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" IoT-BASED SYSTEM USING FUZZY LOGIC METHOD FOR MEASURING SALT QUALITY "

A dissertation submitted in partial fulfilment of the requirements for the award of

MASTERS OF SCIENCE DEGREE IN INTERNET OF THINGS-WIRELESS INTELLIGENT SENSOR NETWORKING

Submitted by:

SHAAME MSHINDO BAKAR (Ref. No: 220020578)

November 2022

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Supervised by:

Main supervisor: Dr. Pierre Bakunzibake

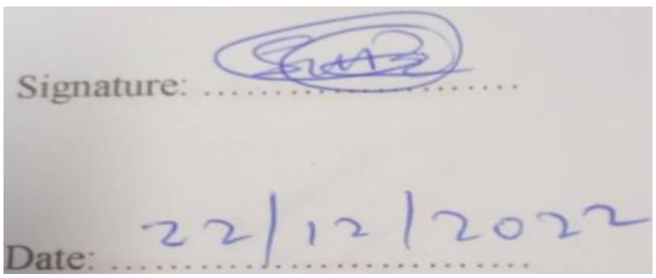
Co-supervisor: Dr. Alexander Ngenzi

DECLARATION

I, SHAAME MSHINDO BAKAR, Master student from African Centre of Excellence in internet of things, at University of Rwanda. I declare that this research thesis is my own original work and it has never been presented before anywhere in the world.

SHAAME MSHINDO BAKAR

Ref: 220020578



BONAFIDE CERTIFICATE

This is to certify that this submitted Research Thesis work report is a record of the original work done by SHAAME MSHINDO BAKAR (Ref. No: 220020578), MSc. IoT-WISNET Student at the University of Rwanda, College of Science and Technology, African Center of Excellence in Internet of Things, the Academic year 2021/2022. This work successfully completed and has been submitted under the supervision of **Dr. Pierre Bakunzibake** and **Dr. Alexander Ngenzi.**

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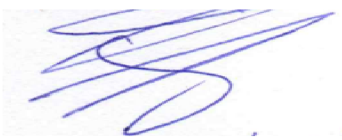

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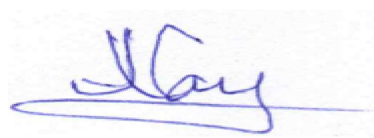

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ABSTRACT

The quality of Salt is an important aspect for human health growth and economic development. The deficiency of quality salt concentration has become a challenge in recent years in Zanzibar. The production of sodium chloride salt from the seawater normally has the minimum level of sodium chloride concentration of about 85 to 90% in dry base, which is below of national and international standards requirements (97-100%). This study uses an Internet of Things (IoT) to reduce this challenge as a real-time technology to measure and infer the salt parameters. The aim of the study is to design and prototype an IoT based system using fuzzy logic approach for measuring sodium chloride salt quality. The system was designed and it includes with electrical conductivity, total dissolved solids, pH and temperature sensors, Arduino Uno microcontroller, GSM device, LCD screen display and ThingSpeak cloud server. The three samples of sodium chloride solution of 5000mg/L were prepared by using distilled water. The fuzzy logic approach was used to analyse the data collected from sensors and transmitted to the cloud server for process and analysis to get the output results. The study results help to estimate the sodium chloride salt concentration and its salt quality. The implementation of the proposed solution was expected to measure and estimate the quality of sodium chloride salt, sending email notification and to help users on decision-making. Therefore, the use of IoT technology would be helpful for measuring of salt quality.

Key words: IoT, Fuzzy logic, EC, TDS, Quality salt, PPM.

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LIST OF ACRONYMS

ACEIoT:	African Centre of Excellence in Internet of Things
IoT:	Internet of Things
GSM800L	Global System for Mobile Communication 800L
TDS:	Total Dissolved Solids
QOS:	Quality of Salt
EC:	Electrical Conductivity
pH:	Hydrogen Potential
LCD:	Liquid Crystal Display
MQTT:	Message Queuing Telemetry Transport
ML:	Machine Learning
IDE:	Integrated Development Environment
FIS:	Fuzzy Inference System
AI:	Artificial Intelligence
API:	Application Programmable Interface
HTTP:	Hypertext Transfer Protocol
IFTTT:	If This Then That
PPM:	Parts per millions
R^2:	Regression index
MQTT:	Message Queuing Telemetry Transport
ML:	Machine Learning
IDE:	Integrated Development Environment
FIS:	Fuzzy Inference System
AI:	Artificial Intelligence
API:	Application Programmable Interface
HTTP:	Hypertext Transfer Protocol

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CHAPTER 1. INTRODUCTION

1.1. Introduction

This chapter explains the background and motivation of the salt production and its quality parameters.

1.2.Background

The sodium chloride known as table salt, mostly used in different applications for human and industrial purposes. The salt has various applications such as home for food cooking, food additive in food processing to influence the product taste and it is useful in texture and storage. Therefore, it is important in everyday human life [1].

The easy way of obtaining sodium chloride is the evaporation process from seawater after being collected in a certain area (special ponds), but still the salt produced has low quality, more process are required to make it a quality salt. The seawater is the main source materials of salt production in Zanzibar, the production process passes in different stages such as collection of seawater to the reservoirs from sea where normal seawater has the salinity approximately 35ppm or 35g of salt per kg of seawater, which is equal to 3.5% [2] . The collected seawater, flowing to the condenser pans where the sun heats the water to increase the salinity by evaporation process until 25-26 Be (Baume scale) where 1Be is equivalent to 10g of sodium chloride per kg of seawater. The salt concentration and crystallization start in this stage, the crystallization process starts with calcium carbonate, followed by calcium sulphate and end with calcium chloride. Therefore, seawater influences the quality of the salt [2], [3]. The salt produced from seawater mostly has an average of sodium chloride concentration of about 85% to 90%, which is below of national and international standards requirements, the salt still is not quality because it mixed with some small quantities of compounds such as magnesium chloride, magnesium sulphate, calcium sulphate and others [1] [4]. The production of salt for human consumption is about 20% international, for industrial use is about 55% and only 15% for de-icing road. The essential micronutrient of iodine has a central role in thyroid hormone production and regulation. The direct method of sodium chloride production using crystallization process still have the problem of the presence of impurities which is quietly a lot, so the concentration of sodium chloride has not yet reached the maximum standard required for salt quality. The existing of compounds such as magnesium chloride, magnesium sulphate, calcium carbonate and potassium chloride that concurrently crystallized during the process of salt production often causes the lower concentration (lower purity) of sodium chloride [5].The evaporation process may increase the concentration of each solute until the concentration reached the saturation. The solubility in water will influences the deposition process. The lower constant of solubility substance will settle in advance of the element that have larger constant solubility. The direct evaporation of seawater without considering the water viscosity, the salt will contain high impurity such as magnesium chloride, magnesium sulphate and calcium sulphate. Thus, the low quality of salt with about 70-80% of sodium chloride content produced. Therefore, the high quality production of salt is paramount important [1] [4].

Because the problem of using un-quality salt has greater impact in human health [6], the use of IoT technology can overcome the problem by measuring some parameters of salt solution, which will give us the information of the sodium chloride concentration, impurities and pH value. IoT is the technology of using physical devices on the network with connectivity and embedded system, which enable things to collect data automatically with data exchanging [7]. The solution should capable of monitoring different parameters of table salt such as salt concentration, total dissolved substances and pH value.

The existing solutions of using lab sample processing or manually data collection have many costs interms of large number of human resource of expertise, work facilities and time consuming. Due to the many restrictions of identifying the quality of salt, the study recommend the use of IoT technology that offers the real-time system solution. This study provides the IoT based solution to solve the salt quality challenge by measuring some salt quality parameters such as salt concentration; salt pH value and total dissolve solids (TDS) value. The proposed embedded system consists of Arduino microcomputer used to process data collected by sensors, EC sensor is compensated with temperature sensor to measure the real-time salt conductivity in solution and TDS sensor used to measure the salt solution concentration, pH sensor used to measure the pH value of salt solution and LCD used to display the output results. The GSM communication module for data transmission from the sensors to the cloud server (ThingSpeak) where fuzzy logic approach used in data process and analysis. The cloud server displayed the results to the dashboard report, which is useful for users to know the salt status.

1.3. Motivation

The project motivation is to provide the solution for quality of salt using the salt quality parameters such as salt concentration, total dissolved solids and pH level.

This study will assist users such as salt farmers, suppliers, and organizations to increase the quality of salt. The use of IoT technology with fuzzy logic approach will increase service delivery by getting the real-time information and precise inference of salt quality to users.

1.4. Problem statement

The sodium chloride known as table salt, mostly used in different applications for human and industrial purposes, such as home for food cooking, food additive in food processing to influence the product taste and it is useful in texture and storage. Therefore, it is important in everyday of human life [1]. The direct method of evaporation of seawater where the sodium chloride produced using crystallization process can cause high impurity such as calcium carbonate, magnesium chloride, magnesium sulphate and calcium sulphate. This process of salt production still has challenges of higher impurity presentation, so the salt concentration become the minimum level and not comply the standard requirement of salt quality [5]. Thus, the low quality of salt with about 85-90% of sodium chloride content produced by this process could have high level of impurities of calcium, magnesium, sulphate and acidity or alkalinity in pH scale, which is unacceptable for human health [1], [3]. While this problem of salt quality continue to be a challenge in Zanzibar, the salt farmers do not have a quick and appropriate method to measure the salt. In most cases, the salt quality in Zanzibar is measured in the laboratory by transferring the samples to town where it is located, which is too far from the salt farms, it is a slow process and sometimes it takes long time to get the results.

Therefore, the solution is required to minimize this problem of higher impurity in sodium chloride salt. The use of IoT based system will helpful to reduce the problem by measuring of sodium chloride electrical conductivity, concentration and pH value in a real-time data and cost effective system.

1.5. Study objectives

The study objective is to design and prototype an IoT based system using fuzzy logic approach for measuring quality of salt.

1.6. General objective

The study aimed to design and prototype an IoT system based on Quality of Salt that can measure and estimate the salt quality by using the parameters of sodium chloride concentration, identify total dissolved substances and pH value of salt solution.

1.6.1. Specific objectives

i. To measure the sodium concentration of a salt solution interms of part per thousands (ppm).
ii. To measure the total dissolved substances (TDS) and the pH level of salt solution.
iii. To use designed prototype to measure and to estimate the salt quality so that the users will be notified about salt status.
iv. The designed system will help users for decision-making.

The study guided by the following questions:

i. What are the parameters of salt quality?
ii. What should consider in designing the IoT real-time system to measure and infer the quality of salt?

1.7. Hypotheses

The hypothesis was that, the IoT technology could be used to measure and estimate the salt quality in real-time system to minimize the salt quality problem.

1.8. Study scope

The study focused on using IoT technology to measure and infer the salt quality using parameters of EC, TDS and pH level. The three salt sample solutions (S_1, S_2 and S_3) considered for prototype design.

1.9. Significance of the study

The contribution of this research study is to propose the method of IoT system based on quality of salt by measuring the salt parameters and provide the output results. Second contribution, the use of IoT technology is to increase the monitoring of salt production. The third one is that, this proposed method results an IoT technology to improve the quality of salt in the salt farmers, suppliers and individual users. In addition, the use of the machine learning based on fuzzy logic in IoT technology provides the real-time data and precise inference of salty quality.

1.10. Organization of the study

The chapter 1 started with introduction of the research study, the chapter 2 gives a review of the related work (literature review) and the gaps identified. Chapter 3 describes the methodology applied in this study and Chapter 4 explains the system model and design, prototype and parameters. The Chapter 5 presents the results and findings analysed from the research study carried out. The last is Chapter 6, which provides the conclusion and recommendations of the study.

1.11. Summary

This chapter presented an introduction of the study, the problem statement provide the evidence of the current situation of the salt measurement and testing of the quality salt and that is why the research study is needed on this area. During the system implementation, this study will contribute on the sustainable development goals in salt farming industry and human health at all.

CHAPTER 2. LITERATURE REVIEW

The chapter two presents the existing literature of the related work of this study. The review of the related work helped to finding the gaps and how to overcome the problem from the gaps obtained. It provides and shows how IoT technology used on the existing research works.

2.1. Digitizing salt quality parameters

Jumaeir et al. [1] entitled "Quality monitoring of salt produced in Indonesia through seawater evaporation on HDPE geomembrane lined ponds", explains the quality monitoring of salt produced in Indonesia by evaporation of seawater with sun light. The authors describe how this method increased the quality of salt of an average of 95.75% from 85.4% of sodium chloride concentration, which fulfilled the Indonesia National standards. The paper did not mention the use of IoT technology in the implementation of the study.

