



University of Peradeniya

Faculty of Engineering

Department of Computer Engineering

Project Design

REAL TIME WATER QUALITY **MEASUREMENT SYSTEM**

Amila Indika (E/14/142)

Nethmal Warusamana (E/14/364)

Erantha Welikala (E/14/380)

Abstract

Real Time Water Quality measurement (RTWQ) is a technique used by environmental authorities all around the world. RTWQ system is basically using sensors to detect parameters of water such as pH, conductance, turbidity, temperature, Biological Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen, concentrations of organic and inorganic substances etc. continuously and update a web server and make data available real time. Current manual system is **time wasting, expensive, require higher labour with expertise** and **difficult to maintain logs and records of data**. Hence, our solution is to develop a power efficient system that is capable of measuring water quality real-time at an affordable cost which can be used from a remote location and having proper security features.

The system consists of several sensors located in remote locations to measure the water quality real time. The information received by sensors are sent to a centralized system which is monitoring the water quality measurement through GSM modules. These informations can be sent at a predefined interval of time and they can be analysed from the central monitoring system. The system is secured with access restrictions and only authorized personnel can access.

Sensors include LM35 temperature sensor, turbidity sensor, conductivity sensor, and pH sensor and they are controlled by an ATmega32 microcontroller at the end node and recorded data is sent via a SIM808 GSM module. As the networking part a RESTful application will be created with the help of HTML, CSS, Bootstrap, java script, and AJAX as frontend technologies and Node.js, MongoDB, Mongoose, PHP as backend technologies. In addition, modern encryption techniques will be used to secure data.

Table of Contents

1) Abstracts.....	i
2) Table of Contents.....	ii
3) Chapter 1	
a. Introduction and Background.....	1
b. Problem Statement.....	2
c. Objectives.....	3
4) Chapter 2	
a. Description of design components and the technical & theoretical background	
2.1) Temperature sensor.....	4
2.2) GSM module	5
2.3) ATmega Micro-Controller Unit.....	6
2.4) pH probe.....	7
5) Chapter 3	
a. Implementation of the of the project	
i. Embedded Systems Design.....	8
ii. Web and Network Application Design.....	10
iii. Computer and Network Security.....	11
b. Block Diagrams & Circuit diagrams.....	14
c. Designs of the system.....	18
d. Designed GUI.....	21
6) Chapter 4	
a. Project Information	
i. Timeline & Expenses.....	22
7) References.....	23

List of figures and tables

1) Figure 01: Temperature Sensor - Waterproof (DS18B20).....	05
2) Figure 02: Pin Assignment of the sensor.....	05
3) Figure 03: SIM808 GSM module	06
4) Figure 04: ATmega 32 IC (left) and ATmega32 pin configuration (right).....	07
5) Figure 05: pH probe.....	08
6) Figure 06: RESTful API.....	12
7) Figure 07: User authentication diagram.....	13
8) Figure 08: Block Diagram of pH sensor.....	14
9) Figure 09: Circuit which is using to connecting the pH probe.....	14
10) Figure 10: Block diagram of turbidity sensor.....	15
11) Figure 11: Circuit diagram of the turbidity sensor.....	15
12) Figure 12: Block diagram of the conductivity sensor.....	16
13) Figure 13: Circuit diagram of the conductivity sensor.....	16
14) Figure 14: Block diagram of the Temperature sensor.....	17
15) Figure 15: Overall design of the RTWQ system.....	18
16) Figure 16: Server-side overview.....	19
17) Figure 17: Database overview.....	19
18) Figure 18: Aspects of the system relevant to the courses.....	20

19) Figure19: Designed GUI	21
20) Figure 19: Timeline of the project	22
1) Table 1: Comparison between the temperature sensors.....	10
2) Table 2: Expenses.....	22

Chapter 1:

a. Introduction and Background

Real Time Water Quality (RTWQ) measurement is a technique used by environmental authorities and different companies involved with water testing which came into light after 1950s. This RTWQ refers to measurement of water quality and making them available on the web in real time. Although this process is said to be real time, in practice what is done is recording data in small intervals varying typically from every five minutes to hourly, and these recording data is considered to be continuous. The process of uploading the data to web servers may also have pre-defined intervals. These data come handy in when making decisions regarding the level of pollution of water, public safety for the consumption of water etc.

