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# Calibration of environmental conductivity and turbidity prototype sensors

Langis OY

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Langis OY intends to design sensors for measuring water solutions for environmental usages, for example, natural water and wastewater from mining site. From water quality point of view, environmental sensors help measure properties of various contaminants in aqueous solutions, which is indispensable for environmental monitoring and industrial safety.

The prototype sensors used in this thesis include a conductivity sensor applied with two-electrode technology and a turbidity sensor using backscattering infrared light measuring method. The aim was to calibrate the two prototype sensors and evaluate the performance of both.

All the laboratory experiments were carried out in Metropolia Environmental laboratories (Leiritie 1, Vantaa). Samples of saltwater and milk were analysed. Performances and limitations of both sensors were found within the calibration curves, which provided satisfactory results of measurement.



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|---|---|
| Keywords | Calibration, sensor prototype, conductivity, 2-pole cell, IR-LED, turbidity, backscattering, voltage in circuit |

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My friends Angelina and Amina faced the same problem with me in the laboratory that I appreciate their being with me.

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# 1 Introduction

## 1.1 Necessity of environmental sensor measurement

Sensors are one of the most frequently used tools in environmental monitoring. Environmental sensors measure various contaminants from different kinds of media to provide information of contaminants. For prevention and control means, environmental sensor measuring is a conduit among technology of sensor and environment system balance.

As the most important component on the earth, water is closely related to environmental health. Water allows lives to live, also it may carry contaminants, pathogens or other harmful elements. This is where we need environmental sensors to examine and provide information for us; thus, we can prevent and control hazardous matters or existence of matters that exceed the environmental policy limitations. From industrial perspective, the increasing pollution is affecting the quality of water resources. Nevertheless, sensor monitoring helps characterize pollutant and allow us to apply solution.

The environmental sensors, in this thesis, measure conductivity and turbidity of liquids. To develop a good environmental sensor, calibration is the very first step and it cannot be omitted. The objectives of calibration are checking the accuracy of sensor measurement and predicting sensor readings. An instrument is calibrated when it does not have a standard comparison of its measurement. However, even though the instrument had been calibrated, the accuracy would degrade over time. Therefore, continued calibration is necessary during the usage.

## 1.2 Intention of calibration

The prototypes were provided by Langis OY, a company specialized in measurement technology and water quality technology. They include a conductivity sensor with 2-pole cell and a turbidity sensor with backscattering IR-LED (infrared red-light-emitting diode) technology. Both sensors need calibrations to have the measurements standardized. Both sensors needed to be calibrated before further development since calibration provides a reference for prototype sensor parameters so that the unknown sample readings can be calculated according to the formula generated by the calibration curve. LGC's best practice for preparing calibration curves [1] was used when planning the calibration procedure conducted in this thesis project. Measurements from standard conductivity meter and turbidity meter were done using dilutions of salt water and milk, respectively, and the readings of salt water and milk measured by prototype conductivity sensor and prototype turbidity sensor were recorded. After that, all data were collected and analyzed in R-studio for calibration curve generation and the prediction formulas.

# 2 Theory

## 2.1 Theory of conductivity

Conductivity is a measure of the ability of an object to conduct electricity, heat or sound. Here, electricity will be the main character to be focused on. From physical perspective, the electrical resistivity is reverse proportional to conductivity, which is the principle that is applied to the prototype conductivity sensor: (see also similar formula on page 4) [2]

$$\rho = \frac{1}{\sigma},$$

where,
$\rho$ is electrical resistivity
$\sigma$ is the electrical conductivity of object (siemens/meter)

Electrical resistivity of aqueous solutions is measured by the conductivity sensor, the performance of which will be explained in the following chapters.

In contrast to 3-pole cell and 4-pole cell sensors, this prototype conductivity sensor has 2-pole cell, which measures only the resistance of aqueous solution with alternating current between two poles. 3-pole cell could achieve better reproducibility of measurement because of the minimization of the influence caused by field effect. 4-pole cell also has minimum influence from field effect, and the accuracy does not suffer from cell tube positions in liquids. [3]