The author Ketut Sumada et al. [3] said that, the seawater quality influences the quality of salt production. The paper explained the method of hydro-extraction as the method of improving the quality of salt from seawater where the mixed of soluble materials such as magnesium (Mg), calcium (Ca) and sulphate (SO4) to observe the impurities can be reduced. However, the author explain the chemical method to improve salt quality, but the method is not real-time system [3].

According to Lauren Wolchok [2], the salt produced by Zanzibar salt farmers faced with calcium sulphate impurity challenges, which degrade their salt status. The high-grade table salt should be at least 96% of pure sodium chloride and should appear clear. Moreover, global standards dictate that high quality salt must 96% sodium chloride; the presence of calcium sulphate gives salt cloudy and off-white appearance, the study did not provide the real solution to overcome the challenges.

The development and calibration of electrical conductivity (EC) sensor can be used to measure the sodium chloride concentration in water bodies. The using of standard solution of sodium chloride from the laboratory is important thig to minimize the errors of the EC sensor, according to Rohan Benjankar et al. [8]. The author of this paper explained the calibration of EC sensor to measure the sodium chloride concentration, but they did not provide the details on how the measurement of total dissolved substance from the EC sensor.

According to Tony Yulianto et al. [9], sometimes the sodium chloride mixed with other impurities, the salt becomes low quality. The assessment of the salt required to measure some quality parameters such as salt concentration, total dissolved substances and the pH level. But the study did not included those parameters form better salt assessment.

The study paper by Yılmaz GÜVEN et al. [10] entitled "Understanding the Concept of Microcontroller Based Systems to Choose the Best Hardware for Applications". The author explain the importance of selecting and understanding the best hardware in the implementation of applications. The study provides the best way of understanding microcontroller and other hardware components with their structure. Because, the authors did not mention what exact components can be used in which system, but they provide the details of components specifications.

The paper entitled "Measurement of Iodine level in salt using the color sensor" from Farniwati Fattah et al. [11]. It explains how the iodine level can be measured using color sensor in IoT technology by grouping it into three categories such as 7-15ppm, 20-27ppm and >30ppm. The Arduino Uno microcontroller used to process data from TCS3200 color sensor where the prepared samples of iodised salt color detected and the results displayed to the LCD. The study was limited on other parameters for salt quality and the communication protocol used for data transmitted to the cloud server for further analysis.

2.3. Sensor development and calibration for measuring salt concentration

According to U.S Geological Survey [12], the calibration of sensor is important for good and precise measurement of salt concentration. The sensors such as temperature, pH, EC, etc require accurate calibration by using standard solution for good data collection. Calibration of individual sensor also required because, each sensor may record different value of the solution. The calibration of sensors may affected by several factors such as water temperature, pH and temperature correction factor, etc. The paper explain the conversion factor to convert EC to salt concentration in part per millions (PPM) can be done by several ways, but the most useful ones are "ECx500" and "ECx700", based on Bluelab Corporation [13]. The sensors were developed and validated in the laboratory and deployed in the field for salt concentration measurement, Parra et al. [14], but there was the limitation of validation measurement of salt concentration based on Perera et al. [15]. Therefore, the use of sensor technology is an alternative method that provides higher frequency and real-time monitoring of data collection for quality management in salt concentration in the future projects monitoring, Glasgow et al. [14]. The missing of microcontroller for data processing made the study to process the data manually by connecting the sensors to the computer with high resolution via USB to download data in text format using Arduino, then data converted in Microsoft excel format for further analysis.

2.4. IoT communication modules and protocols technology for data transmission

The IoT technology faces many challenges on data communication between the machines, when the sensors and gateway devices connected to unreliable bandwidth, low bandwidth or through wireless communication links such as cellular, low or long-range communication links. Therefore, Yuang Chen et al. [16], provide the detail explanations quantitatively by comparing the performance of IoT protocols such as MQTT, CoAP, DDS and UDP protocols.

Shadi Al-Sarawi et al. [7] said that, the right selection of communication protocols in IoT applications depends on the power consumption, security, data transmition rate and other features. The paper described and compared between IoT communication protocols interms of pros, cons, power consumption, speed of data rate and communication range.

According to Tuyen Phong Truong et al. [17], the semtech's LoRa with low power wide area wireless network automatically receive salinity data collected from sensor nodes and transmitted to the cloud server for analysis.

Based on Mahmoud Shuker Mahmoud et al. [18], the use of low power-module techniques such as ZigBee, Low Power WiFi, 6LowPAN, LPWA is very important to conserve power, which leads the IoT network sensors to have long life. The choice of the protocol modules play an important role in battery life because of the power consumption of each protocol. Therefore, it is better to choose the module with low consumption for long life use of IoT application. In this study, the cellular and WiFi protocols used for data transmission to server.

2.5. Fuzzy inference system for measuring, estimating and analysis salt quality

Siti Komariyah et al. [9] explained the method of estimating the production of salt with Fuzzy Inference System of Sugeno method. The paper used matlab application for data analysis. The paper did not provides the IoT architectural design to show how the data processed and even did not mentioned the quality production of the salt.

Achmad Ubaidillah et al. [19] designed the tool that measure the level of salinity (salt concentration) and pH of seawater using a fuzzy logic based on android system. The fuzzy logic system check the conditions of salinity and pH levels of data collected from sensors in seawater, process and analyze them to infer the output results of the seawater status.

The author, C. Riverol et al. [20] used the fuzzy approach to check the behaviour of salinity and total dissolved solids with respect to the temperature changes of the seawater on a year. The methodology based on the minimum and maximum values of the seawater parameters selected instead.

Based on Dr. Arif Khan [21] uses a methodology of fuzzy logic and fuzzy sets to manage the salinity of water variables and interpretation of unacceptable range water parameters and finally quantifying water pollutants. The paper used the TDS, pH, Total alkalinity parameters in the quantification of water pollution.

Moreover, Vivien A. Wardhany et al. [22] proposed to use fuzzy logic method to monitor the temperature, salinity and pH level for survival of vanamei shrimp. The prototype designed to control water pool temperature, salinity and pH level. The fuzzy logic process data where the membership function and logic rules created with respect to the water temperature, salinity and pH level.

2.6. Contribution

Based on the literature reviews mentioned for this research study, the following contributions for development and implementation of this study were observed:

- The identification of sodium chloride salt parameters and impurities for salt quality.
- The identification of sodium chloride salt standards and grades.
- Development and calibration of sensors for measuring the sodium chloride salt concentration and its conversion factors.
- The selection of IoT component devices for IoT system development and implementation.
- The implementation of IoT communication modules and their protocols.
- The fuzzy inference system implementation for estimating the sodium chloride salt quality.

2.7. Gaps Identified

The following are the gaps identified after reviewing and evaluating the above literature works according to their review section:

In digitizing salt quality parameters section:

- The IoT technology was not used to the implementation of the studies.
- The studies used high cost methodology for measure and estimating the salt quality.
- The authors used local methods analytics to analyze the salt quality data.
- The studies used the manually notification to inform their users about their salt quality status.

In sensor development and calibration for measuring salt concentration section:

- The studies did not use any kind of machine learning for measuring and estimating salt concentration.
- The papers did not explain on the use of IoT technology as the method of data collection, processing and analytics.

In fuzzy inference system for measuring, estimating and analysis salt quality section:

- The studies did not explain how to use the cloud server for data visualization, analytics and notification.
- The authors also did not provide the details of how the users can get their salt status through the mobile and email notification using fuzzy logic approach.

2.8. Summary

The aim of the presenting the literature review was therefore to determine the parameters used to identify the sodium chloride salt concentration with salt impurities and the IoT components and software application such as sensors, microcontrollers, communication protocol and analytics technology used for data collection, processing, transmission and data analytics.

CHAPTER 3. METHODOLOGY

In this chapter the method, tools and process used to conduct the study mentioned. The following are the steps considered to complete the study, namely; system design methodology, fuzzy logic system and tools used in prototyping of the proposed solution.

3.1. Research design

To achieve the steps included on the approval proposal, a prototype designed and implemented. The quality problem of sodium chloride concentration has become a challenge on human daily life, because the salt used in different applications such as home for food cooking, food additive in food processing to influence the product taste and it is useful in texture and storage [2] [6]. The machine learning of fuzzy logic approach as explained on this chapter 3 section 3.9 can help to reduce these challenges by estimating and analyze the sodium chloride concentration. The fuzzy logic system used to improve the existing algorithm to analyse the data and provide precise inference an output.

3.2. Study dataset size

The research study used the sodium chloride salt dataset with 1000 rows of data as a data size.

3.3. Study area

The study was based on Zanzibar salt farms where many authors wrote about the salt quality.

3.4. Study duration

The research study period was between July to November 2022.

3.5. Sample size (N)

The study used the rules of thumb with margin of error at 5% to get the sample size of the sodium chloride salt dataset. Therefore, the sample size (N) was 278 data rows of sodium chloride salt [43].

3.6. System design

This section describes the proposed system design into the proposed system technology, conceptual design architecture, physical design architecture and software design architecture of the salt quality development. Figure 3.1 below shows the proposed system design. The study intends to develop the quality of salt prototype the supports the measurement of sodium chloride quality status through the salt solution sample using the IoT technology for reducing the salt quality problem. The prototype design architecture based on the requirements collected shown on the Figure 3.1 below. The design architecture simplified the implementation method of salt quality.

The Figure 3.1 describes the data flow of the prototype; the main parts of the design are the sensing data, communication and data visualization. The sensors used to collect data processed, analysed and display the results on LCD screen, then data sent to the cloud server through communication protocol, which is SIM800L GSM, the server do further processing, and analyzed data to provide the output results and display in ThingSpeak dashboard to users.

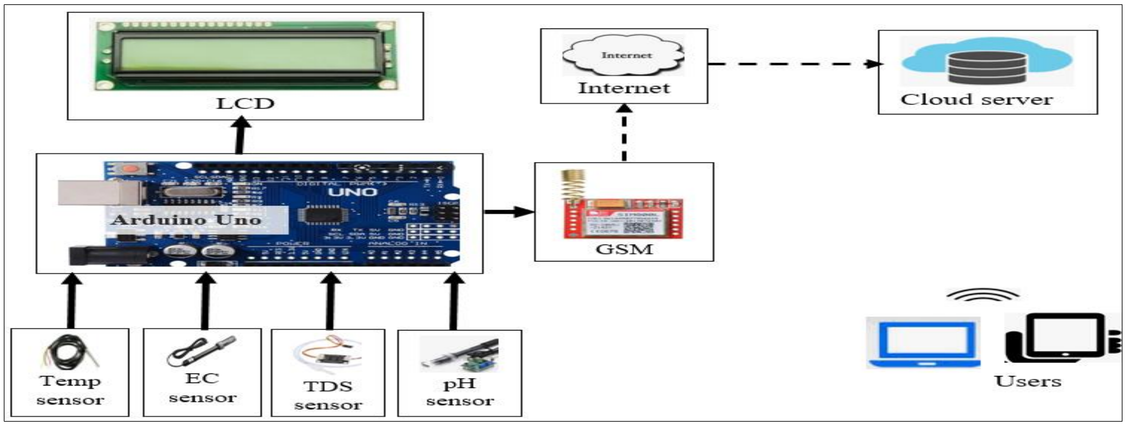


Figure 3.1: System architecture

3.7. Layers of the proposed system

The system architecture used a three-layered architecture in the proposed system as Figure 3.2 shown, namely; application, network and perception layers. These layers describe the data flow from hardware devices to the application layer with the services in application layer. The study used this layered architecture because, the proposed system needs to provide specific services to users such as email notification or sms message report [7]. The three layered architecture as following:

i. Application layer: This layer is responsible to provide application specific services to salt farmers, suppliers, individual users and standard bureau. Other application services include dashboard and data visualization application services established specifically.

ii. Network layer: The GSM communication protocol with 3/4G network services used transmit data from perception layer to application layer.

iii. Perception layer: This layer also known as physical layer, where the proposed system sensors; DS18B20, EC, TDS and pH are available in this layer for collecting required data of temperature, salinity conductivity, total dissolved solids and pH level of a salt solution. The microcontroller process data and converts into specific format for output results and sent to the cloud server for analytics.

