω
4	The phase of the EC measurement	/
5	ROD error	/
6	Water temperature (sensor-tested)	℃
7	The temp corrected impedance	Ω

Table 30 The output of coupling system

Nr.	Output	Unit
1	The temp corrected conductivity	μ S/cm

The limit and property mentioned in Table 31 and Table 32 illustrate the variables that the tester will keep constant and vary and/or measure.

Each limit will be defined as an exact value to eliminate potential bad conditions during the test execution.

Table 31 Limit of the system

Nr.	Limit	Keep constant within..
1	Water temperature(unknown)	Lower limit at 0°C, Upper limit at 30°C

Table 32 Property of the system

Nr.	Property	Unit	Vary/ or measure?	Limit of property
1	Raw resistance of the EC measurement	Ω	Measure	1.33 ~ 80000

2	The phase of the EC measurement	/	Measure	-10~10
				-190~-170
				170~190
				The number out of these three scopes means the measurement is invalid.
3	ROD error	/	Measure	If the value is not 0, the data is invalid.
4	Water temperature (sensor-tested)	℃	Measure	0-30
5	Water with different salt concentration	μS/cm	Vary	From demineralized water to sea water.
6	The temp corrected impedance	Ω	Measure	/
7	The temp corrected conductivity	μS/cm	Measure	/

4. Tools

- imec EC-sensor coupling system prototype
- Laptop with USB port
- 5V battery pack
- Calibration solution: 1413μS/cm
- Demineralized water
  - To wash the probes between the tests.
- The waterproof thermometer
  - To check the temperature of the water before testing

5. Method

1. Use waterproof thermometer to check if the temperature is between 0-30℃.
2. Turn on the device via 5V battery pack/ USB connection of laptop.
3. Set the probe of the EC-sensor into the calibration solution.
4. Observe if the LCD display shows the temp corrected conductivity.
5. Open the serial monitor in Arduino IDE and observe if it shows all the measured values timely.
6. Record the error and present it to the client.

6. Expected Results

If the temp corrected conductivity can display on LCD display timely, meanwhile, all the measured values can show via serial monitor , it proves that the new EC-sensor coupling system can work properly.

EC-sensor Subsystem Validation Test Plan

1. Aim

The new generation EC-sensor is provided by imec. The test aims to prove that the new EC-sensor can export valid data without caring about the quality of outputs from the sensor.

2. Hypothesis

If RealTerm can show all the measured data from the sensor the outputs of the new EC sensor, and display all measured values via serial monitor, then the new EC-sensor coupling system works properly.

3. Variables

The input and output will show below:

Table 33 The input of EC-sensor subsystem

Nr.	Input	Unit
1	Water temperature(unknown)	℃
2	Water with different salt concentration	μ S/cm

Table 34 The output of EC-sensor subsystem

Nr.	Output	Unit
1	Raw resistance of the EC measurement	Ω
2	The phase of the EC measurement	/
3	ROD error	/
4	Water temperature (sensor-tested)	℃

Table 35 Limit of EC-sensor subsystem

Nr.	Limit	Keep constant within..
1	Water temperature(unknown)	Lower limit at 0℃, Upper limit at 30℃.
2	Water with different salt concentration	Lower limit at demineralized water, Upper limit at sea water.

Table 36 Property of EC-sensor subsystem

Nr.	Property	Unit	Vary/ or measure?	Limit of property

1	Raw resistance of the EC measurement	Ω	Measure	1.33 ~ 80000
2	The phase of the EC measurement	/	Measure	-10~10
				-190~-170
				170~190
				The number out of these three scopes means the measurement is invalid.
3	ROD error	/	Measure	If the value is not 0, the data is invalid.
4	Water temperature (sensor-tested)	℃	Measure	0-30

4. Tools

- imec EC-sensor with USB connection
- Laptop with USB port
- Calibration solution: 1413μS/cm
- Demineralized water
  - To wash the sensor probes
- The waterproof thermometer
  - To check the temperature of the water before testing

5. Method

1. Use waterproof thermometer to check if the temperature is between 0-30℃.
2. Turn on the EC-sensor via USB connection of laptop.
3. Set RealTerm to the correct baud rate, port and save path.
4. Set the probe of the EC-sensor into the demineralized water, tap water, calibration solution, respectively.
5. Observe the outputs showing on RealTerm.

6. Expected Results

If imec EC-sensor can output valid data when testing calibration solution and tap water ,and output invalid data when testing demineralized water, it proves that new EC-sensor can be used in prototype build-up.

Arduino Subsystem Validation Test Plan

1. Aim

The test aims to prove that the new EC-sensor can couple with Arduino and display all the measured data on serial monitor.

※The new generation EC-sensor is provided by imec.

2. Hypothesis

If Arduino can display all the measured data on serial monitor, then the new EC-sensor couples with Arduino successfully.

3. Variables

The input and output will show below:

Table 37 The input of Arduino subsystem

Nr.	Input	Unit
1	Water temperature (unknown)	℃
2	Water with different salt concentration	μ S /cm

Table 38 The output of Arduino subsystem

Nr.	Output	Unit
1	The ID of the readout	/
2	Raw resistance of the EC measurement	Ω
3	The phase of the EC measurement	/
4	ROD error	/
5	Voltage A in mV	/
6	Voltage B in mV	/
7	Voltage C in mV	/
8	Water temperature (sensor-tested)	℃

※1. Water temperature(sensor-tested): the temperature has been scanned by EC sensor.

2. The upper 1-8 items are the outputs from new generation EC sensor, they directly display on the 'RealTerm' interface and record in the file.

Table 39 Limit of Arduino subsystem

Nr.	Limit	Keep constant within..
1	Water temperature(unknown)	Lower limit at 0℃, Upper limit at 30℃.

2	Water with different salt concentration	Lower limit at demineralized water, Upper limit at sea water.

Table 40 Property of Arduino subsystem

Nr.	Property	Unit	Vary/ or measure?	Limit of property
1	The ID of the readout	/	Measure	/
2	Raw resistance of the EC measurement	Ω	Measure	1.33 ~ 80000
3	The phase of the EC measurement	/	Measure	-10~10
				-190~-170
				170~190
				The number out of these three scopes means the measurement is invalid.
4	ROD error	/	Measure	If the value is not 0, the data is invalid.
5	Voltage A in mV	/	Measure	/
6	Voltage B in mV	/	Measure	/
7	Voltage C in mV	/	Measure	/
8	Water temperature (sensor-tested)	℃	Measure	0-30

※ Items 1-8 should be measured and displayed on serial monitor

4. Tools

- Laptop with USB port
- The waterproof thermometer
  - To check the temperature of the water before testing

5. Method

1. Use waterproof thermometer to check if the temperature is between 0-30℃.
2. Turn on the Arduino via 5V battery set/USB connection of laptop.
3. Set the probe of the EC-sensor into the calibration solution.
4. Observe if the serial monitor in Arduino IDE shows all the measured outputs from EC-sensor like below.
   #,1179648,645,1,0,-547122,-547122,-254747,228,

6. Expected Results

If the serial monitor in IDE can display all the measured data from sensor, it proves that new EC-sensor can couple with Arduino properly.

Display Subsystem Validation Test Plan

1. Aim

The test aims to prove that LCD display can show conductivity or error status directly.

※The new generation EC-sensor is provided by imec.

2. Hypothesis

If LCD can display the conductivity or error status directly, then Arduino works with LCD successfully.

3. Variables

The input and output will show below.

Table 41 The input of display subsystem

Nr.	Input	Unit
1	The ID of the readout	/
2	Raw resistance of the EC measurement	Ω
3	The phase of the EC measurement	/
4	ROD error	/
5	Voltage A in mV	/
6	Voltage B in mV	/
7	Voltage C in mV	/
8	Water temperature (sensor-tested)	℃

※1. Water temperature(sensor-tested): the temperature has been scanned by EC sensor.

2. The upper 1-8 items are the outputs from new generation EC sensor.

Table 42 The output of display subsystem

Nr.	Output	Unit
1	The temp-corrected conductivity or Error	μ S /cm

Table 43 Limit of the display subsystem

Nr.	Limit	Keep constant within..
1	There is no limit in this system.	

Table 44 Property of the display subsystem

Nr.	Property	Unit	Vary/ or measure?	Limit of property
1	The ID of the readout	/	Measure	/
2	Raw resistance of the EC measurement	Ω	Measure	1.33 ~ 80000
3	The phase of the EC measurement	/	Vary	-10~10
				-190~-170
				170~190
				The number out of these three scopes means the measurement is invalid.
4	ROD error	/	Vary	If the value is not 0, the data is invalid.
5	Voltage A in mV	/	Measure	/
6	Voltage B in mV	/	Measure	/
7	Voltage C in mV	/	Measure	/
8	Water temperature (sensor-tested)	℃	Measure	0-30℃
9	The temp-corrected conductivity or Error	μS /cm	Measure	40-60000

※ Items 1-8 should be measured and displayed on serial monitor

4. Tools

- Laptop with USB port

5. Method

1. Wire the sensor, Arduino and LCD.
2. Turn on the Arduino via 5V battery set/USB connection of laptop.
3. See if LCD display shows the value of conductivity or error status alternatively.

4. Vary the phase of the EC measurement and ROD error manually in the code to see if LCD can reveal correct status in different scope.

6. Expected Results

If LCD display can reveal correct status in different scope, it proves that LCD successfully connected with Arduino-EC sensor.

Appendix 6: Test results

1. Measurement stage

Measurement System Test Results

Test setup

The figure shows the test setup of measurement system. It contains a laptop running with RealTerm, the new generation EC sensor, the demineralized water, test-wanted samples, cups, iron support, thermometer and 5V battery pack. The stuffs in red block are the indispensable elements ,and the ones in blue dotted block are unnecessary if the temperature module of EC sensor is usable.