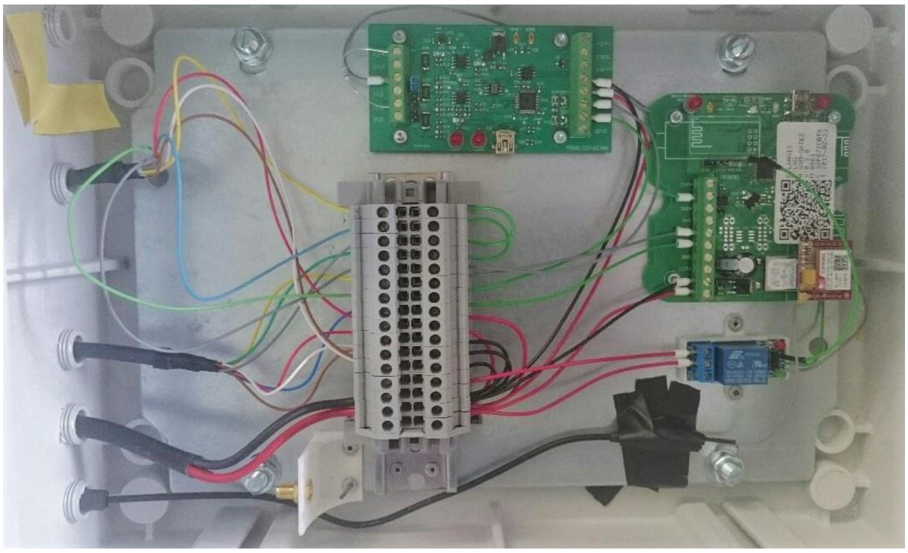
## 2.2 Theory of turbidity

The word *turbid* is usually describing how much the cloudiness there is in a fluid, which indicates the existence of particles of different sizes. Some fluids contain low density particles that would float around the liquid without settling down, while others contain high density particles which would settle down when the fluid stay still for a while. The increase of turbidity tells the raising number of particles and suspended solids. There are also different kinds of cause of high turbidity in a liquid, for example, oil content in water, sludge concentration in water treatment plant, yeast dosage and fat content in milk. In this thesis, the observation of turbidity variation by the fat content in milk is one of the objectives.

## 2.3 Conductivity prototype sensor

### Integrity of the conductivity sensor system

In appearance, the conductivity sensor is a tube-shaped instrument with 2-pole cell technology installed inside. It is connected to an Arduino board with a gateway of Langis in a box container, where the whole system is installed (see demonstration in Picture 1. below). The system has a plug, thus reachable electricity source is needed when using this sensor system. It also allows the sensor to be portable.



*Picture 1. Demonstration the system component of conductivity sensor*

While the system is working, the box must be closed, also touching the board inside is forbidden. This is because live current will used during running the measurement, and any touch off the system is not expected. When measuring liquids with the conductivity sensor, all data will be uploading to cloud, where copying and downloading of data is possible.

### Working principle of the conductivity sensor

The prototype conductivity sensor is a 2-pole sensor that has two electrodes on the sensor head. The theory is to record the voltage drop, which would help observe the resistance of the target solution. As the demonstration in Figure 1. shown below, the sensor system circuit has a CPU operating voltage which provides an approximate 3.3 Volts input; it also gives a fixed value of 3.09 Volts for V_out. The drop of voltage between CPU unit and V_out is caused by the inner resistance of CPU unit. [4] Page 6.

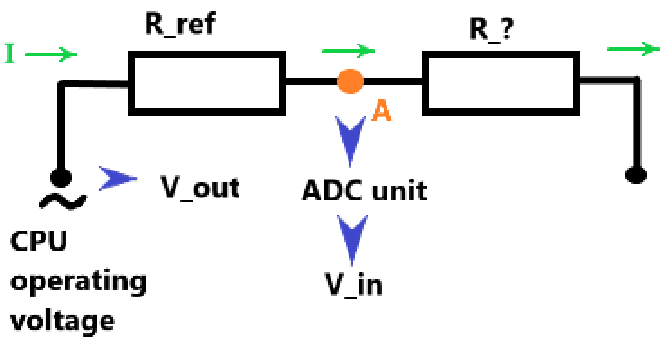



*Figure 1. Demonstration of conductivity sensor working principle*

There is a reference resistance installed in the system that has a fixed value for the calculation of the unknown resistance of target solution. The voltage value at point *A* is sent into an ADC unit (analog-to-digital-conversion) to get the value of *V_in*. The transformation of *V_in* is written as:

$$V_{in} = \frac{R\_?}{R_? + R\_ref} * V\_out \ ,$$

where,

*R_ref* is known values

*V_out* = 3.09

*R_?* is unknown resistance

Thus, the unknown resistance *R_?* is calculated to get the conductivity digital signal, *K*:

$$K = \frac{1}{R\_?} \ ,$$

where,

*K* is conductivity digital signal

*R_?* is known via the last step

The sensor reads analogue signals as input and gives digital signals as output. The output is recorded as Voltage in/ Voltage out ($V_{in}/V_{out}$) and Voltage in/ mean value of Voltage out ($V_{in}/V_{outm}$).

### Data storage

The data measured will be shown on the website linked with the gateway on Arduino system. Fifteen sets of data will appear gradually on the webpage in random order, also data is uploading on the same delay and in random order. Before the data refreshes, there is enough time to take a screenshot or copy directly from the webpage by selecting the data.

## 2.4 Turbidity prototype sensor

### Integrity of the turbidity sensor measuring system

The prototype turbidity sensor is a tube-shaped instrument with backscattering technology installed. On the detection head, there are two poles which stand for infra-red-light transmitter and receiver. To differentiate from regular 90 degrees backscattering turbidity sensors, this prototype is of full backscattering ---- 180 degrees. The 180 degrees angle enables direct comparison of emergent light beam to the incident light beam. Another difference is that regular 90 degrees backscattering turbidity sensor has 15-step elevation process while the given 180 degrees backscattering sensor is 3-step.

### Working principle of the turbidity sensor

The turbidity sensor has an infra-red-light transmitter and a light receiver, which applies the light scattering principle. The theory is that infra-red light passes through the medium from the light emitting diode (LED) emitter, after which the intensity of direction change of light is measured by the reflection signal read by the receiver. The sensor is reading analogue signals and transforming them into digital output. Light is scattered by the particles in the solution, it causes reflection, refraction or diffraction of light. The transmitted infra-red light is attenuated by scattering for prototype turbidity sensor. [5]

Figure 2. below demonstrates how the prototype turbidity sensor works. Terms are similar to the circuit of prototype conductivity sensor. The input IR-LED intensity is defined as *f(V_in)*, while the output *V_out* is sent to an ADC unit and defined as *f(V_in, turbidity)*.