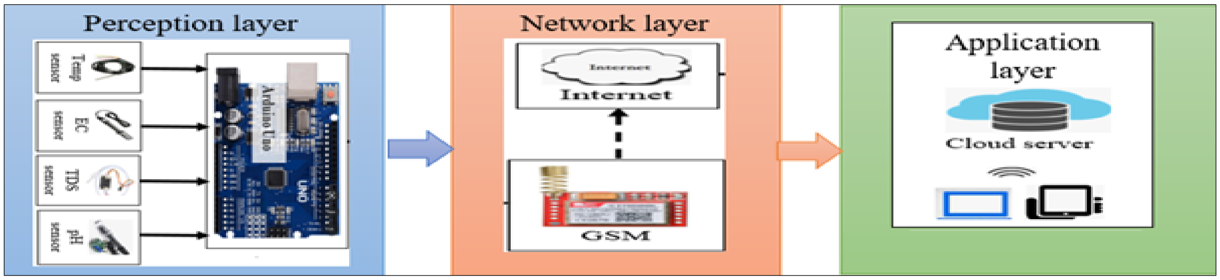


Figure 3.2: Three layered architecture

3.8. Data collection method

The proposed system prototype used to collect during the research study. The system prototype is categorized with hardware components and software parts as following:

System hardware components composed with main three parts, namely; the sensing, communication and the LCD for output results visualization parts:

- The sensing part used for data collection, which consists of sensors; electrical conductivity, total dissolved solids and pH sensors used to collect data from physical environment and convert to digital signal with Arduino microcontroller connected with communication part.
- Communication protocol used to transmit data from sensors to the ThingSpeak cloud server. The GSM communication protocol used in this study.
- The LCD used to display and visualize the output results of the proposed system.

The software part of the prototype composed with Arduino IDE, Matlab toolbox software application and ThingSpeak cloud sever.

- Arduino IDE software used as programming codes editor, debugging and uploading them to the system prototype during system development and implementation [36].
- Matlab toolbox software application used to implement and training of fuzzy logic approach. The software analyze data, develop algorithm and create models and applications [28].
- ThingSpeak cloud is an IoT cloud server where the data from the system prototype stored, processed, analyzed, visualized the output results and email notification alert. ThingSpeak cloud also has matlab analysis and visualization function used to visualize the output results, where fuzzy logic system used to analyzed the salt data and provide the salt status [28].

3.9. Fuzzy logic approach for measuring, data analysis for salt quality

The data collection method will use the fuzzy expert system architecture as Figure 3.3 shown to measure and estimate the salt quality as following:

- Collection of sodium chloride salt parameters: This step the input parameters from the sodium chloride salt such as electric conductivity (EC), total dissolved solids TDS) and hydrogen potential (pH) are collected. The collected data will be used as input values for measuring and estimating the salt quality. The IoT prototype used to collect and prepare the dataset.
- Analyse and select the input parameters: The input parameters of the sodium chloride salt analysed and select parameters to be used in this study based on the expert knowledge of salt quality
- Dataset training preparation: The dataset prepared was used as input for the fuzzy logic rule based system to train proposed system for measuring the salt quality and provide output results.
- Applying fuzzy logic approach: The fuzzy logic approach was applied to measure and estimate the salt quality. The crisp values converted into fuzzy values using fuzzification and gives as an output to the fuzzy inference system to apply rule base algorithms to generate the results based on the knowledge of human experts.
- Fuzzy logic output results: In this step, the fuzzy logic result is analysed and converted into crisp results by Defuzzification mechanism..
- Salt quality report: The final step is the output results of the proposed salt quality system. The generated report expected to have efficiency and accuracy of the proposed IoT system

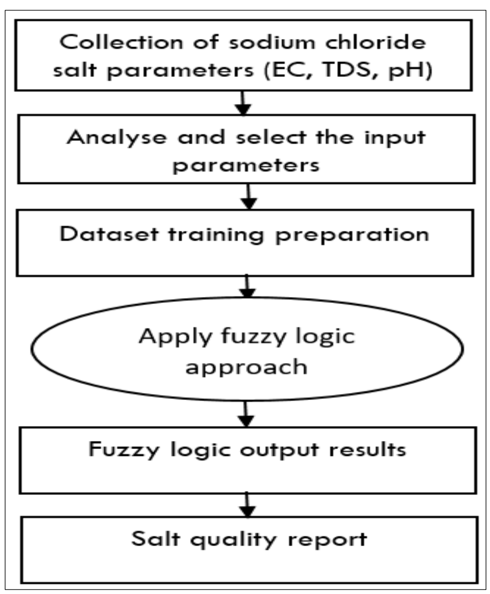


Figure 3.3: Fuzzy logic approach for measuring salt

CHAPTER 4. SYSTEM DESIGN

This chapter describes the conceptual design, software and hardware design architecture relating to quality of salt. The approach selected consists both logical and physical design.

4.1. IoT Data acquisition technology (DAQ)

The DAQ technology has the relation between the place where data being collected by sensors, monitoring, controlling and within its platform. DAQ is the process of digitizing data by using sensors s from the physical environment that can be stored, analyzed and displayed [24] [25]. The sensors can automatically adjust its data collection rate from very low frequency to high frequency to data output rate when the physical variable sensed dramatically changed by using method of self-adaptive data acquisition. The technique can help to reduce energy consumption, bandwidth resources and data transmission burden [26]. In this study, the temperature, EC, TDS and pH sensor used to collect data into digital form from salt solution sample, display output results via LCD and sent to the cloud server for processing, analysis, and visualised as Figure 4.1 shown.

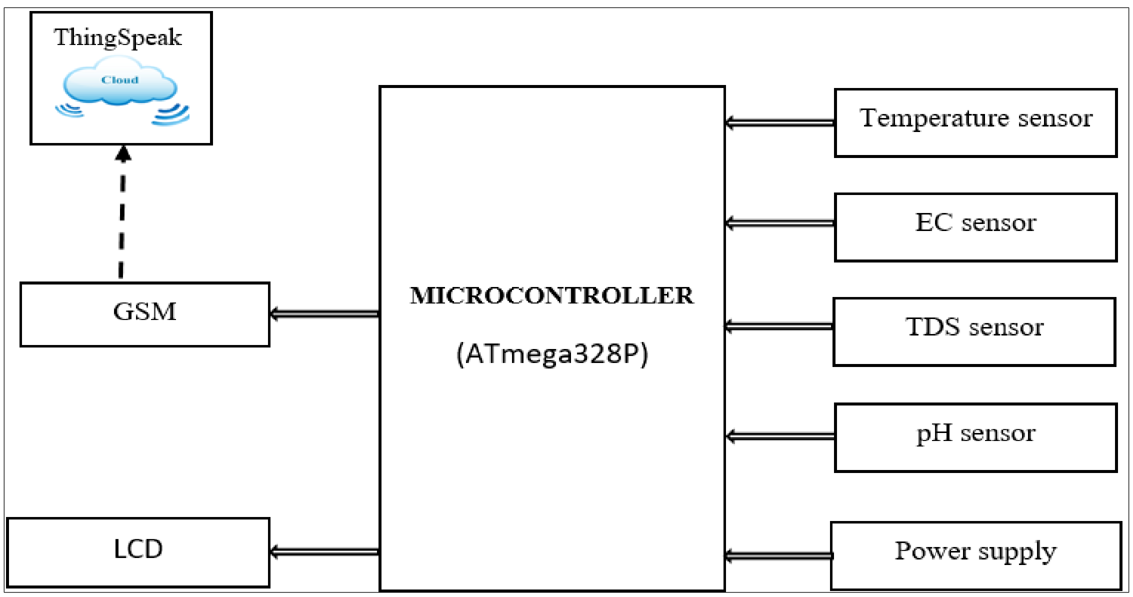


Figure 4. 1: System components block diagram

4.2. Conceptual design

The system architecture Figure 3.1 has already described how data collected form sensors and sent to the cloud ThingSpeak. The data processed and analysed in the cloud application platform and provide the output results for decision. The study used the fuzzy logic system through MATLAB visualization application on ThingSpeak to process, analysed data and to trigger email notification report to users as Figure 4.2 shown. The ThingSpeak cloud server also supports the data visualization dashboard and MATLAB visualization applications, which is very important in the management of data visualization reports [28]. The more details of fuzzy logic system implementation explained in the Software requirement selection section.

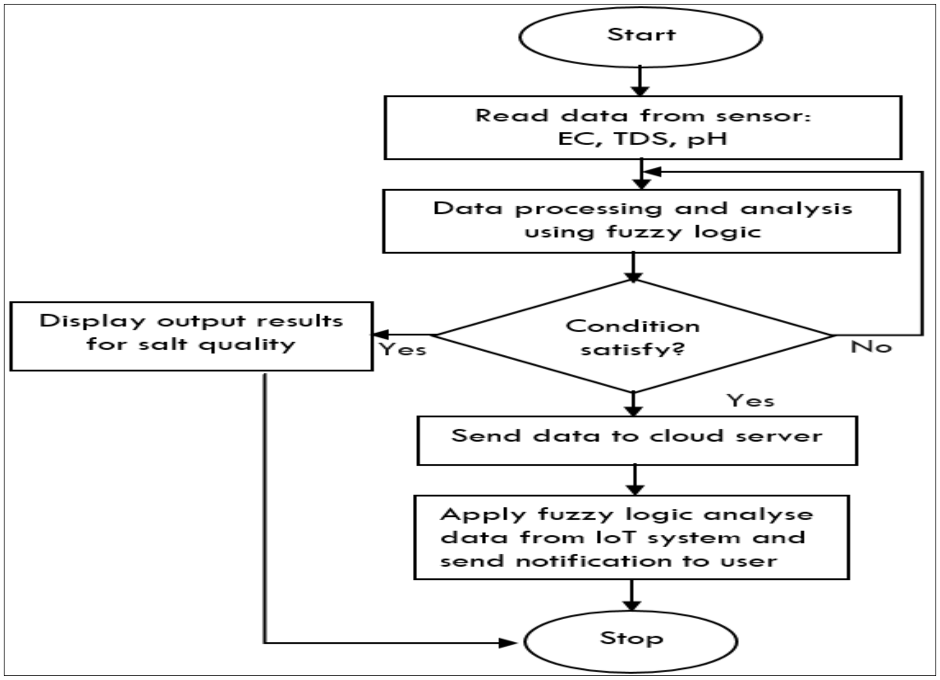


Figure 4. 2: System flow chart

4.3. Data communication technology

The transmission of collected data from the sensors require communication media to reach its destination as Figure 4.1 shown. In this study, the SIM800L GSM used as a media of communication protocol for signal data transmission from sensor devices to the cloud server. The protocol used to send signal data through cellular technology of 2/3G of mobile data services. It operates at 850MHz, 900MHz, 1800MHz and 1900MHz frequency bands [27].

4.4. Hardware system requirements selection

The proposed system in physical design divided into three parts; a sensing, controlling, IoT data communication parts as Figure 4.1 shown. The sensing part consists of temperature, EC, TDS and pH sensors measure the salt solution sample. The controlling part consists of Arduino Uno Atmega328P microcontroller, GSM communication protocol, cloud platform for data analytics and the LCD for output results for user notification [7].

4.4.1. Electrical conductivity sensor (EC)

An electrical conductivity meter sensor used to measure the electrical conductivity of an aqueous solution, and to evaluate the water quality as Figure 4.3. It is often used in water culture, aquaculture, and environmental water detection. Moreover, the sensor used to measure the high electrical conductivity of liquids such as seawater, concentrated brine that is the solution of salt concentration of sodium chloride. It supports inputs voltage of 3-5V main control board, such as Arduino and Raspberry pi [29].

Figure 4. 3: EC sensor

4.4.2. EC and TDS sensors Relationship

In most instances, the EC measured and converted to TDS to get approximate TDS reading. The TDS meter performs this conversion automatically based on the conversion factor. The factor range depends on the sample being tested and it is important to choose the most appropriate meter for the application. Most modern TDS meter allow to adjust the conversion factor to get most accurate conversion when measuring EC [30].

4.4.3. Conversion of EC to Salinity

The EC unit is mS/cm, dS/cm, uS/cm, where 1mS/cm = 500ppm.

The ppm is defined as how many parts or grams of salt contents there are per thousand/million parts, or kilograms (1000g), of salt solution or seawater [31] [32].

To convert the EC value to salinity ppm, the sodium chloride conversion factor of 500ppm used. Therefore, the salinity (ppt) = EC multiply by conversion factor.

Salinity (ppm) = (EC x 500) ppm [13].

4.4.4. Total dissolved solids sensor (TDS)

TDS measures the organic and non-organic substances present in water. This sensor measures the presence of various cations such as calcium, magnesium, potassium, and sodium, and anions in the water solution such as carbonates, nitrates, bicarbonates, chlorides, and sulphates in the solution as Figure 4.4. The cations and anions have positive and negative charges respectively. TDS indicates how many milligrams of soluble solids are dissolved in one litre of water, it uses part per millions (ppm) as unit. The higher the TDS values, the soluble solids are dissolved in water, and the less clean water is. Therefore, the TDS can be used as one reference point for reflecting for the cleanliness water [33]. TDS can work with a wide range of dc supply (3.3~5.5V) with the analog signal output from 0 to 2.3V which corresponding to TDS values from 0 to 1000 ppm with an accuracy of 10% FS (at 25C) as Table 4.1 shown. Because the table salt is a part of TDSs and therefore will be a either a part or all of the readings values. For example, if there is only table in the water, and the reading value is 500ppm, then it is 500 ppm (mg/L) of table salt, another example for TDS level, suggest that out of one million particles, 100 are dissolved ions and 999,900 are water molecules [33].