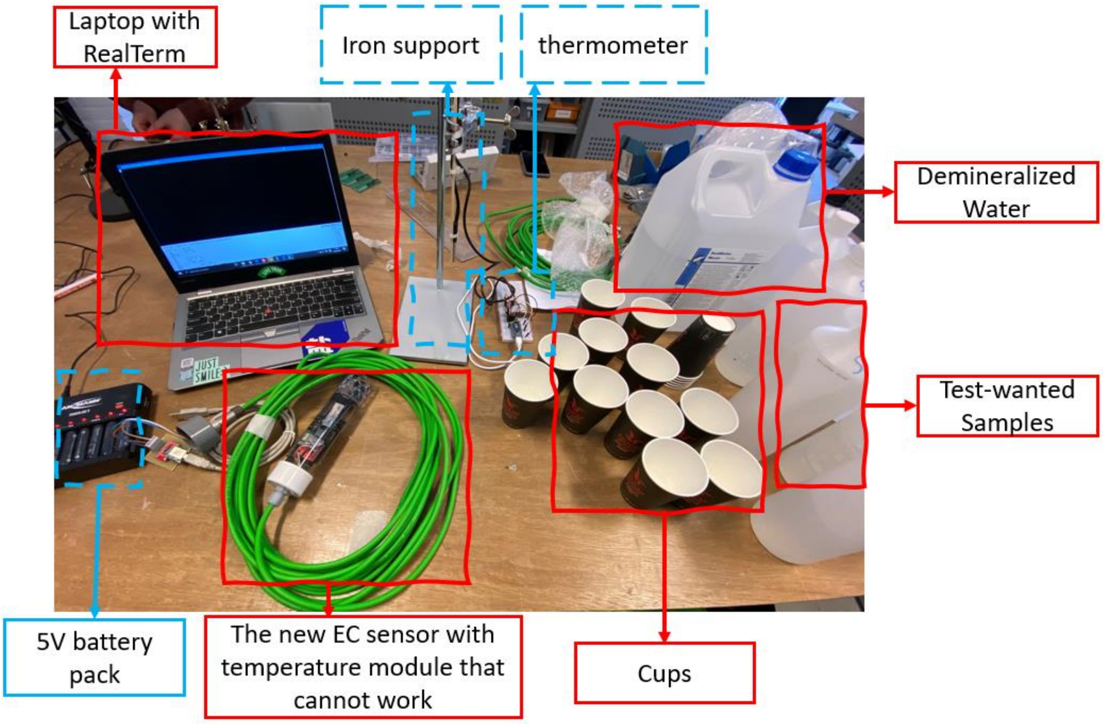


Figure 57 The test setup of measurement system

Preliminary test

During the preliminary test, to make sure the EC sensor can work properly with a large probability before official long-term experiment, it should output valid numbers by measuring tap water lasting 1 minute.

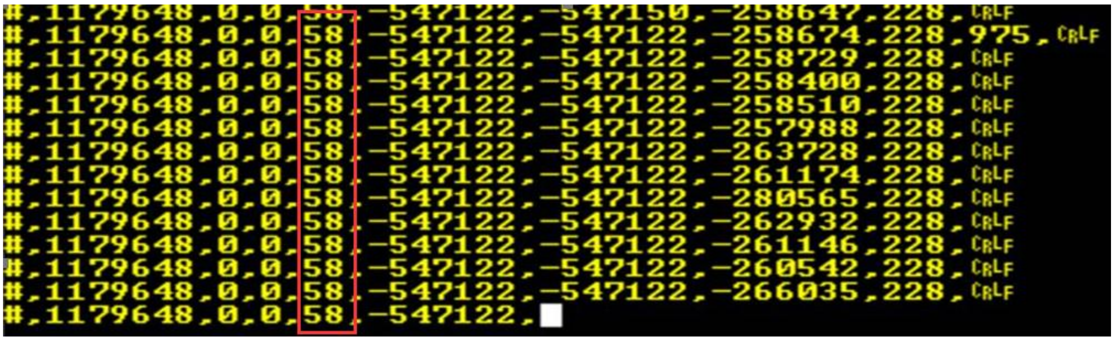
Output (Duration: 1minute)	Status
⩾95% are valid	To go

<95% are valid	Not go

i. The first version of EC sensor

Put the sensor in tap water, there is no valid number coming out.

Output (Duration: 1minute)	Status
<95% are valid	Not go



ii. The waterproof version of EC sensor
Pretest the sensor with tap water, the outputs are almost(95%) valid.

Output	Status
⩾95% are valid	To go

Preparation before testing

The following sheet shows how to get these elements:

Elements	How to acquire
Laptop	Ready-made
The new generation EC sensor	Ready-made
The demineralized water	From HZ lab/ order from other company
Test-wanted samples	Self-made in HZ lab
Cups	Ready-made
Standard value	From the laboratory
Calibration solution	Ready-made
Iron support	Ready-made
Thermometer and 5V battery pack	Ready-made
Thermometer	Ready-made

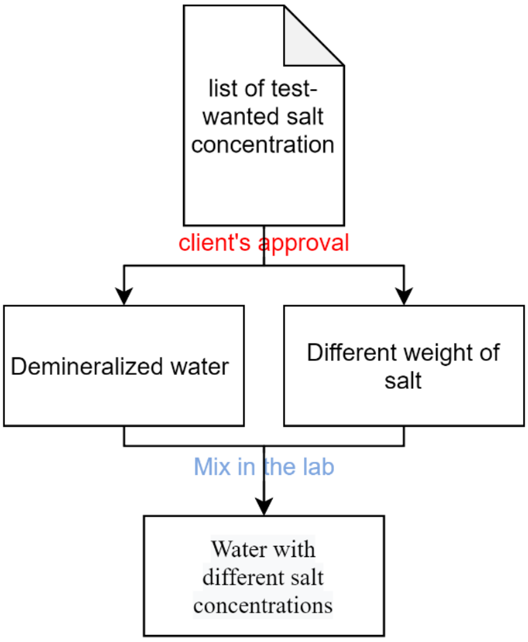
Order the demineralized water. Then prepare the list of test-wanted solutions. Demineralized water tap water and sea water are all ready-made solution. The solutions labeled with certain salt concentrations are the ones which need to modulate in the laboratory(highlight in yellow).The list has been approved by the client.

Table 45 List of test-wanted salt concentration (Baaren, 2015)

Sample	g chlorine (Cl-)/l	g Sodium chloride /l	Rough expecting conductivity(μ S/cm)
1	Demineralized water	/	0.05
2	0.01352	0.02	40
3	Tap water	/	500
4	0.059	0.10	1413
5	1.71	2.82	6000
6	4.29	7.07	12880
7	6.03	9.94	18000
8	8	13.19	24000
9	10	16.48	30000
10	12	19.78	36000
11	14	23.08	42000
12	16	26.37	48000
13	sea water	/	54000
14	20	32.97	60000
15	26.67	43.96	80000

Prepare 15 bottles that can hold one liter of water. Make a mark for each bottle on it for easy identification. Go to the lab.

Now start making solutions. Add 1 liter of demineralized water and calculated pure sodium chloride granules into the bottle until all the solutions are proportioned. Use the milligram electronic scale in the HZ laboratory. Shake the solutions evenly and bring all the solutions back.



Fill the prepared solutions into special bottles of laboratory. Record the lab number of each bottle. Send all the solutions to the laboratory. It took 1-2 weeks for the results.

Sample	g Chlorine$^-$ /l	g Sodium chloride /l	Rough expecting conductivity(µ S/cm)	Lab number for chloride ion	Lab chloride ion(mg/l)	Lab number for Conductivity	Lab conductivity result(µ S/cm)
1	Demi water		0.05	0625023372	<5.0	0640254462	<10
2	0.01352	0.02	40	0625023383	11	0640254456	47
3	Tap water		500	0625023379	32	0640254455	480
4	0.059	0.10	1413	0620314471	76	0640254451	270
5	1.71	2.82	6000	0625023348	1770	0640254452	5500
6	4.29	7.07	12880	0620314509	4550	0640254446	13000
7	6.03	9.94	18000	0625023359	6990	0640254453	19000
8	8	13.19	24000	0625023402	8360	0640254443	23000
9	10	16.48	30000	0625027001	10600	0640254454	29000
10	12	19.78	36000	0625023400	15300	0640254467	38000
11	14	23.08	42000	0625023353	16200	0640254450	40000
12	16	26.37	48000	0625026981	16500	0640254444	42000

13	Sea water		54000	0625026982	18400	0640254531	47000
14	20	32.97	60000	0625026953	7870	0640254537	67000
15	26.67	43.96	80000	0625026956	29200	0640254550	67000

Preparation	Status
All the elements are ready	To go
Everything is ready except for the standard value	To go
Some elements on the list are still missing	Not go

Elements	Status
Laptop	✔
The new generation EC sensor	✔
The demineralized water	✔
Test-wanted samples	✔
Cups	✔
Standard value	✔
Calibration solution	✔
Iron support	✔
Thermometer and 5V battery pack	✔
Thermometer	✔

Preparation	Status
Everything is ready except for the standard value	To go

Since the time limitation, the official test will use the initial version.

After getting ready with all the elements at hand, set RealTerm with 9600 Bd, correct port to start outputting the data. Please follow the steps 1-10 of Method of Measurement System Validation Test Plan.

Official test

Declare the standard of different results:

Table 46 The standard of division of accuracy

Accuracy a	Status
a⩽10%	Very good
10%<a<30%	Good
30%⩽a⩽50%	Bad
a>50%	Very bad

Table 47 The standard of division of stability

RSD b	Stability Status
b⩽1%	Very good
1%<b<3%	Good
3%⩽b⩽5%	Bad
a>5%	Very bad

It took 10 mins per data set to record.