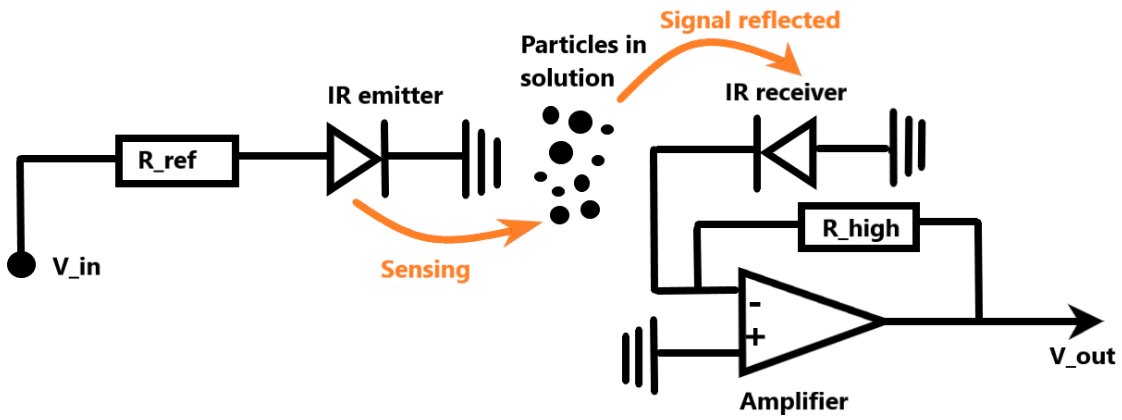



*Figure 2. Demonstration of prototype turbidity sensor working principle*

## Data storage

While the turbidity sensor is measuring, data are shown in the monitor window of Arduino application on computer. The way to store all data is to copy, paste and save as files, usually excel or text. Therefore, the data files can be loaded for further analysis in R-studio.

# 3 Risk assessment

All samples that were measured were liquids. Measurements were done by measuring sensor readings on sample dilutions to make a reading curve. For conductivity measurement, salt water sample dilutions were prepared. They were measured by conductivity meter and prototype conductivity sensor in the laboratory. For turbidity measurement, low-fat and full-fat milk dilutions were measured byturbidity meterand prototype turbidity sensor. After the calibration curves were carried out, mining water samples were tested by the calibrated prototype sensors.

## 3.1 Regular aqueous samples

There was no hazardous matter involved in neither salt water samples nor milk samples. The solid salt and milk were bought from supermarket. During the laboratory work, salt water samples were only used for instrument measurements, while laboratory coat, goggles and gloves were worn. As for milk, since there were many measurements done on milk samples (low-fat, full-fat), all milk packages were bought and used on the same day to keep the sample fresh and to ensure the readings not to be influenced by unexpected microbes.

## 3.2 Mining water samples

The mining water sample was taken from Lappeenranta mining site, and it mainly contains sulphate ions, which is $SO_4^{2-}$. Sulphate is one kind of salt in chemistry; it also exists in our everyday life. It is an anion that is easily to combine with other cations to form different kinds of acid or salt, for instance, it becomes $H_2SO_4$ (sulphuric acid) combining with $H^+$; with $Na^+$ it will turn into $Na_2SO_4$ (sodium sulphate).

In the laboratory work, the mining water sample was diluted with ion exchanged water and no other chemicals were added. Even though no new chemical was generated during the working process, protective gears was always be worn. The concentration of sulphate was also measured through spectrophotometry technology to check the quantity of sulphate in total mining water sample.

### 3.3 Safety regarding prototype sensor

Although the normal industrial grade IP67 box was with high electrical safety, the box had to be closed while the conductivity sensor system was working. The running voltage was 12V, which is not fatal to human health, any move on the system is still unexpected.

# 4 Methodology

The initial goal was to find the calibration curves for both sensors from the experiments. For conductivity sensor, saltwater with its dilutions were chosen to be the target solution to test. Calibration of the conductivity meter was needed to ensure the reliability of standard reference. Then readings from the prototype conductivity sensor were recorded. With the concentration of sample solution and sensor readings, a calibration curve could be carried out. The readings from conductivity meter could provide a standardized unit of sensor output (µS/cm) after the transformation of data. For turbidity sensor, full-fat milk with its dilutions were measured by a turbidity meter in the laboratory as well by the prototype turbidity sensor. Both experiments followed the same procedure so that turbidity sensor readings would be giving a standard unit through the turbidity meter standard reference (NTU).

For the experiments of milk, low-fat milk used at the beginning of test was on the upper limit of the prototype turbidity sensor, which showed a demand of more turbid solutions. Therefore, full-fat milk was selected for further tests.

## 4.1 Calibration curve and its function

The calibration curve is a graphic method used in analytical chemistry for instrument calibration. In this thesis, the curve showed a graph created by readings from the laboratory instrument and the target instrument. Sensor readings were shown on x-axis, while the concentration was shown on y-axis. A best fitted curve of the experimental data was generated by R-studio, and it provided goodness of fit to show the reliability of fitting. This procedure was done to all readings, including those of laboratory instruments.

Removing of the outlier was necessary, while systematic errors, experimental errors or others were analysed to find an explanation for outliers. After getting the calibration curve, a dynamic range of reading prediction was generated so that the range of sensor readings could be predictable as well although the dynamic range was relatively limited due to the limited sample dilutions.