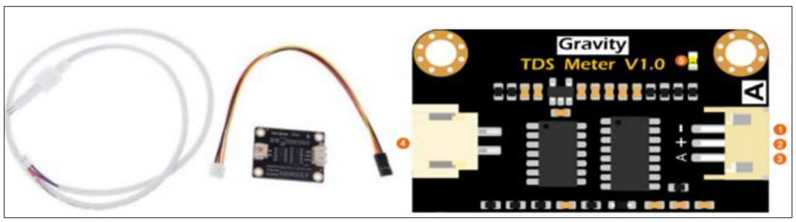


Figure 4. 4: TDS sensor

Table 4. 1: TDS Meter gravity input and output signals

Number	Label	Description
1	–	Power GND (0V)
2	+	Power VCC (3.3~5.5V)
3	A	Analog Signal Output (0~2.3V)
4	TDS	TDS probe connector
5	LED	Power indicator

4.4.5. Hydrogen potential (pH) sensor

The pH scale refers to the hydrogen potential which is the degree that measure acidity or basicity (alkalinity) of an aqueous solution. It measures body's hydrogen ions (H+) concentration. The pH scale goes from 1 to 14, with 7 scale considered neutral. The solution having a pH less than 7 is said to be acidic solution and the one having a pH more than 7 is said to be basic or alkaline solution as Figure 4.5 shown. The pH sensor voltage regulator chip supports the wide voltage supply 3.3~5.5V with the output voltage of 0~3.0V [34].

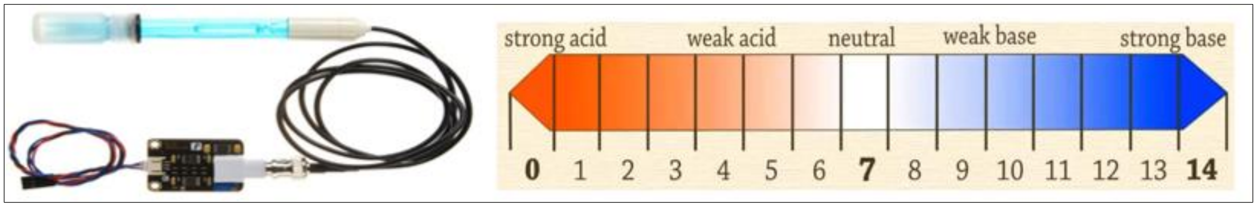


Figure 4. 5: pH sensor

4.4.6. DS18B20 1-wire temperature sensor

DS18B20 is a 1-wire digital thermometer from Dallas Semiconductor Corp. It is based on a 1-wire interface that requires only one pin for circuit connections. It has 64 bit unique serial code for addressing a 1-wire interface. It is possible to power the sensor from the data line itself. It has the output scales measurement from 9-bit to 12-bit resolution and operating temperature range of -55˚C to 125˚C with an accuracy +/-0.5˚C. It measures temperature with precision of 0.0625˚C with default resolution of 12-bit. It can easily fetch temperature measurement at an interval of 1 sec from the sensor network, because; it takes less than 750 ms to convert the reading. The sensor operating on voltage of 3.3~5V with current consumption of 1mA, therefore, it can be easily interfaced with any microcontroller or microcomputer such as Arduino and Raspberry Pi respectively [35]. The DS18B20 sensor has three pins identified by color-coding; GND, Data and VDD with black, yellow and red lines respectively as Figure 4.6 shown. To interface DS18B20 with microcontroller, the GND and VDD pins connected with ground and 5V of the microcontroller pins. The Data pin can be connected with any GPIO and to stabilize the data line, a pull-up resistor of 4.7K is recommended to communicate between Data pin and the supply pin, because the microcontroller built-in pull-up resistors are no sufficient for implementing a 1-wire protocol. Moreover, if the resistor not with sensor, the board will not correctly read from sensor [35].

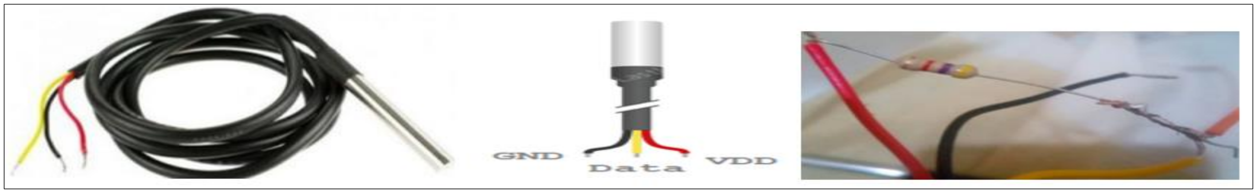


Figure 4. 6: DS18B20 1-wired temperature sensor

4.4.7. Microcontroller Unit (MCU)

The Arduino Uno is microcontroller board based on ATmega328P. It consists of 14 digital input/output pins, the 6 pins used as PWM output, 6 analog inputs, USB connection, 16 MHz ceramic resonator, power jack, an ICSP header and a reset button. It can be powered through USB connection or external power supply from 6 to 20V. The external power can be either come AC to DC or from battery. If the power supplied is less than 7V, although the 5V pin may supply less than 5V, the board may be unstable, and the using more than 12V the voltage regulator may overheat and damage the board. Therefore, it is recommended to use the supply range of 7 to 12V [36]. The Arduino Uno to be a low-cost microcontroller made it considered as a best microcontroller to be used in this research Figure 4.7 shown.

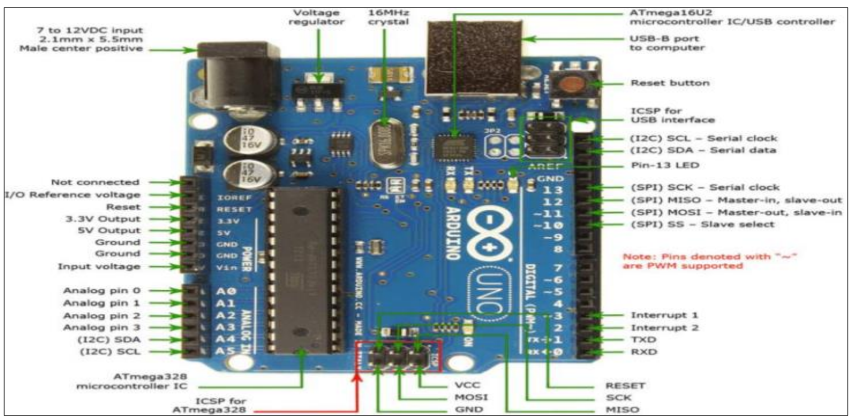


Figure 4. 7: Arduino Uno microcontroller

4.4.8. LCD Display

LCD Figure 4.8 is a liquid crystal display used in embedded system application for displaying various parameters and system status. LCD 20x4 is a 16 pins device that has 4 rows that can accommodate 20 characters each [37].

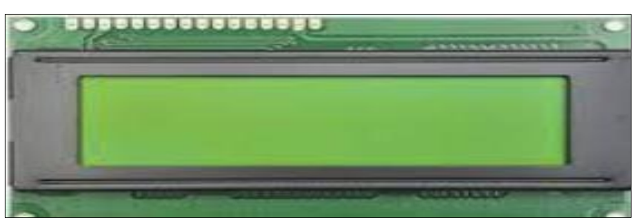


Figure 4. 8: LCD 4x20 character display

4.4.9. Sim 800L GSM

SIM800L GSM/GPRS as Figure 4.9 shown is a miniature GSM modem, which can be integrated with IoT projects. It is used to accomplish SMS text messages, make or receive phone calls, connecting with internet via GPRS, TCP/IP, etc. It supports SIM card to be connected to the mobile operators, also supports quad-band GSM/GPRS network, so it works everywhere. Its operating voltage is 3.4 to 4.4V, which makes difficult to direct 5V power supply. SIM800L is power-hungry device. It uses 2A during transmission or around 216mA during phone calls or 80mA during network transmission [38]. There are two ways you can add an antenna to your SIM800L module. First, one is Helical GSM antenna usually comes with module and solders directly to NET pin on SIM800L board; this is very useful for space saving in your project. The second one is any 3dBi antenna with U.FL to SMA adapter and can be connected on the top-left corner of the module, this type has better performance compare to the first one [38]. See the figure below.

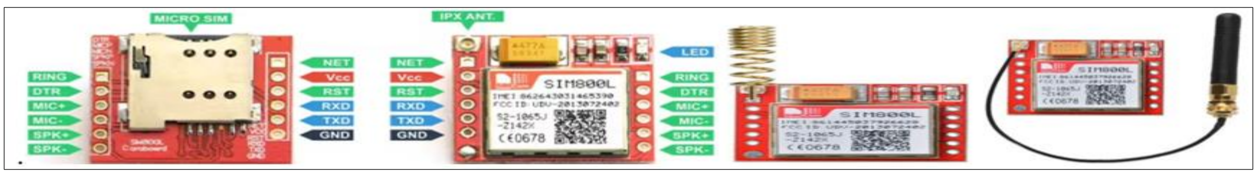


Figure 4. 9: SIM800L-GSM

4.5. Software requirement selection

4.5.1. Fuzzy Inference System (FIS) implementation

A fuzzy inference system is machine-learning algorithm used in inference analysis for quality of salt as Figure 4.10 shown. It is a ruled-based expert system used to produce the output according to the inputs of the system. In this study, the fuzzy logic approach used for analysis and inference of salt quality. The fuzzy logic system used identify the quality of salt from parameters of salinity electrical conductivity, total dissolved solids and pH level. The fuzzy technique on the four main steps, namely; fuzzification, formulation of fuzzy inference rules, defuzzification and model evaluation [39].

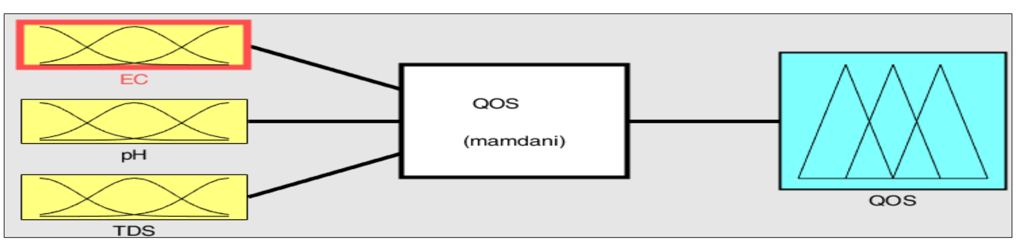


Figure 4. 10: QOS Fuzzy logic design

The fuzzy logic architecture consists of four main parts as Figure 4.10 shown above.

i. Fuzzification: It converts crisp inputs measured by sensors into fuzzy sets and passed into the control system for further processing like EC, TDS and pH known as membership function (MF). The membership function (MF) is the curve defined within the MATLAB environment used to map the input space to the membership value to the output function. The following are the input parameters of the fuzzy sets of this study:

- The EC input MFs are unacceptable (na) with range of 1-6.1, low has range of 6.2-7.5, moderate range is 7.6-8.4 and high has range of 8.5-8.9, as Figure 4.11 and Table 4.2 shown.

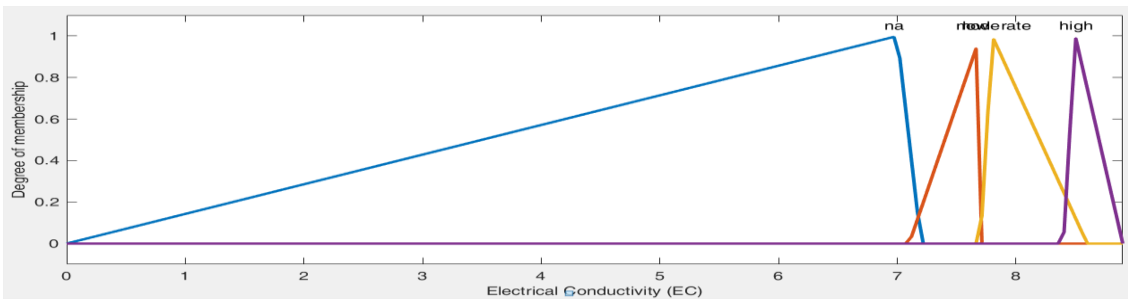


Figure 4. 11: EC input membership functions

- The TDS input range of 0-6164 ppm as Figure 4.12 and Table 4.2 shown. The ranges identifies the unacceptable range is 1000-4087 ppm, low has a range of 4154-5025, moderate has range of 5092-5628 ppm and high has range of 5695-6164 ppm of total dissolved solids of the salt.