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat
#	1.505E+09	130382	27	58	271144	460687	600077	19.9
#	1.505E+09	130382	27	58	270183	551517	568381	19.9
#	1.505E+09	130382	27	58	270787	417648	606586	19.9
#	1.505E+09	130382	27	58	270787	406112	560581	19.9
#	1.505E+09	130382	27	58	260624	515399	557312	19.9
#	1.505E+09	130382	27	58	251945	469915	585657	19.9
#	1.505E+09	130382	27	58	328410	489526	554868	19.9
#	1.505E+09	130382	27	58	262162	544074	549237	19.9
#	1.505E+09	130382	27	58	281636	439373	556516	19.9
#	1.505E+09	130382	27	58	285509	494552	552725	19.9
#	1.505E+09	130382	27	58	266118	399850	603345	19.9
#	1.505E+09	130382	27	58	318276	394631	548523	19.9
#	1.505E+09	130382	27	58	279054	500567	549402	19.9
#	1.505E+09	130382	27	58	273890	468542	570523	19.9
#	1.505E+09	130382	27	58	285344	473925	544376	19.9
#	1.505E+09	130382	27	58	275429	414242	587854	19.9
#	1.505E+09	130382	27	58	277955	423113	541327	19.9
#	1.505E+09	130382	27	58	286058	479831	550720	19.9
#	1.505E+09	130382	27	58	271446	421520	585245	19.9
#	1.505E+09	130382	27	58	287404	394109	540311	19.9
#	1.505E+09	130382	27	58	272325	471920	544788	19.9
#	1.505E+09	130382	27	58	269578	450414	556598	19.9
#	1.505E+09	130382	27	58	324648	475848	529489	19.9

Figure 58 The output of Sample 1

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat
#	1.505E+09	14559	2	0	426409	322807	64874	20.19
#	1.505E+09	14390	2	0	334975	318138	85666	20.19
#	1.505E+09	14290	2	0	513476	331789	91077	20.19
#	1.505E+09	14465	2	0	540805	298747	117307	20.19
#	1.505E+09	14381	2	0	331185	302455	125574	20.19
#	1.505E+09	14332	3	0	465493	301796	133594	20.19
#	1.505E+09	14530	2	0	490405	298418	137000	20.19
#	1.505E+09	14548	2	0	312315	265019	139389	20.19
#	1.505E+09	14413	3	0	480655	290810	149415	20.19
#	1.505E+09	14530	2	0	525149	293941	168943	20.19
#	1.505E+09	14559	2	0	353487	308305	182896	20.19
#	1.505E+09	14496	3	0	554428	334865	187537	20.19
#	1.505E+09	14639	2	0	598951	348708	200007	20.19
#	1.505E+09	14582	2	0	374196	329180	196134	20.19
#	1.505E+09	14525	2	0	561817	331844	197920	20.19
#	1.505E+09	14657	2	0	651878	322203	201051	20.19
#	1.505E+09	14703	2	0	363924	296001	196052	20.19
#	1.505E+09	14568	3	0	511389	296770	198222	20.19
#	1.505E+09	14664	2	0	659925	285152	198359	20.19
#	1.505E+09	14721	2	0	362606	267354	202424	20.19
#	1.505E+09	14684	3	0	547507	283064	203330	20.19
#	1.505E+09	14698	2	0	663880	275813	206736	20.19
#	1.505E+09	14708	2	0	350685	259498	203330	20.19

Figure 59 The output of Sample 2

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat
#	1.505E+09	1368	6	0	205006	167982	256834	22.5
#	1.505E+09	1369	6	0	213603	187070	259608	22.5
#	1.505E+09	1382	7	0	247908	209702	264442	22.5
#	1.505E+09	1365	6	0	207862	157380	254527	22.5
#	1.505E+09	1361	6	0	203907	160648	251341	22.5
#	1.505E+09	1379	7	0	239942	183088	254033	22.5
#	1.505E+09	1361	6	0	226539	152958	253099	22.5
#	1.505E+09	1355	6	0	183115	151282	253318	22.5
#	1.505E+09	1374	7	0	247358	198908	252165	22.5
#	1.505E+09	1361	6	0	246095	188279	246232	22.5
#	1.505E+09	1350	5	0	201792	175013	241069	22.5
#	1.505E+09	1367	7	0	237937	204813	242717	22.5
#	1.505E+09	1364	7	0	322698	216047	246864	22.5
#	1.505E+09	1344	6	0	235054	183472	245600	22.5
#	1.505E+09	1361	6	0	245188	186466	238871	22.5
#	1.505E+09	1365	7	0	308717	206571	239558	22.5
#	1.505E+09	1344	6	0	237443	168970	238844	22.5
#	1.505E+09	1352	6	0	228215	172074	234614	22.5
#	1.505E+09	1363	7	0	268095	193690	238734	22.5
#	1.505E+09	1344	5	0	210609	163944	237718	22.5
#	1.505E+09	1352	6	0	220579	178226	234504	22.5
#	1.505E+09	1361	7	0	251396	163175	232609	22.5
#	1.505E+09	1342	6	0	193443	120630	229231	22.5

Figure 60 The output of Sample 3

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat
#	1.505E+09	2858	2	0	492877	130106	130545	19.9
#	1.505E+09	2870	1	0	399740	125162	132276	19.9
#	1.505E+09	2899	2	0	377492	129969	131314	19.9
#	1.505E+09	2912	3	0	501941	125272	133210	19.9
#	1.505E+09	2888	2	0	504275	120493	141834	19.9
#	1.505E+09	2883	1	0	433907	128733	140241	19.9
#	1.505E+09	2915	2	0	398257	132990	148096	19.9
#	1.505E+09	2936	3	0	545309	142905	147410	19.9
#	1.505E+09	2914	2	0	534048	113022	141175	19.9
#	1.505E+09	2903	1	0	423827	107035	142136	19.9
#	1.505E+09	2928	2	0	371862	99866	140680	19.9
#	1.505E+09	2952	2	0	384194	103107	140900	19.9
#	1.505E+09	2953	2	0	529434	106128	141587	19.9
#	1.505E+09	2931	1	0	506363	98190	140488	19.9
#	1.505E+09	2921	1	0	448849	91654	141312	19.9
#	1.505E+09	2932	1	0	401827	88413	143454	19.9
#	1.505E+09	2951	2	0	377272	84677	140021	19.9
#	1.505E+09	2970	2	0	418471	92944	141834	19.9
#	1.505E+09	2973	2	0	503561	89072	139335	19.9
#	1.505E+09	2963	2	0	518255	83167	137796	19.9
#	1.505E+09	2952	1	0	488015	76987	139884	19.9
#	1.505E+09	2945	1	0	419900	75586	134665	19.9
#	1.505E+09	2964	1	0	380513	75449	138813	19.9

Figure 61 The output of Sample 4

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat
#	1.505E+09	183	2	0	331926	449673	420943	19.6
#	1.505E+09	185	4	0	481863	563684	415340	19.6
#	1.505E+09	179	3	0	662040	625016	423635	19.6
#	1.505E+09	168	2	0	650312	616227	428991	19.6
#	1.505E+09	166	2	0	318578	475436	435116	19.6
#	1.505E+09	171	3	0	392791	434951	412594	19.6
#	1.505E+09	171	4	0	676844	535779	405260	19.6
#	1.505E+09	163	2	0	680442	568491	425558	19.6
#	1.505E+09	159	2	0	665803	497711	424294	19.6
#	1.505E+09	159	2	0	309019	408858	417620	19.6
#	1.505E+09	166	4	0	464093	440664	381942	19.6
#	1.505E+09	163	4	0	678025	455935	384441	19.6
#	1.505E+09	157	2	0	675031	482769	406084	19.6
#	1.505E+09	153	2	0	642676	441982	399080	19.6
#	1.505E+09	155	2	0	321819	363155	386693	19.6
#	1.505E+09	162	3	0	455551	427728	363512	19.6
#	1.505E+09	161	3	0	666874	415945	369555	19.6
#	1.505E+09	155	2	0	676624	434017	372933	19.6
#	1.505E+09	152	2	0	511526	403722	372246	19.6
#	1.505E+09	156	3	0	339342	308553	367165	19.6
#	1.505E+09	160	3	0	534872	409600	349394	19.6
#	1.505E+09	158	3	0	664594	385238	351180	19.6
#	1.505E+09	151	2	0	642292	385979	352306	19.6

Figure 62 The output of Sample 5

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat	Temp corr	Temp corr
#	1.505E+09	113	4	0	212339	295726	330800	19.5	100.57	8054.09168
#	1.505E+09	116	5	0	235905	339946	341045	19.5	103.24	7845.7962
#	1.505E+09	98	6	0	373070	495239	389110	19.5	87.22	9286.86081
#	1.505E+09	87	7	0	584009	515069	422042	19.5	77.43	10461.0616
#	1.505E+09	78	5	0	573050	505456	425201	19.5	69.42	11668.1072
#	1.505E+09	74	6	0	373262	433413	425365	19.5	65.86	12298.8157
#	1.505E+09	73	8	0	293309	351454	405535	19.5	64.97	12467.2926
#	1.505E+09	71	8	0	414242	456210	389989	19.5	63.19	12818.4839
#	1.505E+09	69	8	0	606696	457253	396801	19.5	61.41	13190.0342
#	1.505E+09	66	7	0	619413	493206	413418	19.5	58.74	13789.5812
#	1.505E+09	64	8	0	543744	437066	409435	19.5	56.96	14220.5056
#	1.505E+09	63	8	0	331761	323000	390621	19.5	56.07	14446.2279
#	1.505E+09	65	9	0	329262	346044	381530	19.5	57.85	14001.7286
#	1.505E+09	64	10	0	626719	441735	377877	19.5	56.96	14220.5056
#	1.505E+09	61	9	0	633530	453436	384304	19.5	54.29	14919.8747
#	1.505E+09	60	9	0	536685	406222	383040	19.5	53.4	15168.5393
#	1.505E+09	59	8	0	326570	307591	366149	19.5	52.51	15425.6332
#	1.505E+09	63	9	0	344753	307426	358623	19.5	56.07	14446.2279
#	1.505E+09	61	9	0	641001	405013	364281	19.5	54.29	14919.8747
#	1.505E+09	58	9	0	641358	418993	372603	19.5	51.62	15691.5924
#	1.505E+09	57	8	0	542535	392379	363127	19.5	50.73	15966.8835
#	1.505E+09	58	10	0	350411	306987	357881	19.5	51.62	15691.5924
#	1.505E+09	60	9	0	366039	279631	359090	19.5	53.4	15168.5393

Figure 63 The output of Sample 6

#	The ID of	Raw resis	The phase	The ROD	Voltage A	Voltage B	Voltage C	Temperat
#	1.505E+09	39	16	0	448602	8541	172294	19.9
#	1.505E+09	38	14	0	444537	5273	173255	19.9
#	1.505E+09	37	14	0	430282	823	173035	19.9
#	1.505E+09	37	14	0	440994	2664	170316	19.9
#	1.505E+09	37	14	0	424789	-4779	171937	19.9
#	1.505E+09	37	14	0	392241	-411	170206	19.9
#	1.505E+09	37	14	0	384551	-7388	168641	19.9
#	1.505E+09	39	14	0	338326	-7580	168339	19.9
#	1.505E+09	39	14	0	289216	-9777	169767	19.9
#	1.505E+09	39	14	0	274769	-10849	166251	19.9
#	1.505E+09	42	15	0	282487	-1373	163807	19.9
#	1.505E+09	41	13	0	292320	-5603	164576	19.9
#	1.505E+09	41	13	0	378508	-7855	163614	19.9
#	1.505E+09	40	15	0	416302	-8432	162571	19.9
#	1.505E+09	40	15	0	434264	-4888	167213	19.9
#	1.505E+09	39	14	0	428964	-12085	164356	19.9
#	1.505E+09	39	14	0	365902	-15875	163257	19.9
#	1.505E+09	39	14	0	290700	-13842	164081	19.9
#	1.505E+09	42	15	0	285454	-11892	165262	19.9
#	1.505E+09	41	13	0	343187	-10629	162324	19.9
#	1.505E+09	40	14	0	431023	-16809	165565	19.9
#	1.505E+09	39	14	0	402019	-18512	162076	19.9
#	1.505E+09	38	14	0	318962	-18594	163038	19.9

Figure 64 The output of Sample 7

Only Sample2-6 are valid to measure. Thereinto, Sample 6 has begun to output some invalid values, but very few, controlled within 5%. Among the rest of the solutions, the invalidity of sample1 and 15 are reasonable because they are out of the working range of this sensor.