Real Time Water Quality is made possible because of improvements of sensors and data recording technology. Today, with the evolving computers that are capable of processing a large amount of data simultaneously, it is possible to measure several qualities of water simultaneously. Further, there are sensors that are developed even to measure chemical properties of water.

Water Quality measurement is vital because water is consumed by every human being and animals on a daily basis, and we should have a guarantee that water we are consuming are not harmful to health. Further, it is important in order to maintain a proper eco system without polluting the existing water resources.

Usual parameters measured in water quality testing are **conductance, pH, water temperature, turbidity, BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand) and constituents of the dissolved chemicals.**

Usually, these kinds of systems will cost a lot, and the idea of this project is to deploy a system which is capable of at least giving a rough idea about the quality of water based on several properties selected from the above list. For that purpose, we are thinking of measuring the **conductance, pH, water temperature, and turbidity.** The rest of the parameters may require a deep chemical analysis of the samples and hence may require manual work or else the system should contain sensors measuring chemical constituents of water which would increase the cost of production of such kind of system.

b. Problem Statement

Major drawbacks of the current manual system of collecting samples and measuring them are as follows:

- i) In order to measure quality of water at a certain location, it may require to go to the site to collect samples and analyse them.
- ii) Repetition of taking samples from sites is difficult.
- iii) Cost of collection of samples for several times may be higher because the sampling tools has to be prepared every time sampling is done.
- iv) Higher risks to field officers who actually go to sites as these water resources can be hazardous in some cases.
- v) Inability to analyse several sites simultaneously.
- vi) Higher labour cost.
- vii) Time wasting as it takes a lot of time to collect, analyse and finalize samples.
- viii) Data logging and report generation over space and time is very difficult using manual methods, especially when a large amount of data is available.
- ix) Training of field officers is required, and those personnel should have a certain technical knowledge regarding the field work.

c. Objectives

Proposed Solution

The main objective of the project is to develop a power efficient system that is capable of measuring water quality real-time at an affordable cost which can be used from a remote location and having proper security features.

Specific Objectives

- i) Low power consumption end node with the help of the circuit design.
- ii) Easier Report Generation over space and time.
- iii) Higher security through encryption of data and access levels to web server through
via the front-end design
- iv) Update database at the central server frequently at a predefined interval.
- v) Cost effective product through the design by using components that are not too
much expensive.

Chapter 2:

a. Description of design components and the Technical & Theoretical background

2.1) Waterproof Temperature Sensor

As the temperature sensor, waterproof temperature sensor DS18B20 is planned to be used. With the difficulties of waterproofing LM-35 temperature sensor and with the intention to take more accurate measurements this sensor is far more useful.

This sealed digital temperature probe lets you precisely measure temperatures in wet environments with a simple 1-Wire interface. The DS18B20 provides 9 to 12-bit (configurable) temperature readings over a 1-Wire interface, so that only one wire (and ground) needs to be connected from a central microprocessor.

Features

- 3.0-5.5V input voltage
- Waterproof
- -55°C to +125°C temperature range
- $\pm 0.5^\circ\text{C}$ accuracy from -10°C to +85°C
- 1 Wire interface
- Probe is 7mm in diameter and roughly 26mm long. Overall length (including wire) is 6 feet.

But for this project it can be assumed that the temperature of water won't go below as typically below zero degrees Celsius is ice, not water. Therefore, features of this sensor is good to have.

The following is a brief description of the device found in the data sheet of the waterproof sensor and the link.

DESCRIPTION

The DS18B20 Digital Thermometer provides 9 to 12-bit (configurable) temperature readings which indicate the temperature of the device.

Information is sent to/from the DS18B20 over a 1-Wire interface, so that only one wire (and ground) needs to be connected from a central microprocessor to a DS18B20. Power for reading, writing, and performing temperature conversions can be derived from the data line itself with no need for an external power source.

Because each DS18B20 contains a unique silicon serial number, multiple DS18B20s can exist on the same 1-Wire bus. This allows for placing temperature sensors in many different places. Applications where this feature is useful include HVAC environmental controls, sensing temperatures inside buildings, equipment or machinery, and process monitoring and control.