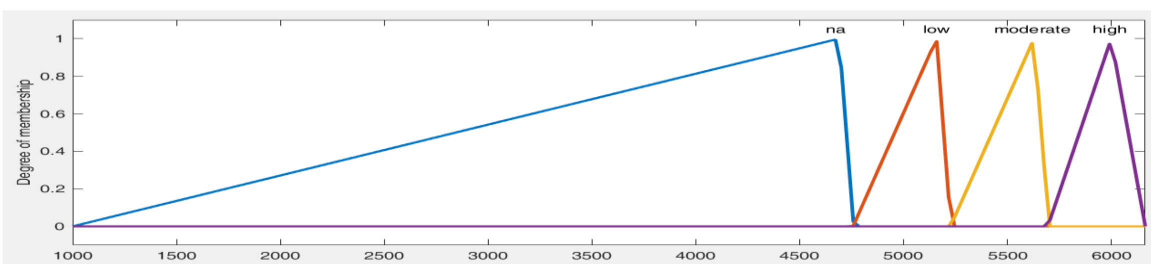


Figure 4. 12: TDS input membership functions

- The pH input range of 0-14 as Figure 4.13 and Table 4.2 shown. The ranges identifies the low1 range is 0-6.4, low2 range is 8.6-14 and good range is 6.5-8.5 pH level of the salt.

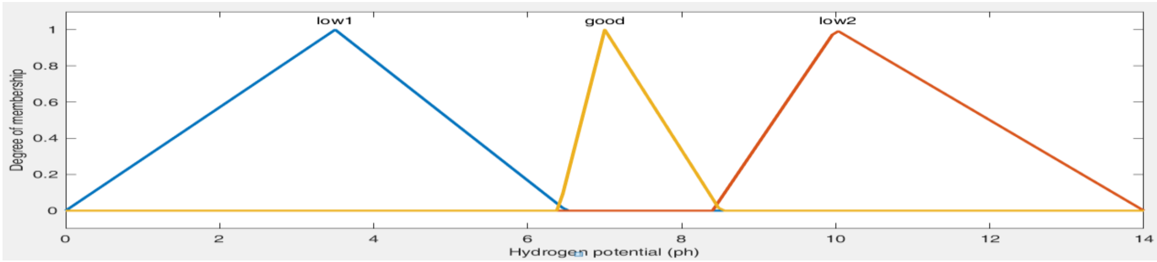


Figure 4. 13: ph input membership functions

- The QOS output range of 0-100% as Figure 4.14 and Table 4.2 shown. The ranges identifies the unacceptable range is <70.5, poor range is 70.5-86.4, moderate range is 86.5-96.5 and good level range is 96.6-100 of the salt.

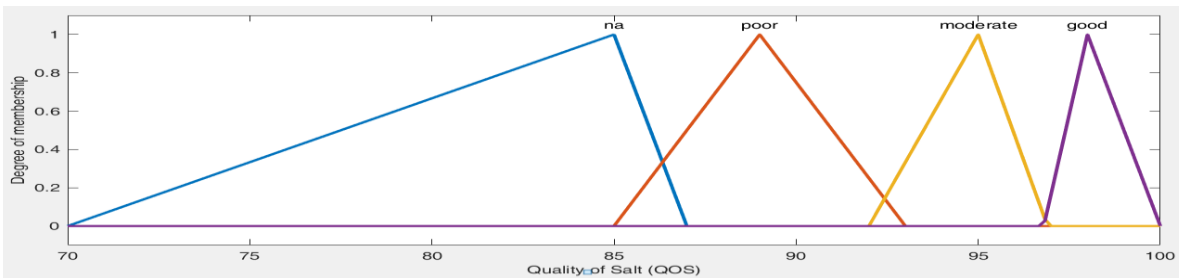


Figure 4. 14: QOS output membership functions

ii. Rule Base: This contains all rules of ‘If-then’ conditions with “AND” connective provided by the salt quality experts to control the decision-making salt quality system. The fuzzy system provides various methods for designing and tuning of fuzzy controller. The study implemented the following fuzzy rules to estimate the salt quality measured as Figure 4.15 shown.

- If (ec is na) and (tds is na) and (ph is low1) then (qos is na)
- If (ec is na) and (tds is na) and (ph is low2) then (qos is na)
- If (ec is low) and (tds is low) and (ph is good) then (qos is poor)
- If (ec is moderate) and (tds is moderate) and (ph is good) then (qos is moderate)
- If (ec is high) and (tds is high) and (ph is good) then (qos is good)
- If (tds is na) and (ph is low1) then (qos is na)
- If (tds is na) and (ph is low2) then (qos is na)

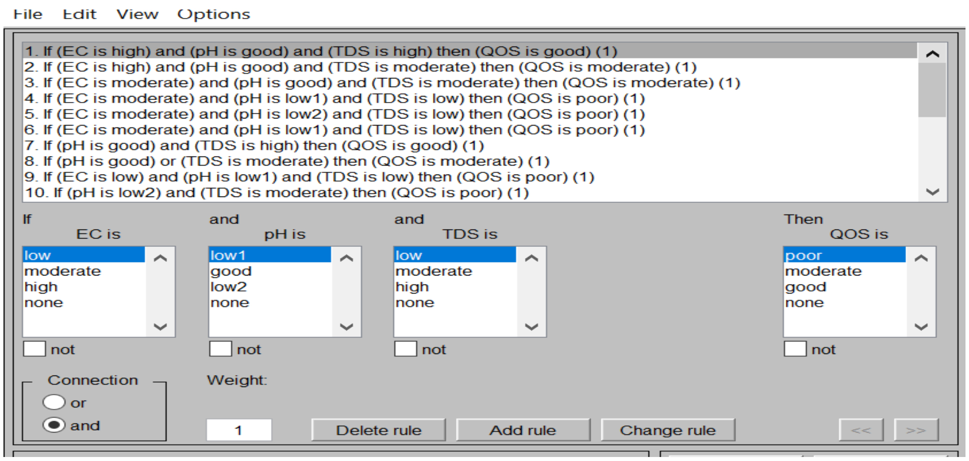


Figure 4. 15: Fuzzy rules implementation

iii. Inference Engine: It determines the degree of match between fuzzy inputs and the rules created. It determines which rules need to implement according to the given input field based on percentage match. Then, the applied rules are combined to develop the control actions. The proposed system of this study consists of three inputs parameter variables and one output variable as Table 4.2 shown.

Table 4. 2: Training dataset

Fuzzy Input Variables	Input/Output	Linguistic Values	Numerical Range	Fuzzy sets
EC	Input	High	8.5-8.9	[8.4,8.5,8.9]
		Moderate	7.6-8.4	[7.7,7.8,8.6]
		Low	6.2-7.5	[7.1,7.7,7.7]
		Unacceptable	1-6.1	[0,7,7.2]
TDS	Input	High	5695-6164	[5695,6000,6164]
		Moderate	5092-5628	[5226,5628,5700]
		Low	4154-5025	[4757, 5159,5228]
		Unacceptable	1000-4087	[0 4690 4760]
pH	Input	Low1	0-6.4	[0 3.5 6.5]
		Good	6.5-8.5	[6.4 7.0 8.5]
		Low2	8.6-14	[8.4 10 14]
	Output	Good	96-100	[96 98 100]

Quality of Salt (QOS)		Moderate	85-95	[86.5 93 96]
		Poor	70-84	[70 79 86.7]
		Unacceptable	<70.5	[0,60,70.7]

iv. Defuzzification: This converts the fuzzy sets into crisp values to present the knowledge of salt quality in to the human natural language. Therefore, the defuzzification of this study to human natural language is presented as the output results of “The Salt is GOOD”, “The Salt is MODERATE” and “The Salt is POOR”.

4.5.8. The converted Fuzzy file into Arduino code

The Matlab fuzzy file code was converted into Arduino code to perform the same outputs actions as Matlab simulation output, so the created Arduino code from the Matlab fuzzy file can get the data collected directly from the sensors and therefore identify the quality of sodium chloride salt concentration percentage (QOS%). The Figure 4.16 below demonstrates the fuzzy codes uses 12314 bytes (38%) fro program storage space and the maximum was 32256 bytes. The global variables use 798% (38%) of dynamic memory, leaving 1250bytes for local variables and maximum was 2048 bytes used for Arduino as Figure 4.16 shown.

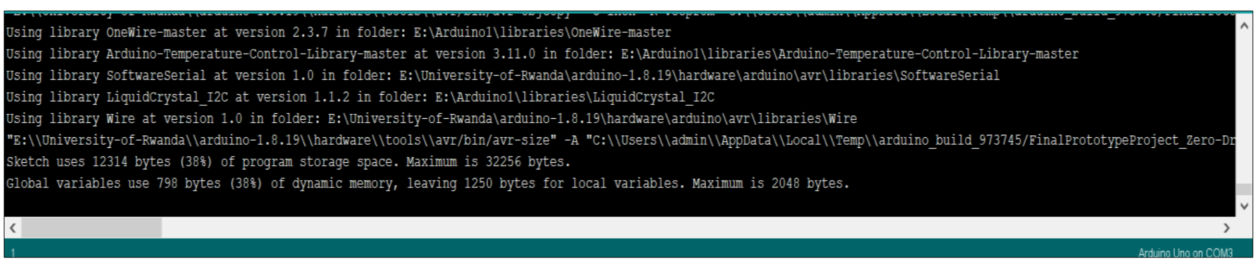


Figure 4. 16: Arduino code performance

4.6. ThingSpeak cloud platform selection

A cloud computing is a large pool of system, connected in public or private network that provide scalable infrastructure and services for application, storage, hosting point, data mining and analysis. This study used the ThingSpeak cloud server for data storage, processing, analysis and notification triggering. ThingSpeak is an IoT analytics open-source platform service that allow users to visualize, combine and analyzed real-time data. It uses API to store and retrieve data from things using the HTTP and MQTT protocol over the internet. In addition, it can perform aggregation, visualization and analytics data streams in the cloud [28].

Figure 4. 17: ThingSpeak cloud block diagram

4.7. Arduino Integrated Development

It is an open source software used to write and upload codes to the microcontroller boards such as Arduino boards. The IDE application is suitable for different operating system such as Windows, Mac OS X and Linux. It supports programming languages C and C++. The program or code written in Arduino IDE called sketching and it is saved with '.ino' extension. In this, study the Arduino IDE version 1.8.19 used [36].

4.8. MATLAB Software

This is a programming platform designed for engineers and scientist to analyse and design systems and products. The software analyze data, develop algorithm and create models and applications [28].

CHAPTER 5. RESULTS AND ANALYSIS

This chapter focuses on the results observed from the research study, results analysis and discussion of the results.

5.1. Prototype implementation

The prototype of the embedded system implemented using different components of IoT devices as Figure 5.1 shown below. The system consisted of Arduino microcontroller connected with EC, TDS and pH sensors, the DS18B20 1-wire temperature sensor used to compensate with EC sensor read the correct data. The 20x4 LCD screen used to display the output results, the GSM device used for data transmission to the thingspeak cloud server and power source of 9v used to power up the prototype.

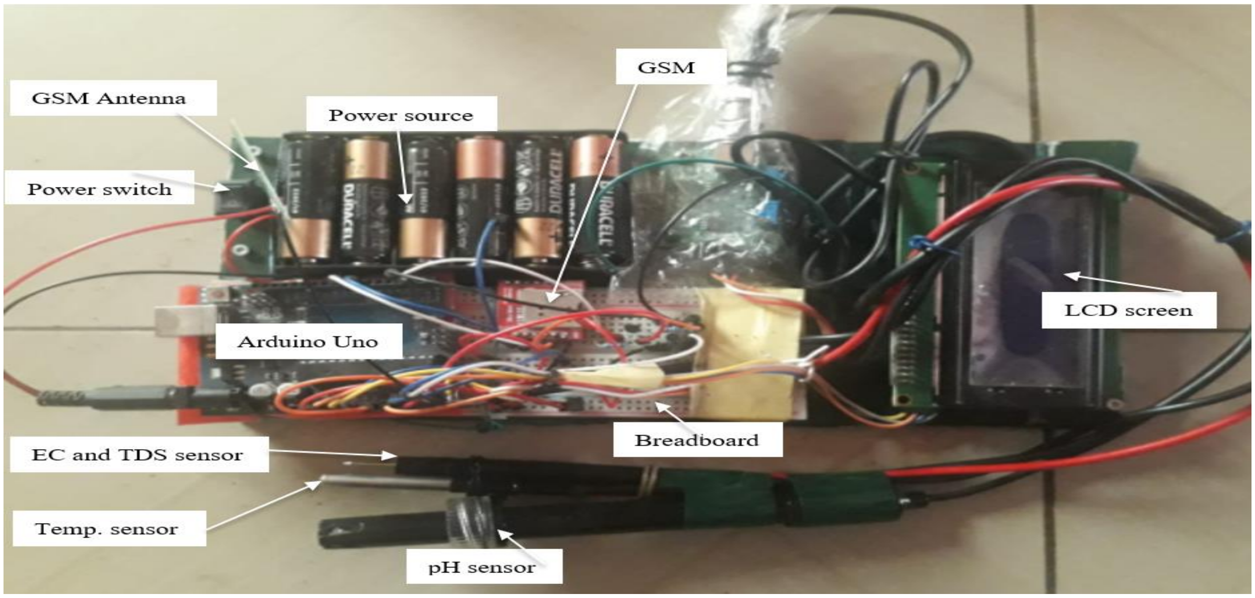


Figure 5. 1: QOS System prototype

5.2. Prototype testing

The prototype testing based on the embedded device prototype and ThingSpeak cloud server. The embedded device test the data collected through three samples (S1, S2 and S3) of sodium chloride solution, where EC, TDS and pH sensors used as input parameters. The data collected on the samples processed and analysed locally and display the output results (QOS %) of the measured salt on LCD screen as Figure 5.2 shown. Furthermore, prototype tested on data transmission to ThingSpeak cloud server using GSM communication module where data analysed and the results visualized on ThingSpeak dashboard.