Sample	Sampling Amount	Test Times	Valid/invalid output
1	106	1	IN
2	327	1	V
3	233	1	V
4	231	1	V
5	221	1	V
6	146	1	V
7	235	1	IN
8	/	1	IN
9	/	1	IN
10	/	1	IN
11	/	1	IN
12	/	1	IN
13	/	1	IN
14	/	1	IN
15	/	1	IN

Regardless of accuracy and stability, this sensor can only measure the water solution between about 50-13000µS/cm.

Calculate out the temperature corrected conductivity of sample 2-6. Draw the tendency chart of the sample results for each sample and select 85 data points in the flat part of chart as the base for calculating the average.

Sample	Sampling Amount	Test Times	Selected Sample number	Average result of Conductivity(μS/cm)
2	327	1	85	63.9
3	233	1	85	775.8
4	231	1	85	295.9
5	221	1	85	5984.3
6	146	1	85	16746.2

Apply the formula of accuracy and RSD.

Sample	Accuracy	RSD
2	35.9%	0.6%
3	61.6%	2.1%
4	9.6%	0.5%
5	8.8%	2.3%
6	28.8%	2.3%

Table 48 The detailed values for each valid sample

Sample	Cond.	Accuracy	Accuracy Status	RSD	Stability Status
2	47	35.9%	Bad	0.6%	Very good
3	480	61.6%	Very bad	2.1%	Good
4	270	9.6%	Very Good	0.5%	Very good
5	5500	8.8%	Very Good	2.3%	Good
6	13000	28.8%	Good	2.3%	Good

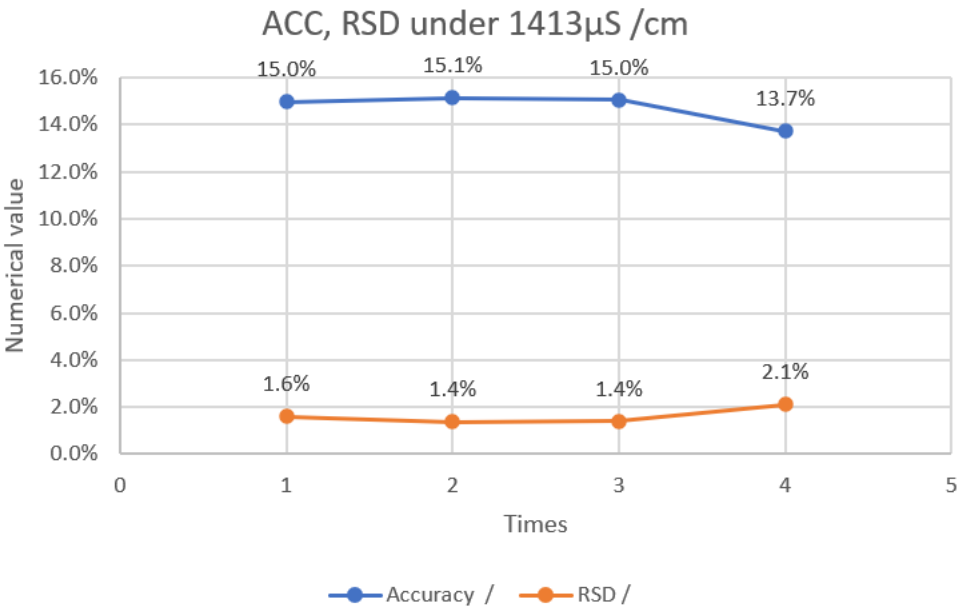
As shown in the table, the stability of all measurable samples with usable values is not bad, especially samples 2 and 4. In contrast, the accuracy results are very unsatisfactory.

Prepare a cup with 1413μS/cm calibration solution. Use the sensor to measure the solution, take it out of the solution after 10 minutes of measurement, place it on the table, and test for another 10 minutes after one minute. Repeat 4 times to obtain four sets of data under the same solution.

Select 85 data for each data set to calculate out the average value.

Sample	Sampling Amount	Test Times	Valid/invalid output	Selected Sample number	Average result of Conductivity(μS/cm)
1413μS /cm	258	1	V	85	1624.6
1413μS /cm	324	2	V	85	1626.9
1413μS /cm	329	3	V	85	1625.6
1413μS /cm	351	4	V	85	1607.0

It can be seen from the figure that the sensor has good working stability when measuring the same solution multiple times.



1413µS/cm Testing Times	Accuracy Status	Stability Status
1	Good	Good
2	Good	Good
3	Good	Good
4	Good	Good

Conclusion

The sensor can output a valid data set when testing a solution of 50-13000µS/cm, of which the solution in the range of 270-13000µS/cm can control the accuracy within 30% and the stability within 3%.

Sample	Lab conductivity result(µS/cm)	Accuracy	RSD
1	<10	/	/
2	47	35.9%	0.6%
3	480	61.6%	2.1%
4	270	9.6%	0.5%
1413µS /cm	1413	15.0%	1.6%
1413µS /cm	1413	15.1%	1.4%
1413µS /cm	1413	15.0%	1.4%
1413µS /cm	1413	13.7%	2.1%
5	5500	8.8%	2.3%
6	13000	28.8%	2.3%

Judging from the experimental results, this sensor did not reach the performance. Hereby are the results of the test as to the performance of new EC sensor.

Table 49 4 criteria of the gained sensor

Working range	270-13000µS/cm
Accuracy	10%-30%
Stability	RSD<3%

Sensitivity	Too few available data points to draw a sensitivity curve for the sensor.

It is believed that this should not be the working performance that this new EC-sensor should have under normal conditions. However, based on the measurement results of the sensor received twice and the easily damaged condition, it is preliminarily concluded that the working performance of the sensor are not stable to meet the commercial requirements.

2. Coupling stage

EC-sensor Subsystem Test Results

Test setup

The image depicts the setup of Arduino subsystem test. It includes laptop, the new EC-sensor from imec, two cups of demineralized water, a cup of tap water, and a cup of 1413 µ S/cm calibration solution.

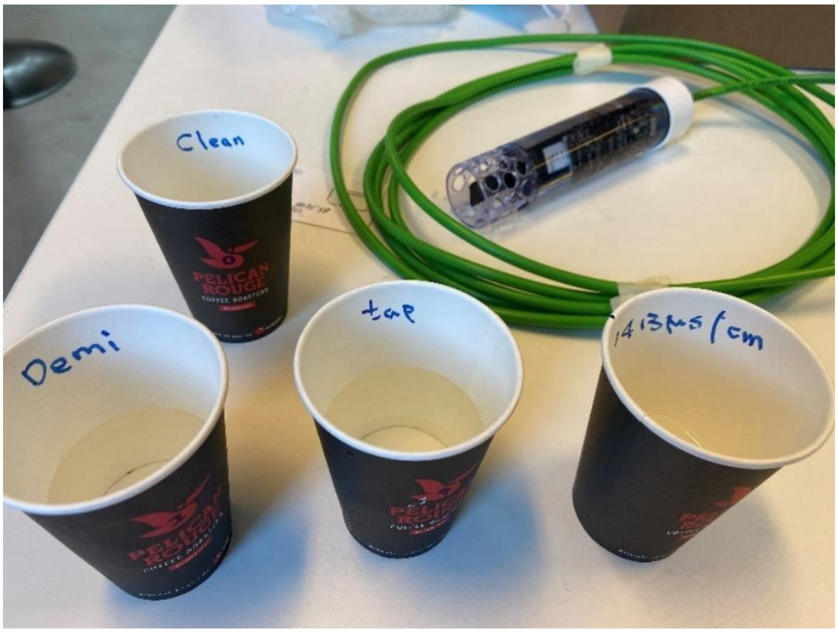


Figure 65 The test setup of EC-sensor subsystem

Official test

Since all the solutions that used in the test stayed in the indoor temperature for a long time, their temperature must be within 0-30℃. The new sensor's cell constant is 1.38(remember change it in the calculation.).

Test the sensor in demineralized water, calibration water and tap water, respectively. Clean the probe between the tests by demineralized water.

The outputs when testing demineralized water:

```
2075590656,0,0,58,17221,33645,128705,207,
```

The outputs when testing tap water:

```
2075590656,3355,0,0,-239091,-200007,-36117,203,
```

The outputs when testing calibration water(1413 µ S/cm):

```
2075590656,1051,0,0,-478540,-492987,-241673,208,
```

Table 50 The results of the new-gained EC-sensor testing in three types of solutions

The type of the solution	Conductivity range	Test results	Good/Bad
Demineralized water	<0.1µS/cm	Invalid outputs	Good
Tap water	150-800µS/cm	457µS/cm	Good
Calibration water	Around 1413µS/cm	1456µS/cm	Good

Conclusion

This sensor is in good condition. It is qualified to use in the new designed coupling system.

Arduino Subsystem Test Results

Test setup

The image depicts the setup of Arduino subsystem test. It includes laptop with Arduino IDE, the new EC-sensor from imec, breadboard, BOB-11189, Arduino Nano, Hook-up wires, and min-USB cable.

