Measurement of Water Salinity for Antarctic Research

Presented by:
Zuhayr Loonat

Prepared for:
Justin Pead
Dept. of Electrical Engineering
University of Cape Town

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Declaration

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Acknowledgments

Make relevant acknowledgements to people who have helped you complete or conduct this work, including sponsors or research funders.

Abstract

- Open the **Project Report Template.tex** file and carefully follow the comments (starting with %).
- Process the file with **pdflatex**, using other processors may need you to change some features such as graphics types.
- Note the files included in the **Project Report Template.tex** (with the .tex extension excluded). You can open these files separately and modify their contents or create new ones.
- Contact the latex namual for more features in your document such as equations, subfigures, footnotes, subscripts & superscripts, special characters etc.
- I recommend using the **kile** latex IDE, as it is simple to use.

Contents

Glossary

PSU Practical Salinity Unit 6, 10, 12

‰ Parts per thousand 6

Acronyms

CTD Conductivity, Temperature, Depth 12

EIS Electrical Impedance Spectroscopy 5

ML Machine Learning 5

Chapter 1

Introduction

1.1 Background to the study

A very brief background to your area of research. Start off with a general introduction to the area and then narrow it down to your focus area. Used to set the scene[?].

1.2 Objectives of this study

1.2.1 Problems to be investigated

Description of the main questions to be investigated in this study.

1.2.2 Purpose of the study

Give the significance of investigating these problems. It must be obvious why you are doing this study and why it is relevant.

1.3 Scope and Limitations

Scope indicates to the reader what has and has not been included in the study. Limitations tell the reader what factors influenced the study such as sample size, time etc. It is not a section for excuses as to why your project may or may not have worked.

1.4 Plan of development

Here you tell the reader how your report has been organised and what is included in each chapter.

I recommend that you write this section last. You can then tailor it to your report.

Chapter 2

Literature Review

2.1 Introduction

Accurate salinity measurement is fundamental to oceanographic research. Traditional measurement techniques have evolved from labour-intensive chemical titration methods to modern electronic sensors, with electrical conductivity emerging as the predominant approach due to its combination of accuracy, speed, and practical deployability. This literature review examines the current state of salinity measurement technology with particular emphasis on conductivity-based methods and emerging machine learning approaches for electrochemical data interpretation. The review is organised into three main sections. First, we establish the fundamental concepts of salinity and provide a comprehensive comparison of available measurement techniques. Second, we examine the theoretical foundations and practical implementation of electrical conductivity measurements for salinity determination, including instrumentation, calibration procedures, and current limitations. Finally, we explore the application of Electrical Impedance Spectroscopy (EIS) and Machine Learning (ML) as advanced approaches for enhanced salinity analysis, examining how frequency-domain measurements and intelligent data processing can overcome limitations of traditional single-frequency conductivity methods. This comprehensive review provides the theoretical and methodological foundation for developing a machine learning-enhanced impedance spectroscopy approach for salinity determination.

2.2 Salinity: Definition

Salinity is a fundamental characteristic of water, and is most commonly defined as the total amount of dissolved salts in water, and in the context of oceanography, seawater. It is typically expressed in ‰ or PSU [1]. The concept of salinity has evoloved significantly from its early definition, which was based on chlorinity measurements. Modern salinty is defined through the Practical Salinity Scale 1978 (PSS-78), where salinity is based on the conductivity ratio of standard seawater solutions, to a standard Potassium Chloride solution, and is dimensionless [2]. The salinity-conductivity relationship is however, quite complex, requiring corrections and calibrations needed for depth and temperature, as these both play a factor in the conductivity of the water.

2.3 Overview of Salinity Measurement Methods

There are a multitude of methods which can be used to measure salinity, each with their own advatages, limitations and levels of accuracy. Traditional methods include gravimetric analysis, chemical titration (such as the Mohr-Knudsen method for chlorinity), and refractometry. While these techniques can provide accurate results, they are often time-consuming, require skilled operators, and are not easily adaptable to in-situ or automated measurements. Modern approaches predominantly rely on electrical conductivity sensors, which offer rapid, repeatable, and automated salinity determination. Other techniques, such as optical methods and ion-selective electrodes, have also been explored, but are less commonly used in oceanographic applications due to issues with robustness, calibration, or specificity. The choice of method depends on the required accuracy, operational environment, and available resources.