5.2.1 Sensor reading results

The sensor reading results performance observed during the samples measuring via the serial monitor. Three samples (S_1, S_2 and S_3) were prepared and the sensors adequately collected the data in each sample.

5.2.2 Electrical conductivity sensor (EC)

The EC sensor can capture electrical conductivity and total dissolved solids data from sodium chloride solution. Due to variation of temperature in the sodium chloride solution, the EC sensor require to compensate with DS18B20 1-wire temperature sensor to read the correct data from the sodium chloride solution. The Appendix A3 shows an EC data collected during sample (S_1) testing of about 8.6-8.8mS/cm, which is acceptable range for good quality of sodium chloride salt observed in the solution. Therefore, the prototype system was able to read the results of sodium chloride conductivity in the sample solution.

5.2.3 Total dissolved solids sensor (TDS)

The Appendix A3 shows the TDS reading results when the EC sensor dipping to the sodium chloride solution of 5784-5886 mg/L of sample (S_1) which is good quality salt concentration. The reading values depend on the sample measured; therefore, the TDS reading results on S_1, S_2 and S_3 displayed the different results due to the sodium chloride dissolved in the solution as reading values shown in the serial monitor.

5.2.4 Hydrogen potential (pH)

The prototype used pH sensor for measuring the acidity and alkalinity, or the amount of base and caustic in the sodium chloride solution as Appendix A3 shown. The recommended range level of pH reading is 6.5-8.5 for good quality of salt [40]. The increasing or decreasing of the recommended pH range means the salt has more concentration of acidity or alkalinity, therefore, that salt not recommended for human use.

5.2.5 The System result (QOS output)

The prototype system was able to collect data from the samples (S_1, S_2 and S_3) based on the EC, TDS and pH, these input parameters were relevant to fuzzy inference system, and intelligently was able to infer the QOS of sodium chloride concentration samples (S_1, S_2 and S_3). The QOS output concentration was measured interms of percentage. The sodium chloride concentration results shown on LCD screen and serial monitor respectively as Figure 5.2 and Appendix A3 shown. The data collected from the embedded system prototype transmitted to the thingspeak cloud server for further data analysis and visualization.

Figure 5. 2: QOS LCD prototype results LCD screen

5.2.6 ThingSpeak dashboard results

The Figure 5.3-5.4 shows data entry values visualization results in ThingSpeak dashboard received from prototype. The visualization graphs demonstrate the sensor data values collected in different sodium chloride solution samples over time given. In Figure 5.26-27 display the results of EC, TDS and pH sensor entries values collected from the system, these entry values show the variations of data collected from three samples of sodium chloride salt solution.

In Figure 5.3 demonstrates the EC sensor reading values of 8.4- 8.8mS/cm for high salt conductivity measured from sodium chloride sample (S1), 7.6-8.1mS/cm for moderate salt conductivity from sodium chloride sample (S2) and 7.1-7.4 mS/cm with lower salt conductivity from sample (S3). Therefore, EC sensor data readings shows that whenever there is increasing of salt concentration in the sample solution also the EC sensor records higher value of salt conductivity as Figure 5.3 shown.

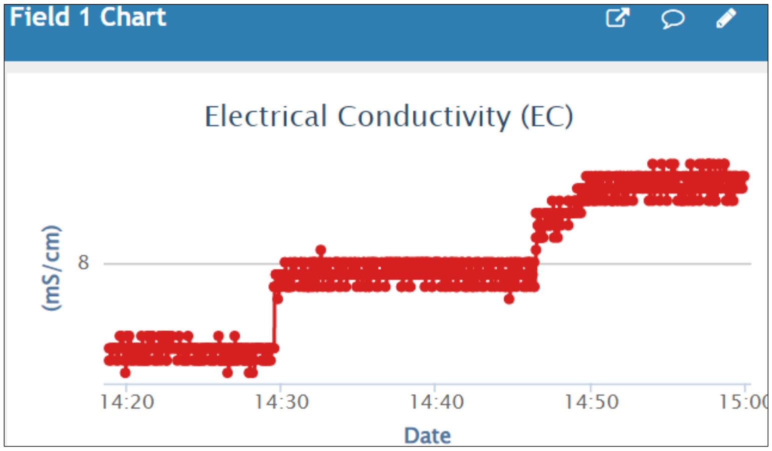


Figure 5. 3: EC input values visualization

In Figure 5.4 demonstrates the TDS sensor reading values of 5509-5868ppm for high salt conductivity measured from sodium chloride sample (S1), 5175-5357ppm for moderate salt conductivity from sodium chloride sample (S2) and 4806-4921ppm with lower salt conductivity from sample (S3). Therefore, TDS sensor data readings shows that whenever there is increasing of salt concentration in the sample solution also the TDS sensor records higher value of salt conductivity as Figure 5.4 shown.

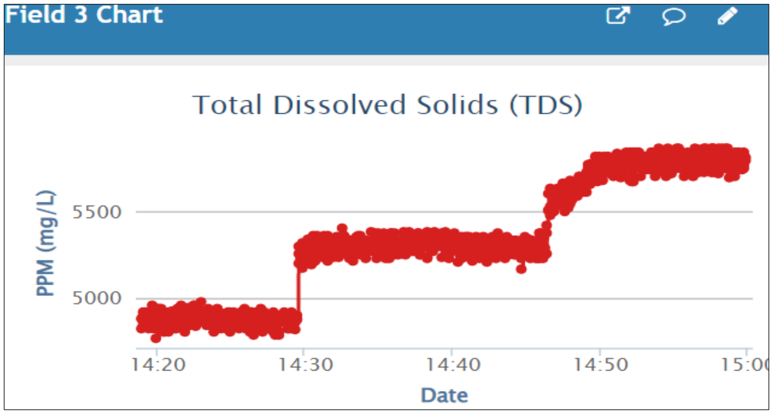


Figure 5. 4: TDS input values visualization

In Figure 5.5 shows the pH sensor readings from ThingSpeak dashboard with the range of 7.3-7.9 ph level for high salt concentration measured from sodium chloride sample (S1) observed to have good pH level, 7-7.5 ph level for moderate salt concentration from sodium chloride sample (S2) and 7.4-7.8 with lower salt concentration from sample (S3). Therefore, the three samples demonstrates to good performance of pH level.

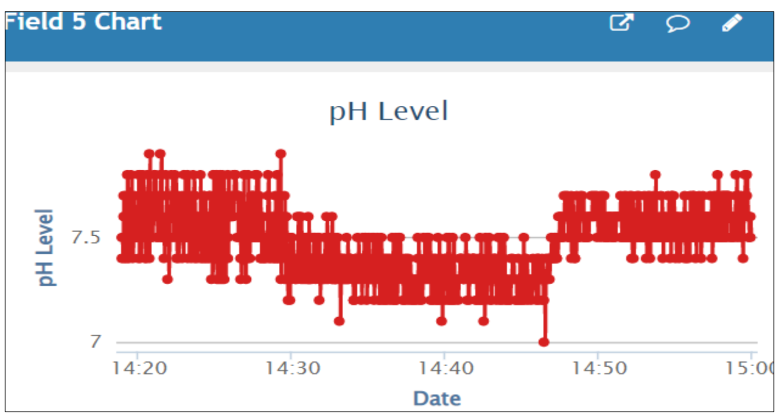


Figure 5. 5: pH input values visualization

In Figure, 5.6-5.8 show the variation of these EC, TDS and pH parameters values in the ThingSpeak dashboard results the sodium chloride to have different concentration values in percentage wise. The Matlab visualization in ThingSpeak dashboard represent the NaCl concentration variation over the EC and TDS changes as shown in. In Figure 5.6 shows the relationship between EC and TDS parameter values, when the EC has low conductivity values, the

TDS also shows the low concentration values. Therefore, whenever there is increasing of EC conductivity values the TDS concentration increases too as observed in Figure 5.6 shown.

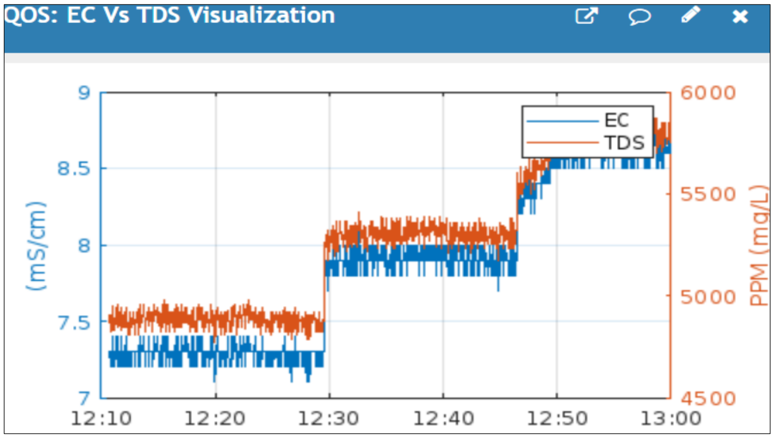


Figure 5. 6: EC Vs TDS visualization

In Figure 5.7 demonstrates the TDS and NaCl concentration interms of percentage. When the TDS is low level, the NaCl salt solution concentration has low concentration range of 80-90%, which is low quality and not good for human health. When the TDS has moderate level, the NaCl salt solution concentration has moderate concentration range of 91-96%, this means, the sample has moderate quality of salt concentration. The last is the higher level of TDS in the salt solution means the NaCl salt has good concentration range of 97-100%, which is good quality for human health.

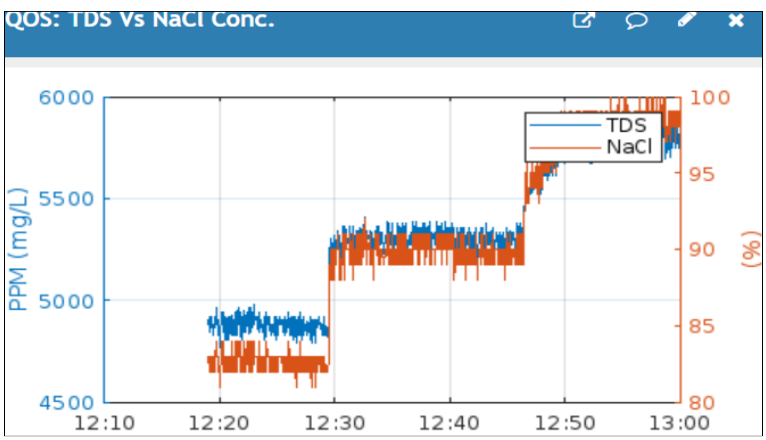


Figure 5. 7: TDS Vs NaCl concentration visualization

In Figure 5.8, represent the comparison performance of TDS and pH level. The two samples (S1 and S2) of NaCl solution observed to have good pH level range of 7-7.9, while the third sample (S3) gradually observed to increase the pH level towards the alkalinity side of pH scale, which make the salt to be not good for human use. Therefore, sodium chloride salt sample solution measured observed to have stable pH level for salt concentration.