## 4.2 Laboratory experiments

### 4.2.1 Equipment

Beakers with different volumes were used. Several 400 mili-litre beakers were prepared for saltwater samples and full-fat milk samples; few 1-litre beakers were used for depths test on low-fat milk; a 2-litre beaker was used to take ion exchanged water for dilution.

A balance was used to weigh 2 grams of salt to prepare saltwater mother solution.

A turbidity meter (HANNA ISO 88713) and a conductivity meter (EUTECH PC 2700) were used to measure milk samples and saltwater samples, respectively, to generate readings with standard units.

It was necessary to keep all samples stirring during each experiment, therefore a stirring machine and a clamp stand were taken into use.

### 4.2.2 Safety gears

To protect from any potential hazardous matters, a laboratory coat, a pair of goggles and nitrile gloves must be worn when entering the laboratory.

### 4.2.3 Quantity of sample and dilutions

Salt was weighed 2 grams in total to dissolve in a 2-litre beaker to make a 2 litre 1g/L saltwater mother solution. The determination of saltwater dilutions is shown in Table 1 below:

*Table 1. Saltwater dilution quantity, Volume = 400 mL*

| Dilutions | Concentration(g/L) | Conductivity (μS/cm) |
|---|---|---|
| 0 | 1 | 1774.3 |
| 1 | 0.85 | 1515.0 |
| 2 | 0.72 | 1301.7 |
| 3 | 0.61 | 1111.3 |
| 4 | 0.52 | 954.7 |
| 5 | 0.39 | 614.3 |
| 6 | 0.29 | 459.0 |
| 7 | 0.18 | 276.0 |
| 8 | 0.11 | 167.1 |
| 9 | 0.04 | 67.0 |
| 10 | 0.01 | 35.27 |

For full-fat milk, dilution was made according to the fat content, which is 3.5 grams in total written on the package. Several packages were used the same day bought from supermarket to keep the content fresh and the goodness of readings, also this might be one of the experimental errors since the quality of each raw sample cannot be guaranteed mathematically same. Samples with higher fat content showed *out of range* signal in turbidity meter, percentage of fat content is presented instead of turbidity values. Full-fat milk dilutions are presented in Table 2 below:

*Table 2. Full-fat milk dilution quantity, Volume = 400 mL*

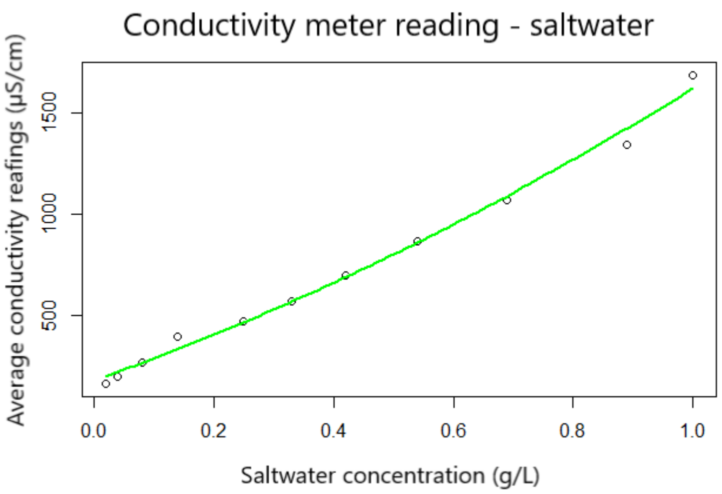
| Dilution | Fat (g) | Percentage |
|---|---|---|
| 0 | 3.50 | 100% |
| 1 | 3.06 | 88% |
| 2 | 2.63 | 75% |
| 3 | 2.19 | 63% |
| 4 | 1.75 | 50% |
| 5 | 1.31 | 38% |
| 6 | 0.88 | 25% |
| 7 | 0.44 | 13% |
| 8 | 0.22 | 6% |
| 9 | 0.18 | 5.0% |
| 10 | 0.13 | 3.8% |
| 11 | 0.088 | 2.5% |
| 12 | 0.044 | 1.25% |
| 13 | 0.022 | 0.63% |
| 14 | 0.004 | 0.13% |

# 5 Data analysis and calibration curves

## 5.1 Conductivity

### Conductivity meter test

A conductivity meter (EUTECH PC 2700) was used to measure the conductivity readings of saltwater dilutions (11 solutions in total). Each point in Graph 1 is the average value of three replicated measurements. The readings showed a great fitness of data to tell that the conductivity meter is functioning in decent linearity. R squared is 99.11%. See R code in Appendix 1.




*Graph 1. Fitness of conductivity meter readings on saltwater*

## Prototype conductivity sensor readings

The same batch of diluted saltwater samples were measured by the prototype conductivity sensor. When the system was connected to the power distribution,–the box was locked. The sensor head was held by a clamp stand and put in the medium depth of the solution with the magnetic stirring machine on. Air bubble was removed by dipping the sensor into the solution several rounds. A demonstration of conductivity sensor measuring system is shown in Picture 2 below:

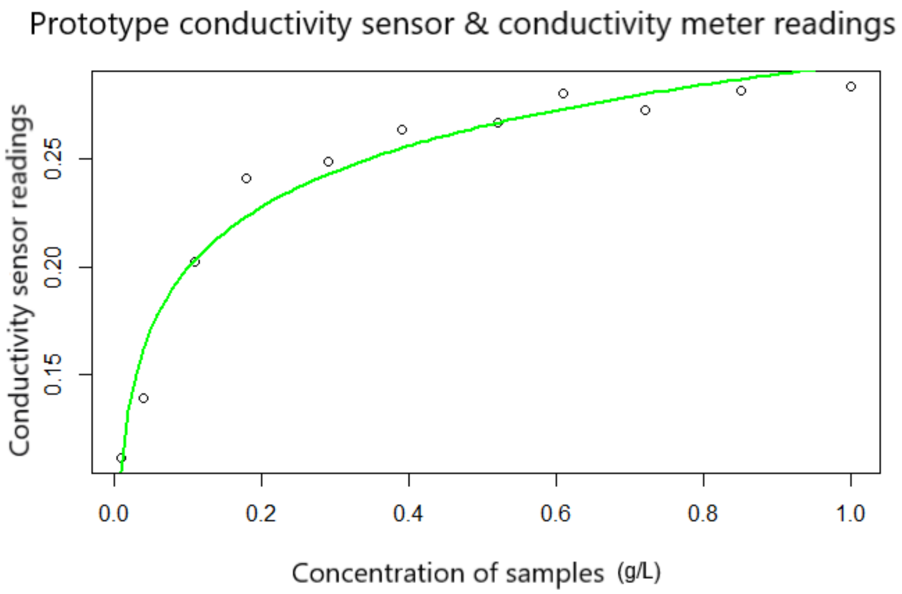
*Picture 2. Conductivity sensor measuring system settlement*

### Calibration curve of prototype conductivity sensor

The readings were plotted with logarithm model. R squared is 96.26% without outliers. See R code in Appendix 2.

Calibration curve formula can be expressed as follows:

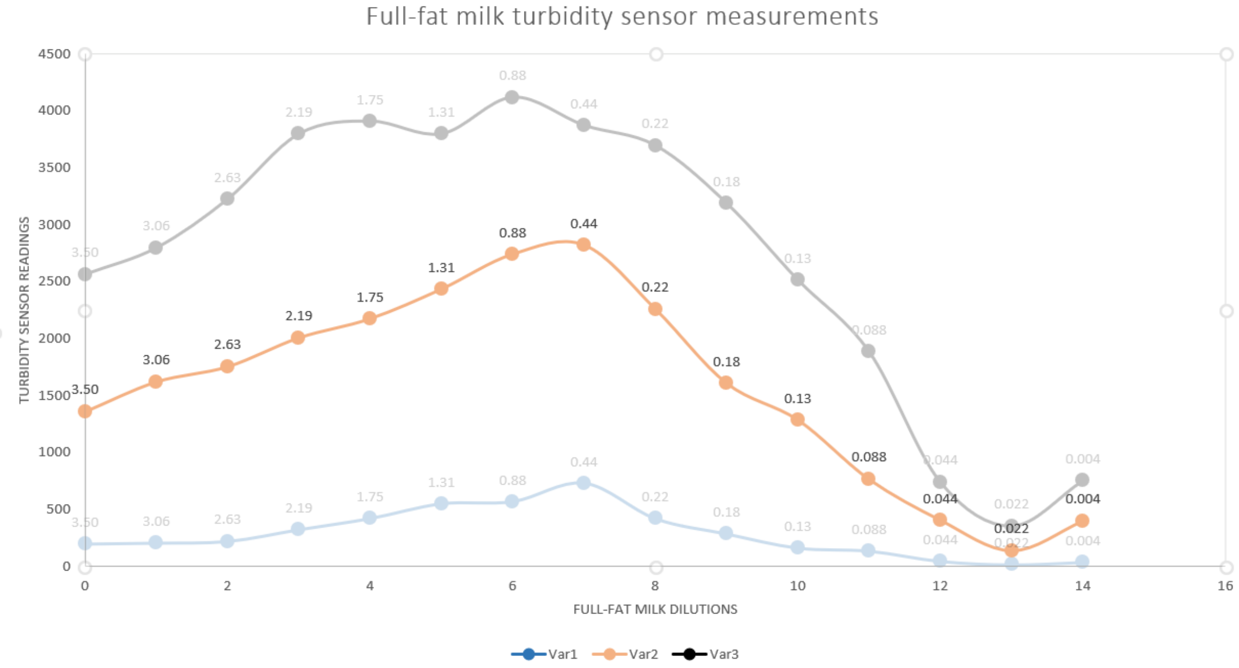
$$y = 0.041 * \log(x) + 0.294$$




*Graph 2. Calibration curve of conductivity sensor readings on saltwater*

## 5.2 Turbidity

The unit of readings is bits signals which is similar to millivolt (mV) readings but a dimensionless output from the AD converter of turbidity sensor. The turbidity sensor has 3-step elevation that is different than normal 15-step elevation sensors. The chosen step to be presented among three steps is based on the best performance. Here is a demonstration of the performance of 3-step elevation turbidity sensor. The test was based on the measurements from full-fat milk (3.5 g fat) with three steps measuring. It is apparent that the orange line has the highest recognition of better linearity, in other words, step 2 has the best performance.