2.3.1 Historical Methods

Chlorinity Titration

Early salinity measurements relied on chemical titration methods, in particular the Mohr-Knudsen chlorinity titration, which used silver nitrate. The chlorinity of a solution has the definition 'the mass of silver required to precipitate completely the halogens in $0.3285234 kg$ of the ocean-water sample' This method was highly accurate, with results within (± 0.001 PSU). However, it relied heavily on toxic chemicals, and was a time-consuming laboratory procedure, with limited practical application in the field.

Gravimetric Methods

Gravimetric analysis, a technique used to determine an amount of a substance, by measuring its change in mass, invloves evaporation and the weighing of dissovled solids. This method directly provided measurements of the salt content, within accuracies of (± 0.001 PSU), under controlled laboratory conditions. This method remains the reference standard for calibration processes, but is however, extremely slow.

2.3.2 Physical Property Based Methods

There are several methods that utilise the relationship between salinity and the physical properties of water.

Hydrometric and Density Methods

Hydrometric methods using density measurements via hydrometers, offer salinity measurements that are low-cost, and electronics free. However, they are limited in precision with accuracies of $\pm 1 - 2$ PSU, and require large sample volumes. The hydrometer is a floating instrument, that sinks to different depths depending on the density of the solution, and by measuring how high or low it floats, the density of the solution can be determined. The following equation is used to map the relationship between salinity and density.

$$\rho = \rho_0(1 + kS) \tag{2.1}$$

where ρ is the density, ρ_0 is the density of fresh water, S is the salinity and k is the proportionality constant.

This can then be inverted to give Salinity from Density:

$$S = \frac{\frac{\rho}{\rho_0} - 1}{k} \tag{2.2}$$

This however, does not include temperature correction.

Refractometric Thechniques

Refractometric techniques measure the refractive index changes cuased by the dissovled salts. The refractive index of seawater is influenced by wavelength, temperature, salinity, and pressure. Within the range of 500-700 nm wavelength, 0-30°C temperature, 0-40 PSU salinity, and 0-11000 dbar pressure, the refractive index equation provides an accuracy of 0.4-80 ppm PSU, with accuracy decreasing as pressure increases. Refractometers, which require only a small sample volume, are compact devices, making them suitable for portable field measurements. Fibre optic refractometers have improved portability and reduced temperature sensitivity, with moderate accuracy (±0.5-1 PSU), making them increasingly popular in aquaculture applications.

Freezing Point Osmometry

Freezing point depression osmometry exploits the colligative (i.e. relating to the binding together of molecules) properties of dissolved salts. The main principle relies on freezing point depression, which is the phenomenon where a solvents freeving point is lowered when a solute is added to it. To perform the measurement, the water is cooled till its freezing point and the temperature drop is measured, which is then used to calculate the osmolality. This method can achieve accuracies as high as (±0.001 PSU), however its requirement for precise temperature control limits its usage to laboratory applications.

Interferometry

Interferometry is a measurement technique which measures how electro-magnetic waves are affected by changes in a solution. Two identical light waves are passed through two solutions, one benchmark and one test sample solution. The gain and phase shift between the waves is then used to calculate the salinity. This method requires precisely aligned mirrors to direct the light waves, causing it to be relatively large.

Electromagnetic Induction and Magnetic Permeability

2.3.3 Advanced Analytical Methods

2.3.4 Remote Autonomous Sensing

2.4 Conductivity-Based Salinity Measurements

2.4.1 Theoretical Foundation

Electrical conductivity has emerged as the predominant method for salinity measurement due to its practical implementation, high accuracy and fast response time. The technique utilises the strong correlation between dissolved ionic content and electrical conductivity.

The conductivity of a liquid is measured by its ability to conduct electrical current. The relationship between conductivity and salinity is based on the concentration of dissolved ions in seawater. The main ions found in sea water $(Na^+, Cl^-, Mg^{2+}, SO_4{}^{2-}, Ca^{2+}, K^+)$ maintain a relatively constant proportional relationship, in ocean waters [3]. This enables robust corrections between conductivity and total dissolved salt content. Unlike other measurement techniques, conductivity accounts for all the ions in the water, not only chlorine, which is why it is considered a more accurate measure of salinity [4].