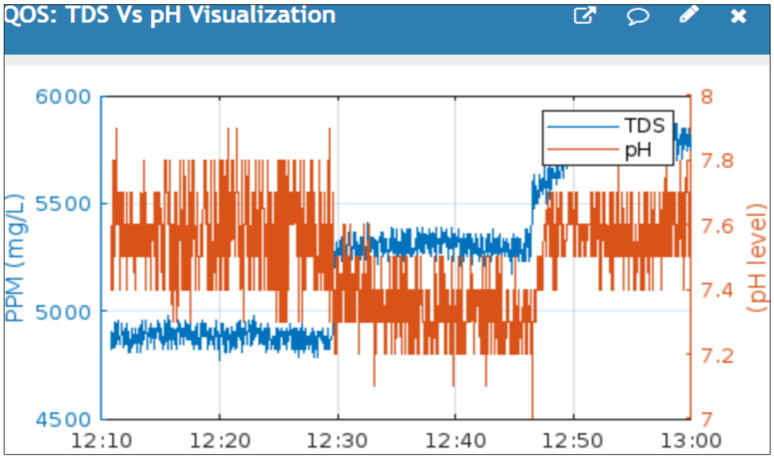
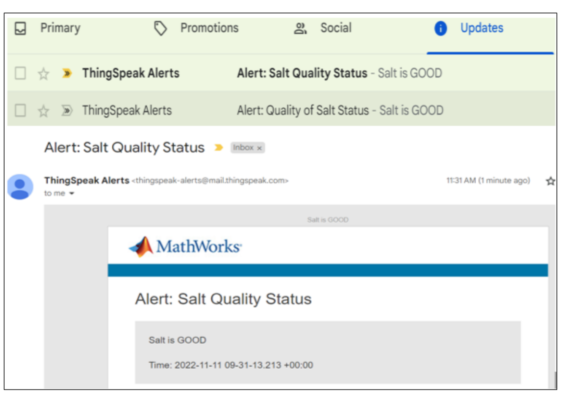


Figure 5. 8: TDS Vs pH level visualization

5.2.7 ThingSpeak Email notification

The data transmitted to the ThingSpeak processed, analysed by using Matlab analysis application where ThingSpeak Alerts email notification services implemented as index A1. Email notification codes shown and the status of the salt quality notified to the user email from ThingSpeak Alerts service as Figure 5.9 shown. In Figure 5.10 show the SMS message alert sent to the mobile phone from the system prototype when the salt solution was measured, when the threshold of the salt concentration reached, the system prototype send an sms message to the users mobile phone to inform about their salt quality status.



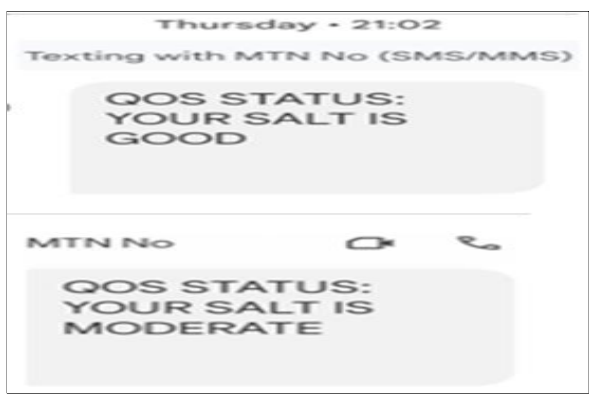


Figure 5. 9: Email notification alert

Figure 5. 10: SMS message notification alert

5.2.8 The system performance and evaluation

In Table 5.1 represents the data generated by the prototype system during experiment of data collection of samples (S1, S2 and S3). In this study, the dataset size collected during experiment was one thousand data rows for all samples, but we considered the sample size of 278 data rows on this research as Table 5.1 data sample shown. Each sample has input parameters of EC, TDS and pH values that provide the output results of QOS of sodium chloride concentration in percentage. The average mean of QOS % was calculated for each sample as Table 5.1 shown. Therefore, the QOS status average mean of sample (S1) was about 97.8%, sample (S2) was 93.4% and sample (S3) was 82.4%. This implies that, the S1 was inferred as good quality salt with high concentration of NaCl, the S2 estimated as moderate quality salt with moderate concentration of NaCl and the last sample (S3) was inferred as poor quality with low concentration of NaCl.

Table 5. 1: Data collection sample

Sample Repetition		**Input Data Collection**			**Output**	**% Error**	**% Accuracy**
		EC (mS/cm)	**TDS (PPM)**	**pH level**	**QOS (%)**		
S1	1	8.5	5705	7.5	97	0.3	99.7
	2	8.5	5675	7.6	96		
	3	8.7	5845	7.5	99		
	4	8.7	5845	7.6	99		
	5	8.6	5774	7.6	98		
	Mean (QOS %)				97.8		
S2	1	8.1	5422	7.3	92		
	2	8.2	5509	7	93		
	3	8.4	5605	7.3	95		
	4	8.2	5509	7.3	93		
	5	8.3	5531	7.4	94		
	Mean (QOS %)				93.4		
S3	1	7.2	4825	7.5	82		
	2	7.3	4864	7.4	82		
	3	7.3	4864	7.5	82		
	4	7.3	4864	7.5	82		
	5	7.2	4825	7.5	84		
	Mean (QOS %)				82.4		

The mean (average) value, percentage error (% error) and percentage accuracy (% accuracy) of the proposed system can be calculated using the following formulae:

$$\overline{\mathbf{X}} = \frac{\sum Xi}{n}$$

Where $\overline{X}$ is the mean value, Xi is the individual measured value and n is the number of measurements.

5.2.9 Data training and accuracy

The Matlab Toolbox was used to train the sodium chloride salt dataset. The validation of system prototype based on the data generated during data collection. The dataset of 278-sample size used to find the prototype system accuracy, which means the good, moderate or poor quality of salt. When the dataset training was applied on fuzzy logic model, the system training error was about 0.3% as Figure 5.11 shown, where % Error is the percentage error of the data trained model, experimental value is the mean value and the true value is the maximum measured value minus percentage deviation value [41]-[42]. The percentage accuracy is equivalent to 100% minus percentage Error. Therefore, the system accuracy was about 99.7% as Figure 5.11 shown and the percentage accuracy is the percentage accuracy of the system model. This performance results demonstrates that, the system prototype was effectively able to estimate the salt quality concentration on a real-time condition.

Figure 5. 11: Data training, error and accuracy

In Figure 5.12 shows the regression equation to obtain QOS concentration index we can see the QOS concentration index value, QOS y = 0.0171x - 0.9903. The value of the determination of the coefficient (R^2) was 0.9998. The R index had the best determination coefficient (R^2) of 0.9998. Therefore, the regression equation for R index was used to determine the concentration of sodium chloride in the samples.

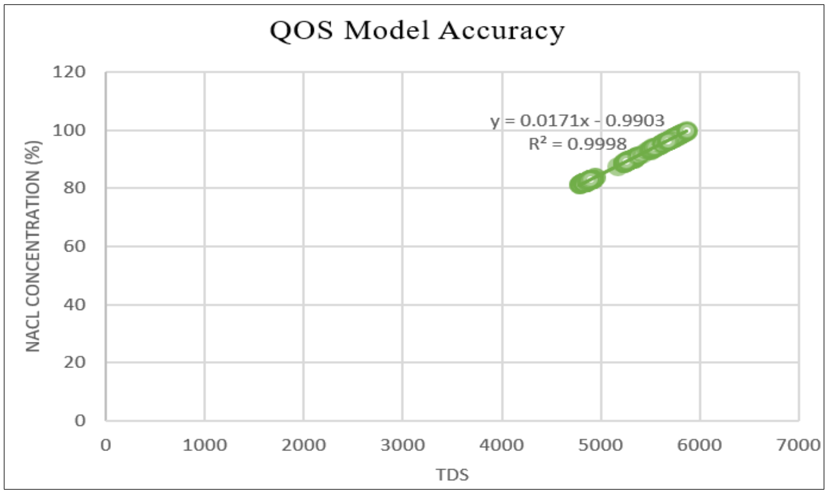


Figure 5. 12: QOS regression concentration index

5.3. Discussion of the Results

The matlab application toolbox was used to train the fuzzy logic approach which was used to validate the performance of the proposed IoT system prototype by measuring three salt solution sample (good salt, moderate salt and poor salt). The approach verified the salt status results experimentally from the input parameters of EC, TDS and pH. The fuzzy logic rules provide the output results according to the input parameters of the salt solution sample as the following:

Result status one: Salt is Good, this represents the QOS of sodium chloride is good. In this case, the input parameters values of QOS status considered, namely, EC: 8.5-8.9, TDS: 5695-6030 and pH: 6.5-8.5. The fuzzy rule implemented for analysis: If (EC is high) AND (TDS is high) AND (pH is Good) then (Salt is Good, S1) as Figure 4.15 and Table 4.2 shown. After fuzzy rule implementation, the analysed result message displayed in the LCD "Salt is Good, S1" as Figure 5.2 shown with EC, TDS and TDS parameter values that correctly estimates the QOS of sodium chloride status as Figure 5.6-5.8 shown. The analysed result justifies the performance of the QOS IoT system to measure the sodium chloride concentration of about 97-98.3% as Figure 5.7 shown.

Result status two: The salt is Moderate; this means QOS of sodium chloride has moderate concentration. The QOS input parameter values considered in this case are, EC: 7.6-8.4, TDS: 5092-5628 and pH. 6.6-8.4. The fuzzy logic rule implemented for analysis: If (EC is Moderate) AND (TDS is Moderate) AND (pH is Good) then (Salt is Moderate, S2) as Figure 4.15 and Table 4.2 shown. After implemented of fuzzy logic rule, the analysed result message displayed on LCD screen as "Salt is Moderate, S2" as Figure 5.2 shown with EC, TDS and TDS parameter values, the fuzzy rule estimates correctly the QOS of sodium chloride concentration as Figure 5.6-5.8 shown. The analysis results validates the performance of the QOS IoT system to measure the sodium chloride concentration, which was 93.4% concentration of NaCl salt Figure 5.7.

Result status three: The salt is Poor; this means QOS of sodium chloride concentration was very low. The case status three considered the following input parameter values EC: 6.2-7.5, TDS: 4154-5025 and pH: less than 6.5 or greater than 8.5 with fuzzy logic rule of; If (EC is low) AND (TDS is low) AND (pH is low1) then (Salt is Poor, S3) as Figure 4.15 and Table 4.2 shown. The fuzzy rule analysed the input parameter values and provides the output results message displayed in the LCD screen "Salt is Moderate, S3" as Figure 5.2 shown. This output results validates the working performance of the QOS IoT system to measure the sodium chloride salt concentration, which is about 82.4% as Figure 5.7 shown.

The proposed system showed the high performance on measuring the sodium chloride salt concentration of about 99.7% with an error of 0.3 % as Table 4.1 shown. In Figure 5.7 shows, the sodium chloride concentration measured by prototype in different salt solution samples. The implemented prototype improved the measurement of sodium chloride concentration by using EC, TDS and pH input parameters. The prototype can make the basic and advance processing, analysis and send email and SMS notification not only the local measurement sample, but also the notification can be sent to the remote place as Figure 5.9-5.10 shown. The Matlab analysis and visualization with fuzzy logic method used to trigger the email notification when thresholds of the salt input parameters reached as Figure 5.9 shown, while the research study of [8] measured the sodium chloride concentration and the data transferred to the computer using USB cable for data analysis. Therefore, this study shows higher performance and real-time on measuring and estimating the salt quality. The Ketut Sumada et al. [3] used the hydro-extraction method to improve salt quality, which needed a lot of chemistry procedures and time consuming, while this proposed IoT based quality of salt prototype used IoT technology with low cost effective real-time method to measure the salt quality. Therefore, the proposed study is helpful to measure and estimate the quality of sodium chloride salt.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

This research study presents an IoT-based system using fuzzy logic approach for measuring and estimate of sodium chloride salt using Mamdani inference system to assist an effective measurement management of salt in the community. The significance of this study is to assist the salt farmers and community to know the quality of sodium chloride status for human health. The previous research study propose different methods of measuring and increasing the quality of salt, but, in this study we use an IoT based on the fuzzy logic method to measure and estimate the quality of sodium chloride salt. The thee parameters used in this approach, namely, electrical conductivity (EC), total dissolved solids (TDS) and hydrogen potential (pH) under different samples (S1, S2 and S3) data collection situations to estimate the quality of salt concentration (QOS). The IoT system intended to provide output results according to the situation of the salt measured. The QOS is the output parameter, which represents the percentage of the salt concentration and the result displayed after an appropriate condition applied, such as displaying result on LCD screen to show the quality of salt status and input parameters measured. The samples experiments were conducted for data collection using an IoT system prototype and the results obtained were 97.8%, 93.4% and 82.4% for (S1, S2 and S3) respectively. The average accuracy of the system was about 99.7% with percentage error of about 0.3%. The intended future works is to develop an intelligent fuzzy logic system based on QOS with more input and output parameters

6.2. Recommendation

Based on this research study findings, I would like to recommend the following for better quality of sodium chloride salt:

There is a need for awareness of using the quality salt by implementing the AI model system for measuring the quality of sodium chloride salt for human better health. The limited time of the research study was the main challenge on the study development and implementation. It was somehow challenge to get all components and materials of the research project on the required time due to the high costs and even it took long time for waiting. It was challenge to prepare some sample salt solution due to the absence of some salt materials that results on the problem of data reading from the solution.