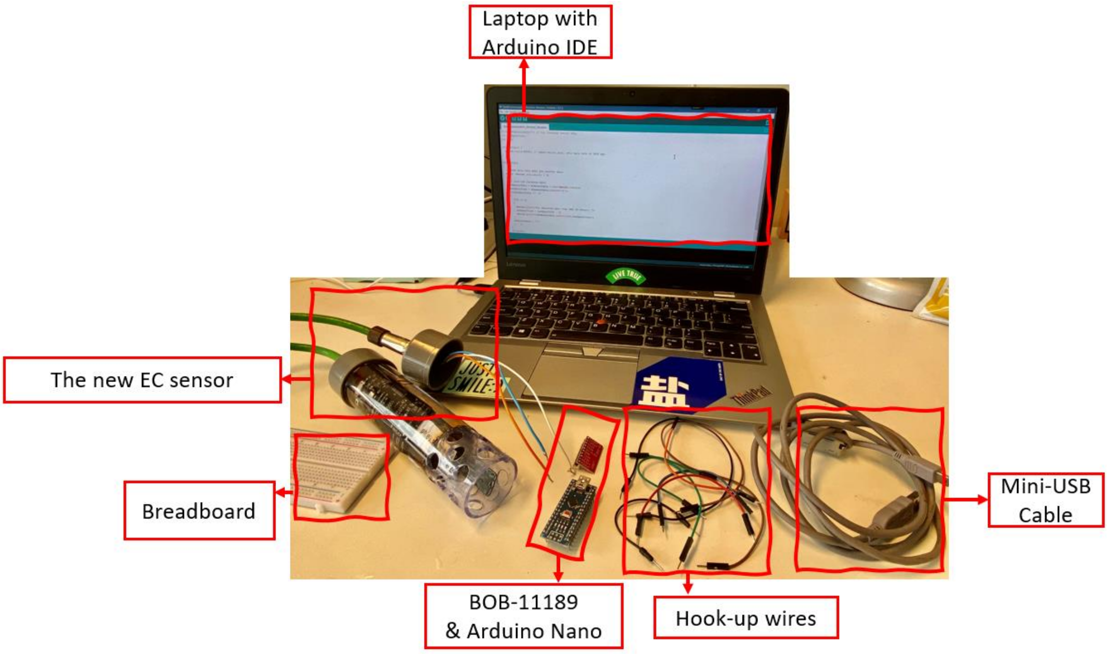


Figure 66 The test setup of EC-sensor subsystem

Wire diagram

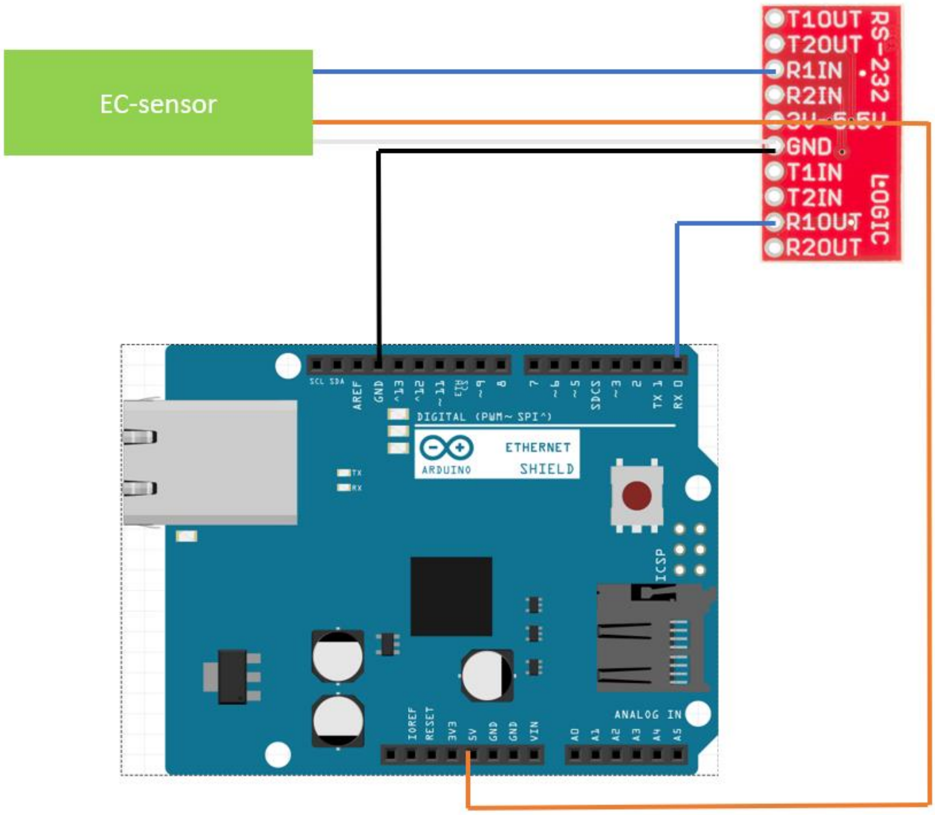


Figure 67 Wire diagram of Arduino subsystem

Code

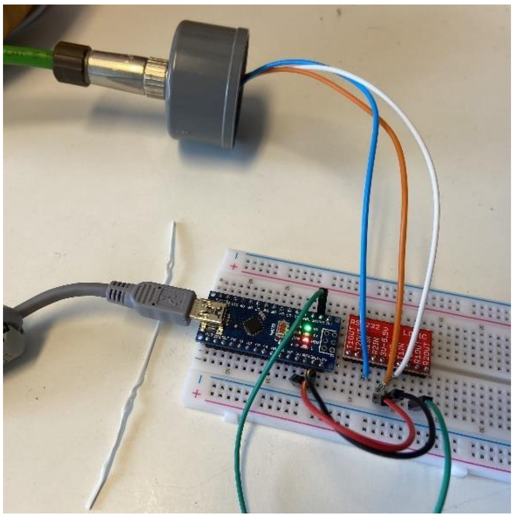
```
String ECmeasurdata=""; // for incoming serial data
int hashposition;
int i=0;

void setup() {
  Serial.begin(9600); // opens serial port, sets data rate to 9600 bps
}

void loop()
{
  // send data only when you receive data:
  while (Serial.available() > 0)
  {
    // read the incoming byte:
    ECmeasurdata = ECmeasurdata + char(Serial.read());
    hashposition = ECmeasurdata.indexOf('#');
    if(hashposition != -1)
    {
      if(i == 1)
      {
        Serial.print("All measured data from imec EC-sensor: ");
        hashposition = hashposition - 1;
        Serial.println(ECmeasurdata.substring(1,hashposition));
      }
      ECmeasurdata = "";
      i = 1;
    }
    delay(2);
```

```
    }
}
```

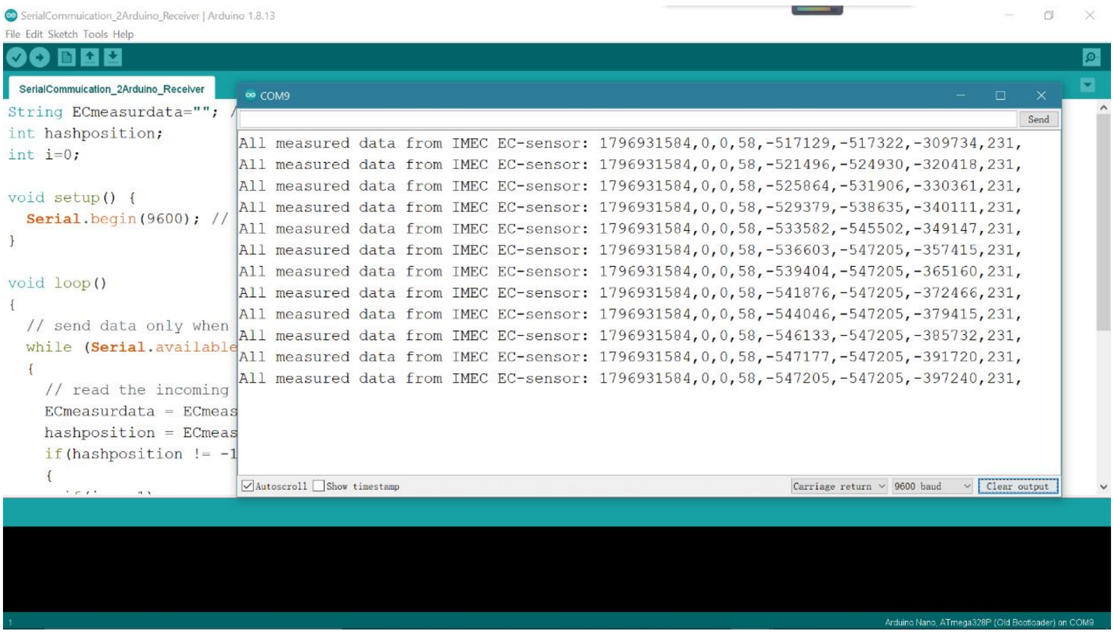
Official test

To prevent the intact EC-sensor from electrical damage during the test, plus, the emphasis is on readout, the sensor with unworked EC-chip has been arranged.

Wire the circuit. Turn on the Arduino via 5V battery set/USB connection of laptop.



Observe the serial monitor in Arduino IDE, the correct outputs have been printed.



Conclusion

The new generation EC-sensor can properly couple with Arduino. The serial monitor of Arduino IDE can read out all the measured data of the sensor.

Display Subsystem Test Results

Test setup

The image depicts the setup of Arduino subsystem test. It includes laptop with Arduino IDE, the new EC-sensor from imec, breadboard, BOB-11189, Arduino Nano, Hook-up wires, and min-USB cable.