The Practical Salinity Scale 1978 (PSS-78) defines Practical Salinity S_p through the conductivity ratio K_{15}, as shown below [5]:

$$K_{15} = \frac{C(S_p, 15, 0)}{C(KCl, 15, 0)} \tag{2.3}$$

where the numerator, $C(S, 15, 0)$ represents the conductivity of seawater sample at 15°C and standard atmospheric pressure $(1atm/101.325kPa/0dbar)$, and the denomimator, $C(KCl, 15, 0)$ is the conductivity of a standard KCl (Potassium Chloride) solution under identical temperature and pressure. The standard KCl solution consists of $32.4356 \times 10^{-3}kg$ of KCl dissolved in $1kg$ of water [6]. When the ratio between the water sample and the KCl solution is 1, i.e. $K_{15} = 1$, then the Practical Salinity S_p is, according to the definition, 35 [5].

It is important to note that Practical Salinity is a unit-less quantity, and though it may be convenient, it would be incorrect to quote it in PSU. Practical salinity should rather be quoted as a certain Practical Salinity 'on the Practical Salinity Scale PSS-78' [5].

When K_{15} does not equal 1, Practical Salinity, S_p can be calculated using the equation below [5]:

$$S_p = \sum_{i=0}^{5} a_i (K_{15})^{i/2} \tag{2.4}$$

where K_{15} is the equation defined above (Equation 2.3), and the coefficients a_i are given in Table (2.1).

2.4.2 Temperature and Pressure Compensation

When calculating salinity at conditions other than 15°C, and $0dbar$, the conductivity ratio R is expanded to the product of three ratios R_p, R_t and r_t as follows [5]:

$$R = \frac{C(S_p, t, p)}{C(35, 15, 0)} = R_p R_t r_t \tag{2.5}$$

where t, and p are the temperature and pressure valid over the ranges $-2°C \leq t \leq 35°C$ and $0 \leq p \leq 10000dbar$ respectively.

These ratios can be expanded as follows:

$$R = \frac{C(S_p, t, p)}{C(35, 15°C, 0)} = \frac{C(S_p, t, p)}{C(S_p, t, 0)} \cdot \frac{C(S_p, t, 0)}{C(35, t, 0)} \cdot \frac{C(35, t, 0)}{C(35, 15°C, 0)} = R_p R_t r_t \tag{2.6}$$

This equation represents the ratio between the conductivity measurement of a sample $C(S_p, t, p)$ and the conductivity of the standard solution $C(35, 15°, 0)$ [5]. In order to find the salinity, R_p, R_t and r_t need to be caculated. First, r_t is calculated using the temperature of the sample:

$$r_t = \sum_{i=0}^{4} c_i t_i \tag{2.7}$$

R_p is then calculated as a function of the temperature t, pressure p, and conductivity ratio R:

$$R_p = 1 + \frac{\sum_{i=1}^{3} e_i p^i}{1 + d_1 t + d_2 t^2 + R[d_3 + d_4 t]} \tag{2.8}$$

Finally, R_t can be evaluated using R, R_p and r_t:

$$R_t = \frac{R}{R_p r_t} \tag{2.9}$$

At standard conditions, i.e., temperature $t = 15°\text{C}$, R_t is equal to K_{15} an therefore Practical salinity S_p can be calculated from Equation 2.3. For cases where the temperature is not $t = 15°\text{C}$, Practical Salinity S_p is given as a function of R_t, with $k = 0.0162$ [5]:

$$S_p = \sum_{i=0}^{5} a_i (R_t)^{i/2} + \frac{t - 15}{1 + k(t - 15)} \sum_{i=0}^{5} b_i (R_t)^{i/2} \tag{2.10}$$

Note that Equations (2.3) to (2.10) are only valid in the range $2 < S_p < 42$, $-2°C \leq t \leq 35°C$ and $0 \leq p \leq 10000dbar$.

i	a_i	b_i	c_i	d_i	e_i
0	0.0080	0.0005	$6.766\,097 \times 10^{-1}$		
1	-0.1692	-0.0056	$2.005\,64 \times 10^{-2}$	3.426×10^{-2}	2.070×10^{-5}
2	25.3851	-0.0066	$1.104\,259 \times 10^{-4}$	4.464×10^{-4}	-6.370×10^{-10}
3	14.0941	-0.0375	-6.9698×10^{-7}	4.215×10^{-1}	3.989×10^{-15}
4	-7.0261	0.0636	1.0031×10^{-9}	-3.107×10^{-3}	
5	2.7081	-0.0144			