*Graph 3. Performance on 3-step elevation signal output*

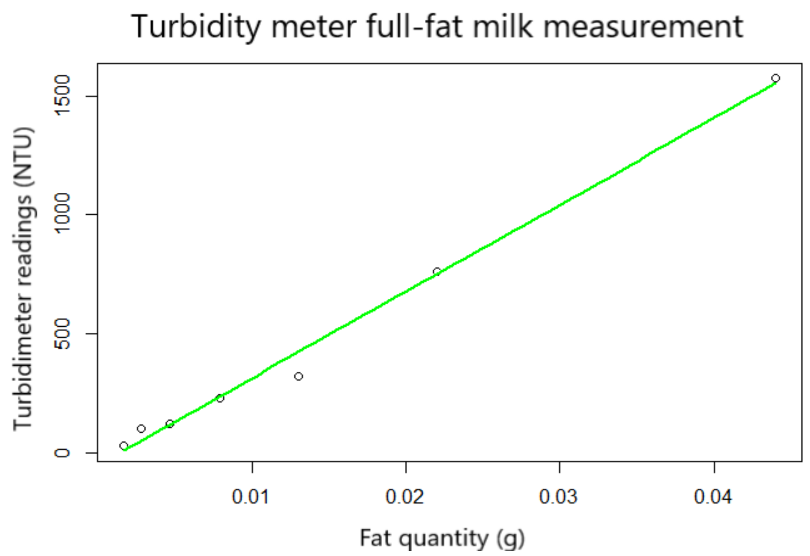
The characteristics of step 2 curve shows that the sensor has a response of higher range of turbid samples from full fat content 3.5 g till 0.44 g dilutions (backscattering); it absorbs the light from 0.44 g to 0.022 g dilutions. The bottom limit of the sensor stays at 0.022 g fat content according to this measurement.

### Turbidity meter test

The turbidity meter (HANNA ISO 88713), whose range is 0 ~ 4000 NTU, was tested for its reliability. There were 20 full-fat milk dilution samples measured by the turbidity meter in the laboratory, only 7 samples were given reliable readings. The turbidity meter gave “out of calibration range” or “out of range” signal for higher turbidity samples.

However, by reviewing the previous Graph 3 in 5.2, the measurement shown below only contains the range between 0.044 g fat to 0.022 g fat. Thus, the outcome from this test cannot be applied with the transformation curve of turbidity sensor.

A linear model fitting was applied on turbidity meter measurement and the R squared value was 99.26%, which tells the excellent performance of the turbidity meter. See R code in Appendix 1.




*Graph 4. Fitness ofturbidity meterreadings on full-fat milk*

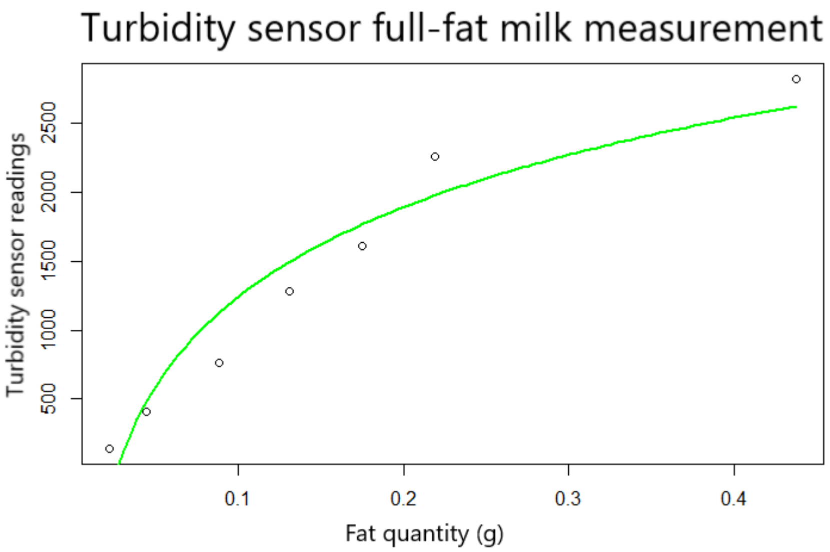
### Prototype turbidity sensor readings

Since the prototype turbidity sensor applies IR-LED technique, the clearance of liquid was considered to influence the readings, thus two tests were done to check the approximate immersing depth. The results showed obvious big variance at different depths for ion exchanged water. For low-fat milk, the results remained the same at all depths. See Chapter 7 for detailed description.

Therefore, the conclusion for the influence of liquid clearance was that the more turbid the liquid was, the more stable the readings would be. This conclusion confirmed that depth would no longer be a factor of influence by the following measurement of full-fat milk.

### Calibration curve of prototype turbidity sensor

As mentioned in 5.3, step 2 was chosen to be the best output to help comprehend the performance of the turbidity sensor. Also, the values that exceeded upper and lower limit were removed so that there was no misleading information. By applying R script with logarithm model, a graph shown in Graph 5 was received:




*Graph 5. Turbidity sensor calibration curve*

The readings were plotted with logarithm model. R squared is 92.71%. See R code in Appendix 2

Calibration curve formula can be written as follows:

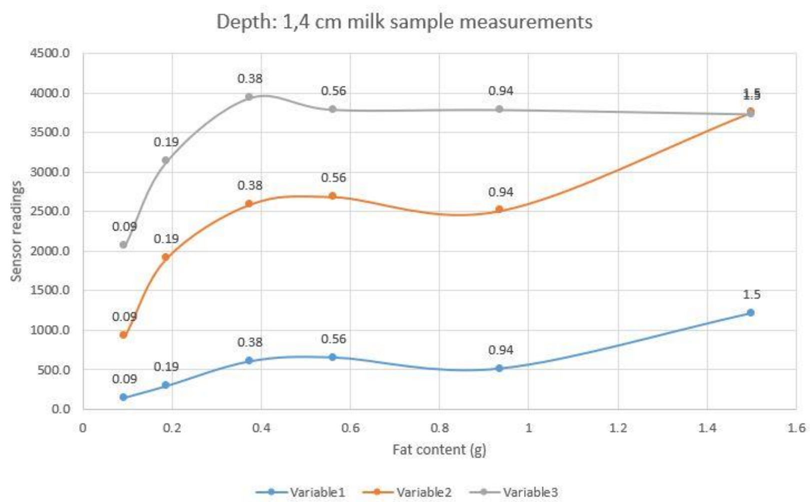
$$y = 934 * \log(x) + 3392.3$$

# 6 Other tests

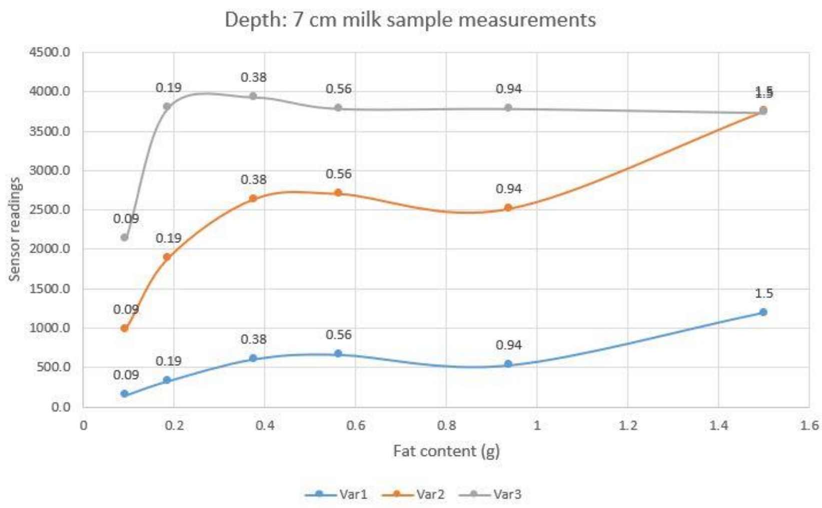
## 6.1 Influence of depth variation on turbidity sensor readings

As mentioned in 5.4, two tests were made to detect the influence of immersion depths to the prototype turbidity sensor readings. One of the test was conducted to measure ion exchanged water in three depths. A 1L tall beaker was chosen to collect samples so that there would be a decent range of depths to mark on. The determination of depths was measured by a ruler, three depths were chosen: 1.4 cm, 7 cm and 10.7 cm. Since the beaker itself was over 13 cm, the influence of water level growth caused by putting sensor inside sample was calculated so that no sample would leak from the rim of beaker. After the calculation, one litre of ion exchanged water was taken in the laboratory with the 1L tall beaker. Depth marks were measured and marked as mentioned above. The ion exchanged water test was done without dilutions. The results showed that the range of reading was too wide from hundred to over three thousand (shallow to deep). This is a normal situation for IR-LED sensors when they measure high clarity liquids.

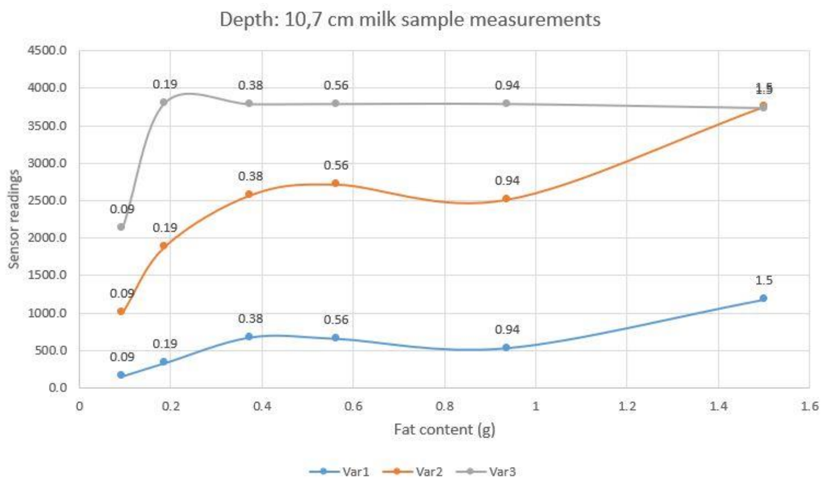
As for low-fat milk test, there was a raw sample with its five dilutions. Preparations were the same for the ion exchanged water test. A stirring machine and magnet were used to make proteins and fat evenly distribute in each sample. See Appendix.3 for the dilution table.




*Graph 6. Low-fat milk 1.4 cm depth measurement*




*Graph 7. Low-fat milk 7 cm depth measurement*




*Graph 8. Low-fat milk 10.7 cm depth measurement*

The result showed that the actual values measured at different depths for one sample remained the same, which explained that the depths did not have significant effect on IR-LED sensor readings when samples become turbid enough (see graphs 6-8).

## 6.2 Tests on natural water

This was done only for the interest on the accuracy of the conductivity sensor. Two different natural water samples were tested: normal rain water and lake water from Sääksjärvi near Nurmijärvi, Finland. [6]

Sääksjärvi is one of the biggest water sources in Finland and it has very high clarity. However, it contains much more nutrients than rainwater, which partly causes the conductivity of the lake water to be slightly higher.