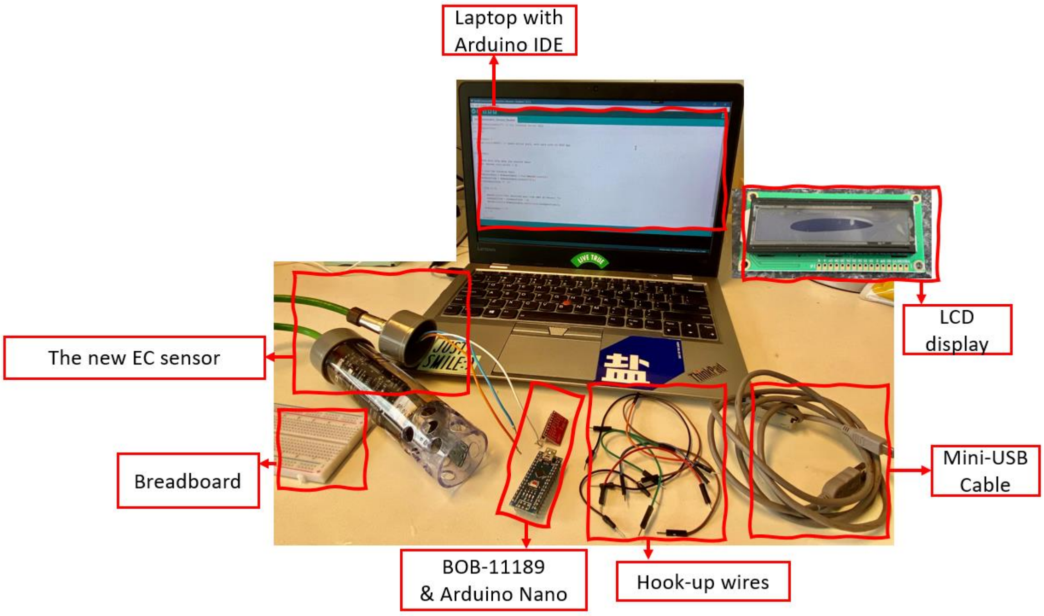


Figure 68 The test setup of EC-sensor subsystem

Wiring diagram

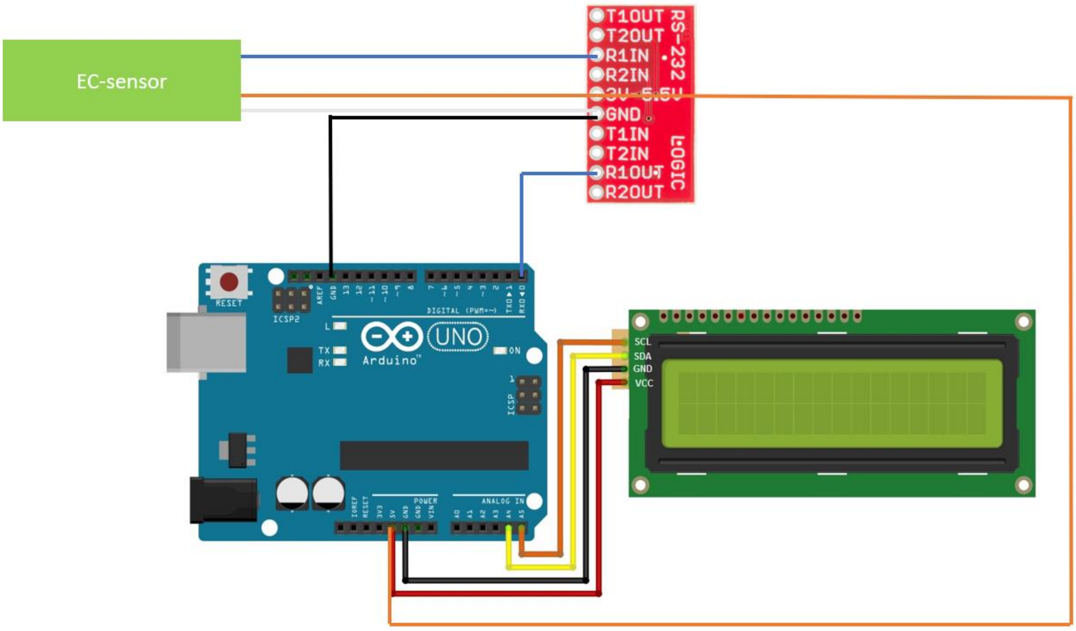


Figure 69 *Wire diagram of display subsystem*

Code

```
// set up LCD
#include <Wire.h>              // Library for I2C communication
#include <LiquidCrystal_I2C.h>    // Library for LCD
LiquidCrystal_I2C lcd(0x3F, 16, 2);

// Readout and extract the required data for calculation
String ECmeasurdata=""; // for incoming serial data
int hashposition;
int i=0;
int comma_num=0;
int comma_position=-1;
String raw_r,phase,rod,temp;
int RAW_R,PHASE,ROD,TEMP;
int Condu;

void setup() {
  Serial.begin(9600); // opens serial port, sets data rate to 9600 bps
  lcd.init();                // initialize the lcd
  lcd.backlight();        // Power on the back light
}

void loop()
{
  lcd.setCursor(0, 0);
  lcd.print("Condu.=");
  lcd.setCursor(0, 1);
  lcd.print("Temp:");
```

```
    // send data only when you receive data:
    while (Serial.available() > 0)
    {
      // read the incoming byte:
      ECmeasurdata = ECmeasurdata + char(Serial.read());
      hashposition = ECmeasurdata.indexOf('#');                    //
Indexing "#" and locate it in the data set
      if(hashposition != -1)
      {
        if(i == 1)
        {
          Serial.print("All measured data from imec EC-sensor: ");
          hashposition = hashposition - 1;
          Serial.println(ECmeasurdata.substring(1,hashposition));
          while (ECmeasurdata.indexOf(',') != -1)                  //
Indexing "," in the data set
          {
            comma_position = ECmeasurdata.indexOf(',');            //
Use commas to locate the value you want to extract
            if (comma_num == 2)
            {
              raw_r=ECmeasurdata.substring(0,comma_position);
              RAW_R=raw_r.toInt();
// Readout substring(raw_r,phase,rod,temp) and transfer into
int(RAW_R,PHASE,ROD,TEMP)
            }
             if (comma_num == 3)
            {
              phase=ECmeasurdata.substring(0,comma_position);
              PHASE=phase.toInt();
            }
```

```
if (comma_num == 4)
{
    rod=ECmeasurdata.substring(0,comma_position);
    ROD=rod.toInt();
}
if (comma_num == 8)
{
    temp=ECmeasurdata.substring(0,comma_position);
    TEMP=temp.toInt();
}
comma_num += 1;

ECmeasurdata=ECmeasurdata.substring((comma_position+1),ECmeasurdata.length()
);    // Delete the front string and proceed reading the contents before the next ","

}
// Judge if the data set is valid or not
if (((PHASE >= -10 && PHASE <= 10)||(PHASE >= -190 && PHASE <= -
170)||(PHASE >= 170 && PHASE <= 190))&&(ROD == 0))
{
    TEMP=TEMP/10;
    Condu=810000/(RAW_R+0.02*RAW_R*(TEMP-25));
    lcd.setCursor(7, 0);
    lcd.print(Condu);
    lcd.print("\xE4""S/cm");
    lcd.setCursor(5, 1);
    lcd.print(TEMP);
    lcd.print(F("\xDF""C"));
    delay(500);
}
```

```
                else
                {
                  TEMP=TEMP/10;
                  lcd.setCursor(7, 0);
                  lcd.print("ERROR");
                  lcd.setCursor(5, 1);
                  lcd.print(TEMP);
                  lcd.print(F("\xDF""C"));
                  delay(500);
                }
            lcd.clear();
            comma_num = 0;
        }
        ECmeasurdata = "";        // Reset and clear
        i = 1;
    }
    delay(2);
  }
}
```

Preliminary test

The pretest devotes to check the working performance of LCD to ensure the robustness of the component.

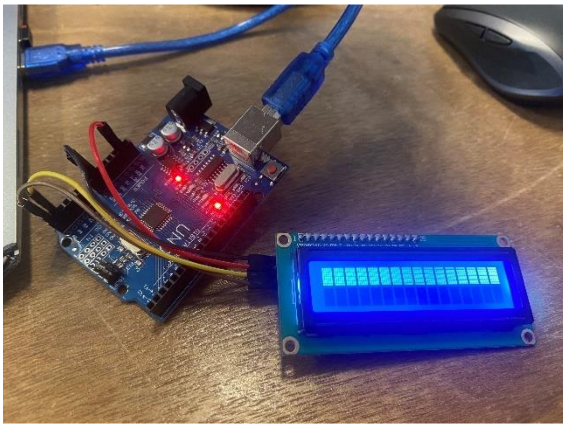


Figure 70 LCD component test

Firstly, connect Arduino with LCD-I2C directly. For convenience, UNO has been used instead of NANO.

It failed several times at first, and no numbers or symbols were displayed on the screen at all. It happened in several LCD, so that probably the code problem. It was finally discovered that the address was wrong. Generally, online examples apply 0x27 to be the address like this:

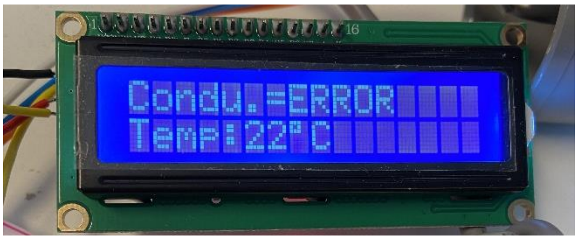
```
LiquidCrystal_I2C lcd(0x27,20,4);  // set the LCD address to 0x27
```

After researching, changing 0x27 to 0x3F then will fix it. It works in the end.

Pretest for display subsystem	Status
The sensor can run with ‘Hello World’ basic display example.	To go
The sensor cannot run ‘Hello World’ basic display example.	Not go

Official test

Wire EC-sensor, Arduino and LCD-I2C. Connect Arduino with Laptop to power and upload the code. The screen displays as follows:



The sensor that used in the test is without an intact conductivity chip. Thus, artificial assignment for the outputs is necessary.

```
    ECmeasurdata=ECmeasurdata.substring((comma_position+1),ECmeasurdata.length());

  }

  // Only use this part to change the values manually
  RAW_R=562;
  PHASE=1;
  ROD=0;
  TEMP=205;

  // Judge if the data set is valid or not
  if (((PHASE >= -10 && PHASE <= 10)||(PHASE >= -190 && PHASE <= -170)||(PHASE >=
```

Figure 71 The code that can be artificially changed for checking judgment and calculation function

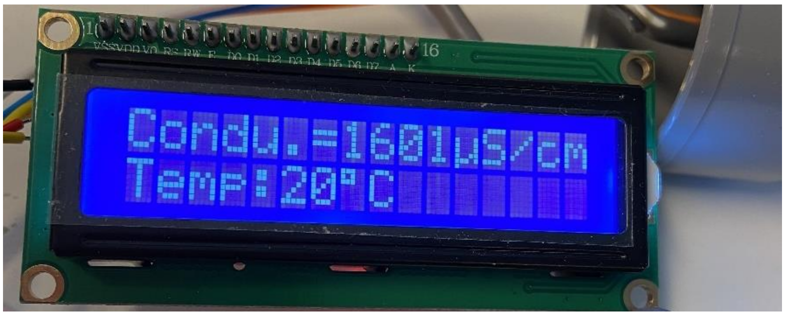
Next it is needed to test two aspects:

1. If the subsystem can judge the validity of the outputs.
2. If the subsystem can calculate correctly.

Table 51 The results of judgement and calculation test

Judge-calculation test	Valid sample1	Valid sample2	Valid sample3	Invalid sample1	Invalid sample2	Invalid sample3
Temperature*10	205	220	230	210	220	230
Raw resistance	562	600	600	600	600	600
ROD error	0	0	0	1	0	1
The phase of EC-measurement	1	-190	190	-190	-191	169
If the judgement is correct?	YES	YES	YES	YES	YES	YES
If the calculation is correct?	YES	YES	YES	/	/	/

The image shows valid sample 1, which sets up the recorded outputs of 1413 μ s/cm(under 25℃) solution collected in measurement stage. The result meets the expectation.