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APPENDICES

A 1: QOS Email Notification Codes

QOSEmailNotification

MATLAB Code

```
% Store the channel ID for the moisture sensor channel.
channelID = 1677126;
ecFieldID = 1;
tdsFieldID = 3;
phFieldID = 5;
naclFieldID = 4;
readAPIKey = 'MSRJG5VA7CYCQX2P';
% Provide the ThingSpeak alerts API key.  All alerts API keys start with TAK.
alertApiKey = 'TAKGCr1jdIrLN/U/Nna';
% Set the address for the HTTTP call
alertUrl="https://api.thingspeak.com/alerts/send";
% webwrite uses weboptions to add required headers.  Alerts needs a ThingSpeak-Alerts-API-Key h
options = weboptions("HeaderFields", ["ThingSpeak-Alerts-API-Key", alertApiKey ]);
% Set the email subject.
alertSubject = sprintf("QOS Status");
% Read the recent data.
[naclData] = thingSpeakRead(channelID,'Fields',[naclFieldID], 'NumPoints',100,'ReadKey',readAPI
% Check to make sure the data was read correctly from the channel.
if isempty(naclData)
    alertBody = ' Waiting For Sample. ';
elseif (naclData>=96.6)
        alertBody = ' Salt is GOOD ';
elseif (naclData<96.5 & naclData>=87.5)
        alertBody = ' Salt is Moderate ';
elseif (naclData<87.5 & naclData>=70.0)
        alertBody = ' Salt is Poor. ','NaCl:';
elseif (naclData<70.0 & naclData>=11.0)
        alertBody = ' Not Applicable. ';
elseif (naclData<11.0 & naclData>=0)
        alertBody = ' Waiting For Sample. ';
    end
% Catch errors so the MATLAB code does not disable a TimeControl if it fails
try
    webwrite(alertUrl , "body", alertBody, "subject", alertSubject, options);
catch someException
    fprintf("Failed to send alert: %s\n", someException.message);
end
```

A 2: QOS Visualization Codes

QOS: EC Vs TDS Visualization

MATLAB Code

```
readChannelID = 1677126;
ecFieldID = 1;
tdsFieldID = 3;
%phFieldID = 4;
readAPIKey = 'MSRJG5VA7CYCQX2P';

[data, timeStamps ] = thingSpeakRead(readChannelID,'Fields',[ecFieldID tdsFieldID], 'NumPoints

ecData = data(:, 1);
tdsData = data(:, 2);
%phData = data(:, 4);

yyaxis left
plot(timeStamps, ecData);
ylabel('(mS/cm)');
yyaxis right
plot(timeStamps, tdsData);
ylabel('PPM (mg/L)');
legend({'EC','TDS'});
grid('on');
```

QOS: TDS Vs pH Visualization

MATLAB Code

```
readChannelID = 1677126;
tdsFieldID = 3;
phFieldID = 5;
readAPIKey = 'MSRJG5VA7CYCQX2P';

[data, timeStamps ] = thingSpeakRead(readChannelID,'Fields',[tdsFieldID phFieldID], 'NumPoints

tdsData = data(:, 1);
phData = data(:, 2);
%phData = data(:, 4);

yyaxis left
plot(timeStamps, tdsData);
ylabel('PPM (mg/L)');
yyaxis right
plot(timeStamps, phData);
ylabel('(pH level)');
legend({'TDS','pH'});
grid('on');
```

QOS: EC Vs NaCl

MATLAB Code

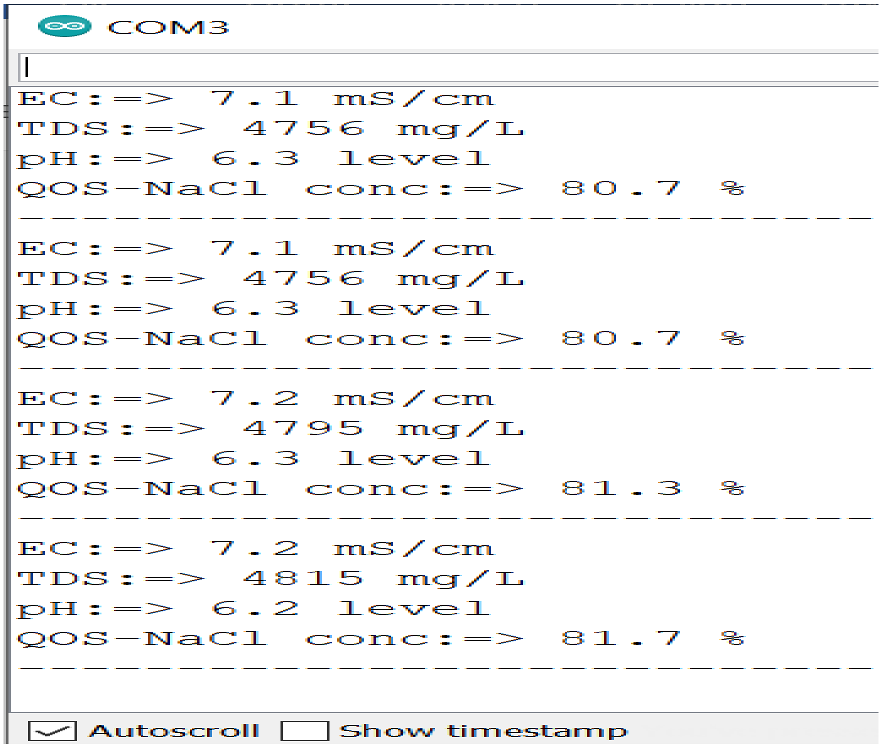
```
readChannelID = 1677126;
ecFieldID = 1;
naclFieldID = 4;
readAPIKey = 'MSRJG5VA7CYCQX2P';

[data, timeStamps ] = thingSpeakRead(readChannelID,'Fields',[ecFieldID naclFieldID], 'NumPoint

ecData = data(:, 1);
naclData = data(:, 2);
%phData = data(:, 4);

yyaxis left
plot(timeStamps, ecData);
ylabel('(mS/cm)');
yyaxis right
plot(timeStamps, naclData);
ylabel('(%)');
legend({'EC','NaCl'});
grid('on');
```

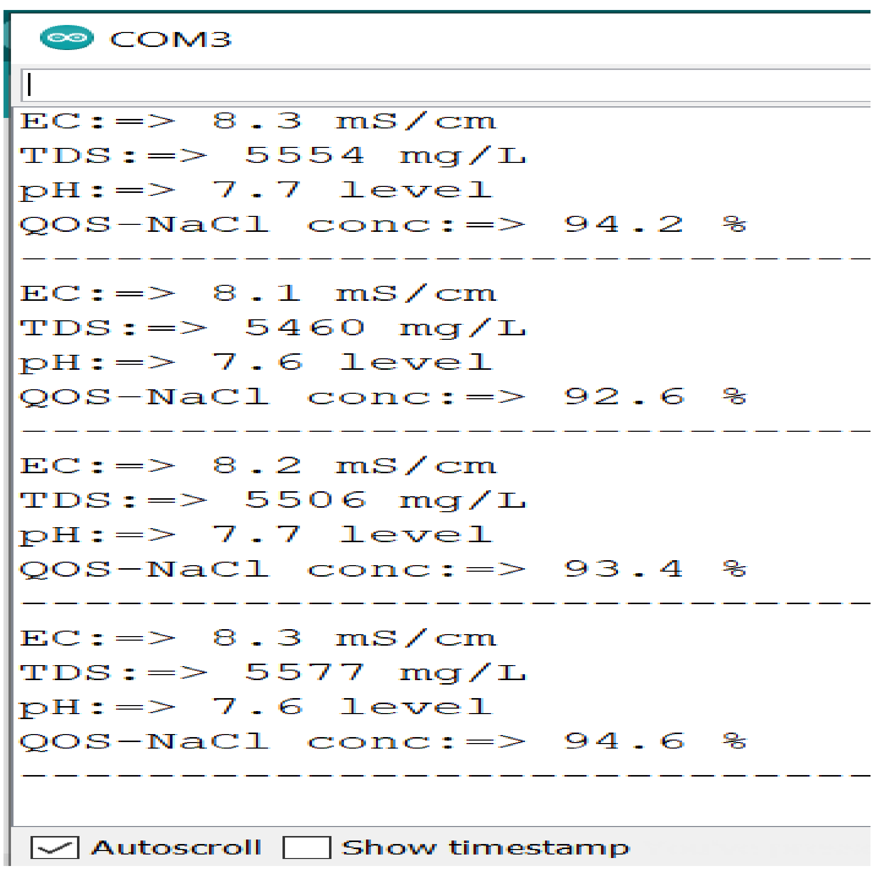
QOS: TDS Vs NaCl Conc.

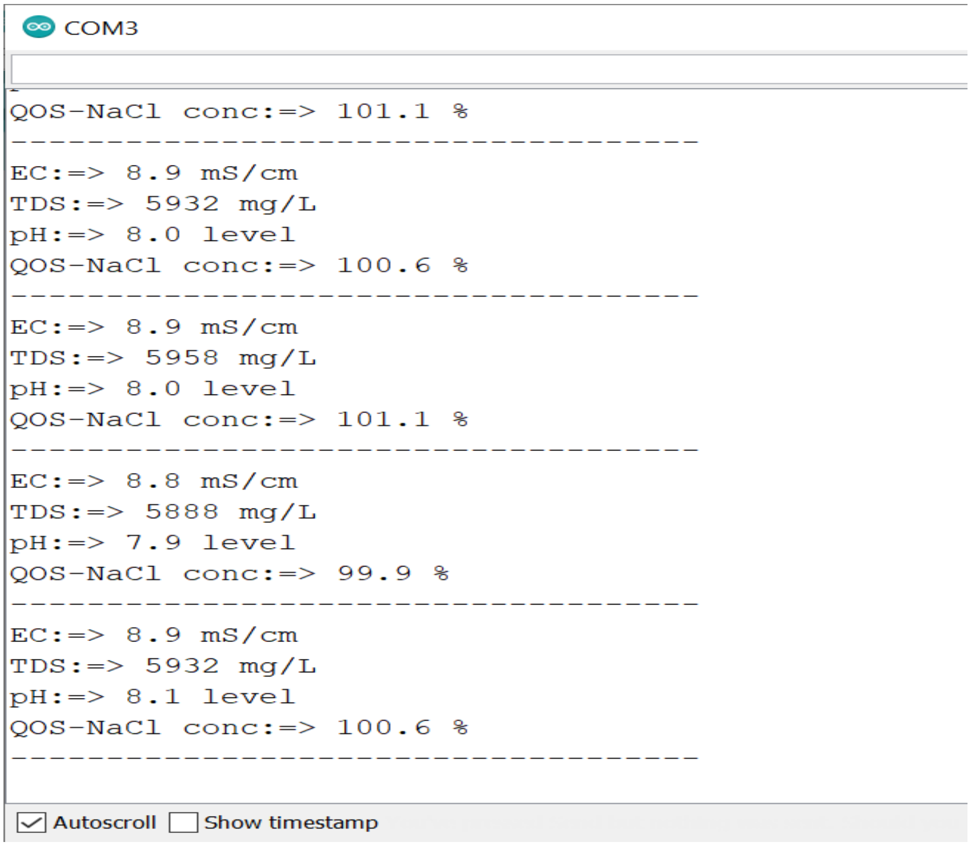
MATLAB Code

```
readChannelID = 1677126;
tdsFieldID = 3;
naclFieldID = 4;

readAPIKey = 'MSRJG5VA7CYCQX2P';

[data, timeStamps ] = thingSpeakRead(readChannelID,'Fields',[tdsFieldID naclFieldID], 'NumPoin

tdsData = data(:, 1);
naclData = data(:, 2);
%phData = data(:, 4);

yyaxis left
plot(timeStamps, tdsData);
ylabel('PPM (mg/L)');
yyaxis right
plot(timeStamps, naclData);
ylabel('(%)');
legend({'TDS','NaCl'});
grid('on');
```

A 3: EC, TDS and pH sensor readings on serial monitor






COM3
QOS-NaCl conc:=> 101.1 %

EC:=> 8.9 mS/cm
TDS:=> 5932 mg/L
pH:=> 8.0 level
QOS-NaCl conc:=> 100.6 %

EC:=> 8.9 mS/cm
TDS:=> 5958 mg/L
pH:=> 8.0 level
QOS-NaCl conc:=> 101.1 %

EC:=> 8.8 mS/cm
TDS:=> 5888 mg/L
pH:=> 7.9 level
QOS-NaCl conc:=> 99.9 %

EC:=> 8.9 mS/cm
TDS:=> 5932 mg/L
pH:=> 8.1 level
QOS-NaCl conc:=> 100.6 %

Autoscroll
Show timestamp