Table 2.1: Table of Coefficients for PSS-78 Equations [5]

It must be noted that the PSS-78 equations use the IPTS-68 temperature scale and in order for them to work with the current ITS-90 scale, must be converted using the equation below [5]:

$$t_{68}^{circ} C = 1.00024 \times t_{90}^{circ} C \tag{2.11}$$

2.4.3 Instrumentation and Technology

The most common method for measuring salinity is by using a Conductivity, Temperature, Depth (CTD) device. The fundamental concept of these devices involves placing two electrodes in a sample of water, applying a voltage across them and measuring the water's response. This is then paired with a temperature and depth correction, allowing for an accurate salinity measurement. The depth value for these calculations is taken from the pressure at which the measurement is taken. This pressure is then traslated to depth using the standard depth to pressure equation. Modern CTD systems achieve salinity accuracies better than ± 0.005 PSU, with some instruments like the Sea-Bird 911 Plus demonstrating historical accuracies of ± 0.002 PSU or ± 0.0002 PSU.

2.4.4 Applications and Limitations

Conductivity-based salinity measurements excel in most oceanographic and water quality applications due to its accuracy, speed, and reliability. The conductivity method allows for real-time data capture, continuous monitoring, and easy integration with autonomous devices.

However, this method does face some limitations. Due to its dependance on the water's capacity to conduct electricity, freshawater applications require specialised low-conductivity sensors, while hyper-saline environments could exceed the standard calibration range.

The method's reliance on emperical correlations derived from typical seawater compositions can introduce errors in waters ocean waters affected by external factors such as pollution or freshwater inflow from connecting rivers, which can alter ionic composition and introduce variability not captured by standard seawater-based calibrations. In such environments supplementry practices may be necessary for accurate salinity measurements.

Chapter 3

Methodology

This is what I did to test and confirm my hypothesis.

You may want to split this chapter into sub chapters depending on your design. I suggest you change the title to something more specific to your project.

This is where you describe your design process in detail, from component/device selection to actual design implementation, to how you tested your system. Remember detail is important in technical writing. Do not just write I used a computer give the computer specifications or the oscilloscopes part number. Describe the system in enough detail so that someone else can replicate your design as well as your testing methodology.

If you use or design code for your system, represent it as flow diagrams in text.

IMPORTANT: Include a motivation for your selection of an appropriate technique, or engineering or IT tool to solve your project problem. Discuss any limitations if appropriate.

Chapter 4

Results

These are the results I found from my investigation.

Present your results in a suitable format using tables and graphs where necessary. Remember to refer to them in text and caption them properly.

4.1 Simulation Results

4.2 Experimental Results

Chapter 5

Discussion

Here is what the results mean and how they tie to existing literature...

Discuss the relevance of your results and how they fit into the theoretical work you described in your literature review.

Chapter 6

Conclusions

These are the conclusions from the investivation and how the investigation changes things in this field or contributes to current knowledge...

Draw suitable and intelligent conclusions from your results and subsequent discussion.

Chapter 7

Recommendations

Make sensible recommendations for further work.

Bibliography

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[5] International Oceanographic Commission,, "TEOS-10: The International thermodynamic equation of seawater – 2010: calculation and use of thermodynamic properties.," *Manuals and Guides*, vol. 56, 2015. Publisher: UNESCO.

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Appendix A

Additional Files and Schematics

Add any information here that you would like to have in your project but is not necessary in the main text. Remember to refer to it in the main text. Separate your appendices based on what they are for example. Equation derivations in Appendix A and code in Appendix B etc.

IMPORTANT: Appendix A (see the table below) should provide a summary of how you have met the GAs associated with the course, and where in the report the evidence can be found.

If you have used AI in writing your report, you need to provide details in one of the appendices of how you used it.

If appropriate, in a subsequent appendix, provide a link to any GitHub repository where the code and additional materials for your project can be found.

GA	Requirement	Justification and section in the report
1	Problem-solving	Description here
4	Investigations, experiments and data analysis	Description here
5	Use of engineering tools	Description here
6	Professional and technical communication (Long report)	Description here
8	Individual work	Description here
9	Independent learning ability	Description here

Appendix B

Addenda

B.1 Ethics Forms

Appendix C

GitHub Repository

Click here to access the GitHub repository.

GitHub Structure