Conclusion

LCD successfully connected with Arduino-EC sensor, which marks the success of the experiment. It can reveal correct conductivity and status in different scopes.

Coupling System Test Results

Test setup

The image depicts the setup of Arduino subsystem test. It includes laptop with Arduino IDE, designing prototype of the EC-sensor coupling system, min-USB cable, two cups of demineralized water, a cup of tap water, and a cup of 1413 μ S/cm calibration solution. The cell constant(KCELL) of this sensor is 1.38.

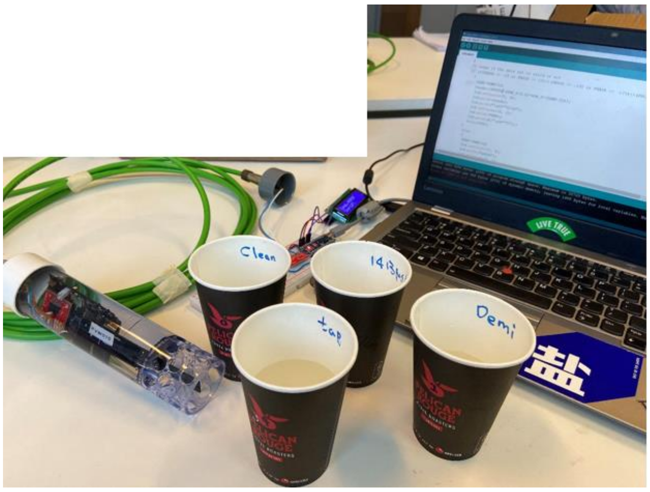


Figure 72 The test setup of EC-sensor subsystem

Wiring diagram

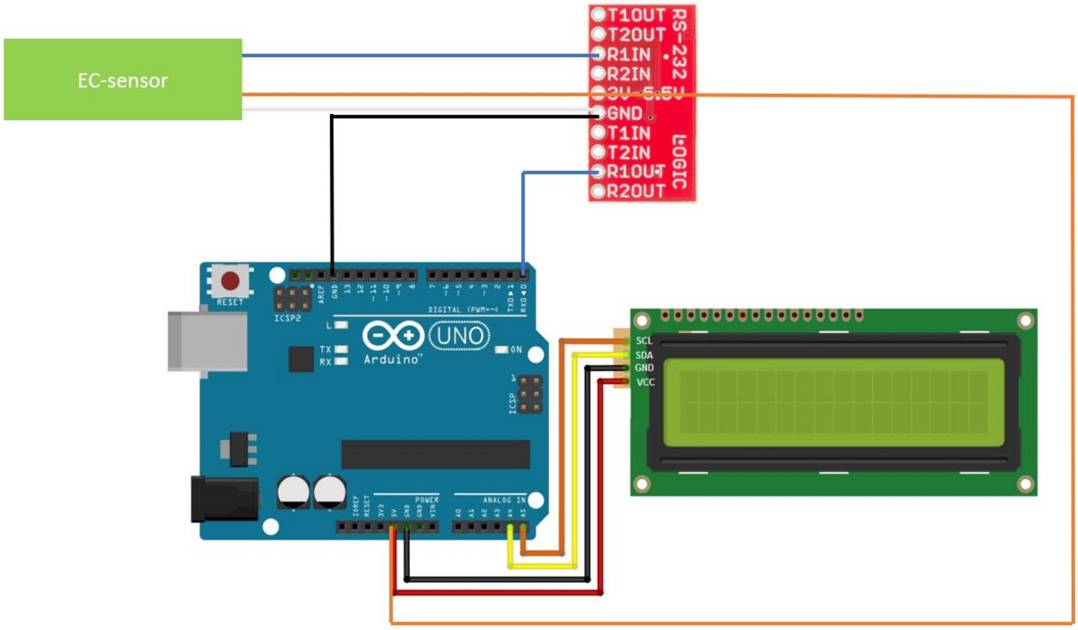


Figure 73 Wire diagram of coupling system

Code

```
// set up LCD
#include <Wire.h>              // Library for I2C communication
#include <LiquidCrystal_I2C.h>    // Library for LCD
LiquidCrystal_I2C lcd(0x3F, 16, 2);


// Readout and extract the required data for calculation
String ECmeasurdata=""; // for incoming serial data
int hashposition;
int i=0;
int comma_num=0;
int comma_position=-1;
String raw_r,phase,rod,temp;
int RAW_R,PHASE,ROD,TEMP;
int Condu;
int K_CELL=1380000; //K_CELL="KCell of EC-sensor"*10^6-
```

```
int CorrectedImp;

void setup() {
   Serial.begin(9600); // opens serial port, sets data rate to 9600 bps
   lcd.init();                 // initialize the lcd
   lcd.backlight();        // Power on the back light
}

void loop()
{
   lcd.setCursor(0, 0);
   lcd.print("Condu.=");
   lcd.setCursor(0, 1);
   lcd.print("Temp:");
   // send data only when you receive data:
   while (Serial.available() > 0)
   {
      // read the incoming byte:
      ECmeasurdata = ECmeasurdata + char(Serial.read());
      hashposition  =  ECmeasurdata.indexOf('#');                                    //
Indexing "#" and locate it in the data set
      if(hashposition != -1)
      {
         if(i == 1)
         {
            Serial.print("All measured data from IMEC EC-sensor: ");
            hashposition = hashposition - 1;
            Serial.println(ECmeasurdata.substring(1,hashposition));
```

```
while (ECmeasurdata.indexOf(',') != -1)                    // Indexing "," in the data set
{
  comma_position = ECmeasurdata.indexOf(',');              // Use commas to locate the value you want to extract
  if (comma_num == 2)
  {
    raw_r=ECmeasurdata.substring(0,comma_position);
    RAW_R=raw_r.toInt();
// Readout substring(raw_r,phase,rod,temp) and transfer into int(RAW_R,PHASE,ROD,TEMP)
  }
  if (comma_num == 3)
  {
    phase=ECmeasurdata.substring(0,comma_position);
    PHASE=phase.toInt();
  }
  if (comma_num == 4)
  {
        rod=ECmeasurdata.substring(0,comma_position);
        ROD=rod.toInt();
  }
      if (comma_num == 8)
  {
          temp=ECmeasurdata.substring(0,comma_position);
          TEMP=temp.toInt();
  }
  comma_num += 1;

ECmeasurdata=ECmeasurdata.substring((comma_position+1),ECmeasurdata.length()
);    // Delete the front string and proceed reading the contents before the next ","
```

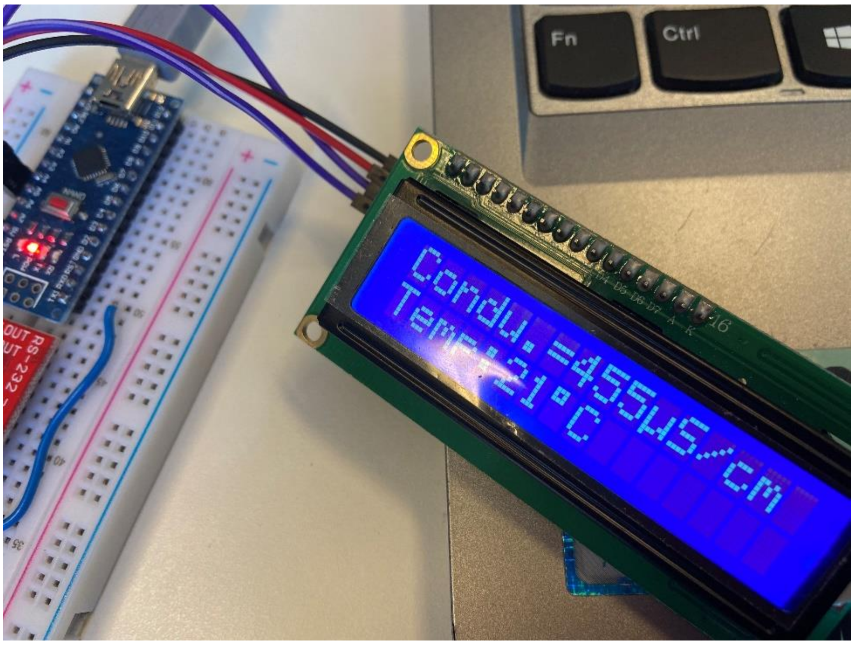
```
        }
        // Judge if the data set is valid or not
        if (((PHASE >= -10 && PHASE <= 10)||(PHASE >= -190 && PHASE <= -
170)||(PHASE >= 170 && PHASE <= 190))&&(ROD == 0))
          {
            CorrectedImp=RAW_R+((2*RAW_R)/100)*((TEMP-250)/10);
            Condu=K_CELL/CorrectedImp;
            lcd.setCursor(7, 0);
            lcd.print(Condu);
            lcd.print("\xE4""S/cm");
            lcd.setCursor(5, 1);
            lcd.print(TEMP);
            lcd.print(F("\xDF""C"));
            delay(500);
          }
           else
           {
            TEMP=TEMP/10;
            lcd.setCursor(7, 0);
            lcd.print("ERROR");
            lcd.setCursor(5, 1);
            lcd.print(TEMP);
            lcd.print(F("\xDF""C"));
            delay(500);
           }
        lcd.clear();
        comma_num = 0;
      }
      ECmeasurdata = "";        // Reset and clear
```

```
            i = 1;
        }
        delay(2);
    }
}
```

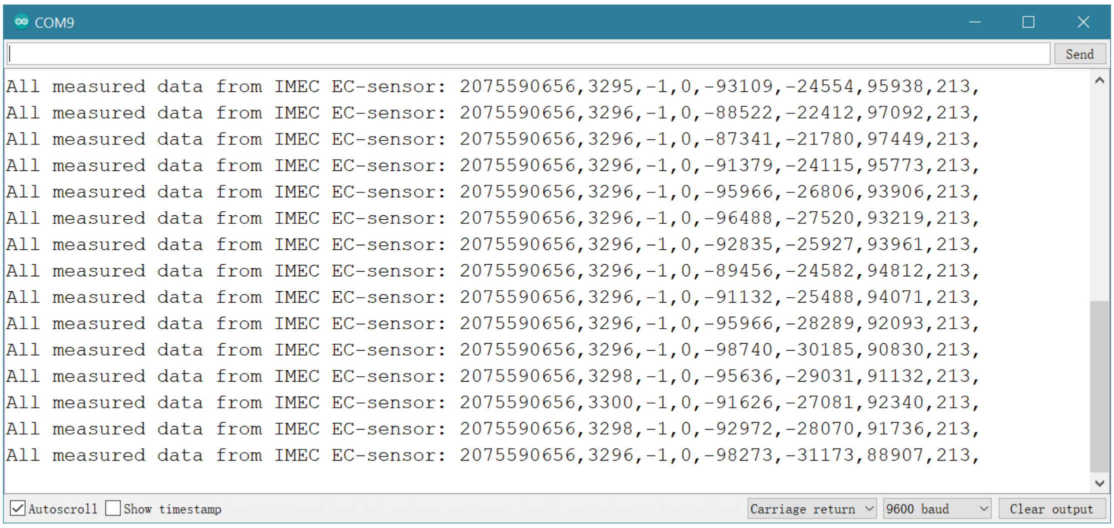
Official test

The temperature of all the solutions applied in this test is within 0-30℃. Randomly choose a solution and put the sensor in it. The tap water has been selected first.