Both samples were tested in a 400 mL beaker by the prototype conductivity sensor. The results of conductivity reading on rain water and lake water were 0.056 and 0.096 bits (mV) respectively. It was as expected that the conductivity of rainwater is slightly lower than that of lake water, which also indicates a decent accuracy of the prototype conductivity sensor.

## 7 Sources of interference

### Temperature

All laboratory measurements were done under room temperature between 19°C to 21°C. The influence of temperature is relatively easy to predict since the electrical resistance of material decreases as temperature increases, which leads to the rise of conductivity. For the prototype conductivity sensor, a changing temperature causes fluctuation on electrodes and it cannot be compensated.

Due to the lack of space and time, the temperature test for prototype turbidity sensor could not be done. However, turbidity change could possibly cause the rise of temperature in theory. It would be very meaningful for the next person who could do the experiment about  of the influence of temperature on turbidity range.

### Air bubble and stirring

There are two examples of air bubble appearing on both prototype sensors.
Picture 3 shows air bubbles on the prototype conductivity sensor:

*Picture 3. Air bubbles on prototype conductivity sensor*

Picture 4 shows air bubbles on the prototype turbidity sensor.

*Picture 4. Air bubbles on prototype turbidity sensor*

Air bubbles and foam are regarded similar in that both interfere the sensor readings since they would be recognized as particles in aqueous solutions and reflect signal to the receiver. For conductivity sensor, air bubbles and foam increase the resistance of solution, while for turbidity sensor, they reflect IR light that causes inaccuracy. During the laboratory experiment, large air bubbles were removed by moving the sensor head towards the spinning magnet until bubbles moved to sample surface.

As for stirring, the magnetic field of the magnet might have interference with the circuits of both sensors so that some of the readings suffered from variation when the replicated measurements were taken. Thus, more replicates were done to calculate the average readings to minimize the influence of it.

## 8 Conclusion

The prototype conductivity sensor and the turbidity sensor have exhibited quite satisfactory performances, suggesting that it is positive to use both sensors for environmental measurements. From the statistical point of view, the analysis in R-studio indicates that the conductivity sensor has slightly better performance than the turbidity sensor. Conductivity sensor measures resistance generated by the quantity of ions existed in samples in a stable way. There is no unexpected variation occurring neither when switching the sensor to different samples nor when uploading data to the cloud. The turbidity sensor measures the quantity of particles in samples, and it has a slight latency of data uploading when switching the sensor to other samples. The true reading would show in the new sample after showing few readings from the previous sample. It does not affect the fine performance in practical use.

Also, both sensors have a length of approximately 20 cm, and a stand is needed for mounting the sensors fixed. The prototype conductivity sensor with its system box is portable and needs a power supply. The prototype turbidity sensor uses USB cable connected to Arduino in a PC. It is less space-consuming than the conductivity sensor.

However, due to the limited time and space, replicate of measurements with both sensors could not be done. One suggestion for further testing is that the next person would do several replicates of measurement to determine the uncertainty of sensor measurement so that the variance of sensor readings would be known for further accuracy assessment.

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## Appendix 1 R code for the conductivity and turbidity meter test

### Conductivity meter test R code

```
Data <- read.table('Cond_saltwater.txt', header=TRUE)

source('http://users.metropolia.fi/~velimt/R/DOE_functions_v5.r')

extract.var(Data)

x <- Concentration
y <- Average

quadratic.model <- lm(y ~ x + I(x^2))
summary(quadratic.model)

plot(x,y)
coef(quadratic.model)

predicted <- fitted(quadratic.model)
curve(predict(quadratic.model,data.frame(x)),col='green',lwd=2,add=TRUE)
```

### Turbidity meter test R code

```
Data5 <- read.table('Turb_meter_full_milk.txt', header=TRUE)

source('http://users.metropolia.fi/~velimt/R/DOE_functions_v5.r')

extract.var(Data5)

x <- fat
y <- Average

model <- lm(y ~ x)
summary(model)

plot(x,y)

coef(model)

predicted <- fitted(model)
curve(predict(model,data.frame(x)),col='green',lwd=2,add=TRUE)
```

## Appendix 2 R code for prototype conductivity and turbidity sensor test

### Prototype conductivity sensor calibration R code

```
Data2 <- read.table('Cond_sensor.txt', header=TRUE)

source('http://users.metropolia.fi/~velimt/R/DOE_functions_v5.r')

extract.var(Data2)

x <- Concentration
y <- Vin_Voutm

log.model <- lm(y ~ log(x))
summary(log.model)

plot(x,y)

coef(log.model)

predicted <- fitted(log.model)
curve(predict(log.model,data.frame(x)),col='green',lwd=2,add=TRUE)
```

### Prototype turbidity sensor calibration R code

```
Data4 <- read.table('Turb_full_milk.txt', header=TRUE)

source('http://users.metropolia.fi/~velimt/R/DOE_functions_v5.r')

extract.var(Data4)

x <- fat
y <- step2

log.model <- lm(y ~ log(x))
summary(log.model)

plot(x,y)

coef(log.model)

predicted <- fitted(log.model)
curve(predict(log.model,data.frame(x)),col='green',lwd=2,add=TRUE)
```

## Appendix 3

### Low-fat milk dilution table

| Order | Fat (g) | Percentage |
|---|---|---|
| 1 | 1.5 | 100% |
| 2 | 0.94 | 63% |
| 3 | 0.56 | 38% |
| 4 | 0.375 | 25% |
| 5 | 0.19 | 13% |
| 6 | 0.09 | 6% |