LCD shows like this:



Then open the serial monitor, it looks like this:



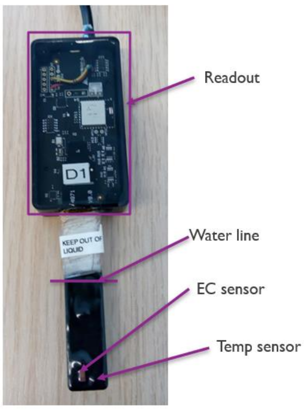
Conclusion

The designing prototype of new EC-sensor coupling system can work properly. User can observe the conductivity and temperature of water via LCD and check all the measured data via serial monitor of Arduino IDE.

Appendix 7: The received imec EC-Sensors

imec sent four sensors back and forth. Some were good, some could not work properly and should be sent back. The contents below give a specific explanation about these sensor’s condition, their concrete application, return reason and fault analysis from imec.

✧ First time:



Condition: A non-watertight EC-sensor with a good EC-chip and a good temp-chip

(KCELL=0.81)

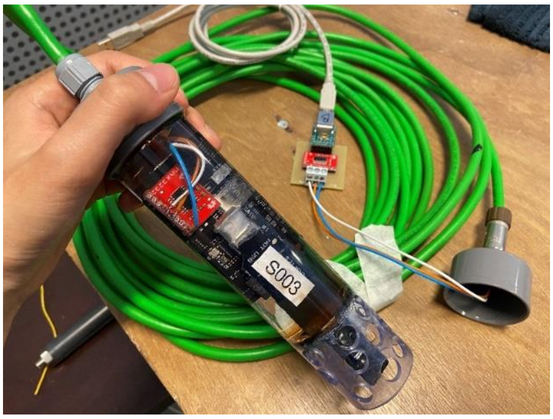
Concrete application: Test the performance of the sensor

Return reason: It only outputted invalid number when testing the tap water.

Fault analysis☒:

Thijl Boonen: “*The first sensor I had sent you had layer on the sensor when we got it back. We did some more tests and cleaning and now it seems to work fine. It looks like something made it “dirty” in a way we have never seen before. We are going to do more stability tests because it’s new for us*.”

✧ Second time:



<u>Condition: </u>A waterproof EC-sensor with a good EC-chip and a bad temp-chip

(KCELL=0.81)

<u>Concrete application: </u>Test the performance of the sensor(temperature will use an external thermometer to test).

<u>Return reason:</u> It can only output valid measured data in a solution of 50-13000 μ S/cm.

<u>Fault analysis☒:</u>

Thijl Boonen: “ *The EC was chipped in a way we've never seen before, which probably affected sensor performance. I do not know if it happened on your end, but it would explain the poor results. I would like to urge you again to be careful when putting the sensor in bottles and test tubes and the like.*

This is what a sensor is supposed to look like under the microscope:

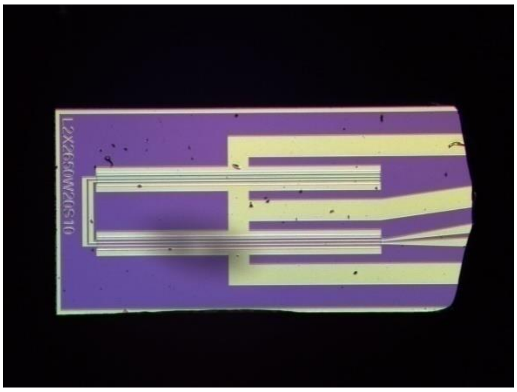


Figure 74 What the sensor looks like under a microscope

Your sensor was broken in 2 places. The bottom round one might be an issue because it can water to leak in underneath the black epoxy. The chip in the top corner is probably cutting though the electrodes themselves. And water can also get under the epoxy and mess op the measurements.

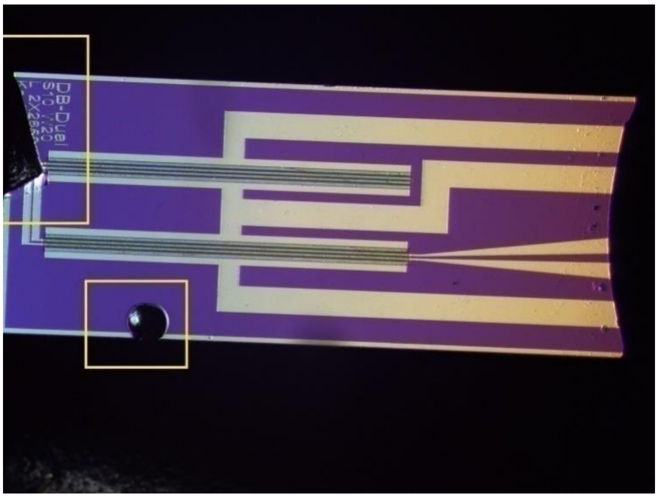


Figure 75 Damage observation of waterproof sensor used to measure working performance

First, we thought it might have been dirt, but you can see the material is chipped. We will try to do some more tests to see the extent of the damage."

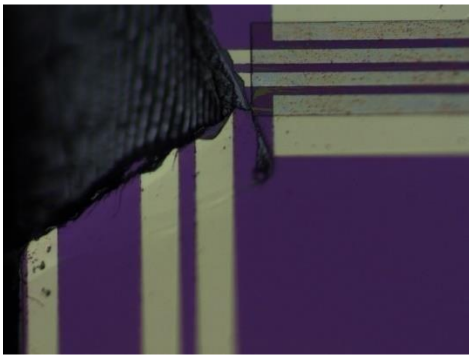


Figure 76 Close-up of the sensor's damage

Condition: A waterproof EC-sensor with a bad EC-chip and a good temp-chip

Concrete application: Test the designed Arduino sub-system, display sub-system.

✧ Third time:

Condition: Waterproof EC-sensor with a good EC-chip and a good temp-chip. (KCELL=1.38)

Concrete application: Use in the EC-sensor subsystem test. After testing out that the sensor is in good condition, it has been applied in the designed coupling system.

Appendix 8: Component list

The component list shows all the components which has been used in new EC-sensor coupling system. It contains the components' type, name, cost, amount, and link.

Table 52 Invoice

Type	Name	€/each	Amount	€	Link
Arduino sub-system					
Arduino Nano	Controller	4	1	4	aliexpress.com
BOB-11189	RS-232 to TTL convertor	5	2	10	https://www.digikey.nl/product-detail/nl/sparkfun-electronics/BOB-11189/1568-1193-ND/5673779
Display sub-system					
LCD I2C 1602	Display	3	1	3	aliexpress.com
Assemble fee(Soldering, wires)					
Connecting Materials	/	/	/	10	/
Total price for invoice				27	
The cost of building a whole coupling system				22	
The cost of the coupling part				18	

※Total price for invoice=Arduino Nano(1)+ BOB-11189(2)+ LCD I2C 1602(1)+Connection materials

※The cost of building a whole coupling system =Arduino Nano(1)+ BOB-11189(1)+ LCD I2C 1602(1)+Connection materials

※The cost of the coupling part = BOB-11189(1)+ LCD I2C 1602(1)+Connection materials

Signature from the customer:

Approved by: Jos Goossen
May 27th 2021

Appendix 9: Search plan

Table 53 Search plan for Theoretical framework

Search plan			
2.1	**Microcontroller info.**		
Nr.	Checklist	Remarks	Type of sources
1	Why choosing Arduino as a microcontroller?	Paragraph 2.1; 2.1.1	Experts; Arduino official website
2	How to find more sources regarding Arduino?	Paragraph 2.1.1	Arduino official website
3	What classic boards does Arduino have? How to use UART communication on Arduino?	Paragraph 2.1.2.1	Arduino official website; forum; play with the physical board;
4	What other hardware is relevant to this project?	Paragraph 2.1.2.2	Literature; Product specification; Experts;
5	What software does Arduino use?	Paragraph 2.1.3	Arduino official website;
2.2	**EC-sensor info.**		
6	What are the functions of different parts on EC-sensor?	Paragraph 2.2.1	Experts;
7	Announcement when using the EC-sensor	Paragraph 2.2.1	Experts;
8	The improved(waterproof) imec EC-sensor	Paragraph 2.2.2	Experts;
9	The specific part to be designed	Paragraph 2.2.3	Clients; Experts;
10	How to collect and process data from EC-sensor?	Appendix 2	Experts;
11	How to calculate the electrical conductivity by measured data from EC-sensor?	Paragraph 2.2.4	Experts;
12	The definition of conductivity	Paragraph 2.2.5.1	Literature;
13	The merit of 4-electrode conductivity sensor	Paragraph 2.2.5.2	Competitor;
14	The principle of 4-electrode	Paragraph 2.2.5.3	Scientific article;
15	Conversion between conductivity and chloride ion	Paragraph 2.2.5.4	Scientific article;

16	Conversion between g/l NaCl and g/l chlorine (Cl-)	Paragraph 2.2.5.5	Scientific article;
17	Basic information of the embedded chip	Appendix 3	Experts;
18	The conductivity range of regular liquids.	Appendix 4	Experts;
2.3	**Performance criteria info.**		
19	Working range	Paragraph 2.3.1	Scientific article; Experts;
20	Accuracy	Paragraph 2.3.2	Scientific article;
21	Stability	Paragraph 2.3.3	Scientific article;
22	Sensitivity	Paragraph 2.3.4	Scientific article;