URL of the datasheet: - <https://cdn.sparkfun.com/datasheets/Sensors/Temp/DS18B20.pdf>



Figure 1: Temperature Sensor - Waterproof (DS18B20)

PIN ASSIGNMENT

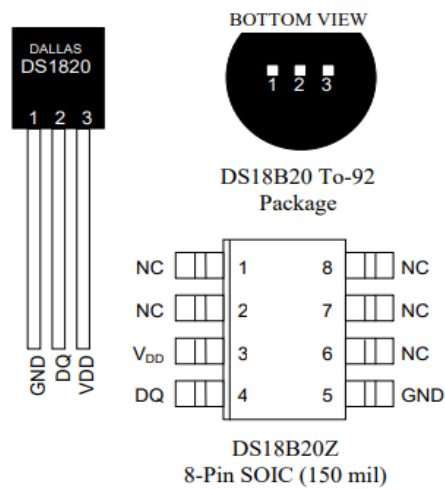


Figure 2: Pin Assignment of the sensor

2.2) GSM Module

GSM module is used to transfer data from an end node to the central server via GPRS. The model we are hoping to use is SIM808 GSM module. SIM808 module is a GSM and GPS two-in-one function module. It is based on the latest GSM/GPS module SIM808 from SIMCOM, supports GSM/GPRS Quad-Band network and combines GPS technology for satellite navigation. It features ultra-low power consumption in sleep mode and integrated with charging circuit for Li-Ion batteries, that make it get a super long standby time and convenient for our project and it can even be used with rechargeable Li-Ion battery. The module is controlled by AT command via UART and supports 3.3V and 5V logical level. The following are the key features of this GSM module

Features

- Supports multiple frequencies (Quad-band 850/900/1800/1900MHz)
- GPRS multi-slot class12 connectivity: max. 85.6kbps(down-load/up-load)
- GPRS mobile station class B
- Controlled by AT Command (3GPP TS 27.007, 27.005 and SIMCOM enhanced AT Commands)
- Supports charging control for Li-Ion battery
- Supports Real Time Clock
- Supply voltage range 3.4V ~ 4.4V
- Integrated GPS/CNSS and supports A-GPS
- Supports 3.0V to 5.0V logic level
- Low power consumption, 1mA in sleep mode
- Supports GPS NMEA protocol
- Standard SIM Card
- Operating Temperature range -40°C ~ 90°C



Figure 3: SIM808 GSM module

2.3) ATmega MCU

ATmega32 will be used as the embedded platform for this project. ATmega32 is an 8-bit high performance microcontroller of Atmel's Mega AVR family. ATmega32 is based on enhanced RISC (Reduced Instruction Set Computing) architecture with 131 powerful instructions. Most of the instructions execute in one machine cycle. ATmega32 can work on a maximum frequency of 16MHz. ATmega is easier in setting up in a shorter time. Since it contains **in-built internal pull up resistors** to avoid floating of pins, an extra circuitry is avoided. Further, it consists of a variety of on-chip peripherals such as **3 timers** (two 8-bit and one 16-bit timers), 8 channel 10 bit **ADC**, **PWM** mode, **I²C** bus, **USART**, **SPI serial interface**, **sleep modes** (watchdog timers) and many more. It consists of a reasonable size of RAM and ROM which help to process data and store codes conveniently. The following are the key features of the ATmega32 MCU.

Key Features:

- 32 x 8 general working purpose registers.
- 32K bytes of in system self-programmable flash program memory
- 2K bytes of internal SRAM
- 1024 bytes EEPROM
- Available in 40 pin DIP, 44 lead QTFP, 44-pad QFN/MLF
- 32 programmable I/O lines
- 8 Channel, 10-bit ADC
- Two 8-bit timers/counters with separate pre-scalers and compare modes
- One 16-bit timer/counter with separate pre-scalers, compare mode and capture mode.
- 4 PWM channels
- In system programming by on-chip boot program
- Programmable watch dog timer with separate on-chip oscillator.
- Programmable serial USART
- Master/slave SPI serial interface



(PCINT14/RESET) PC6	1	28	PC5 (ADC5/SCL/PCINT13)
(PCINT16/RXD) PD0	2	27	PC4 (ADC4/SDA/PCINT12)
(PCINT17/TXD) PD1	3	26	PC3 (ADC3/PCINT11)
(PCINT18/INT0) PD2	4	25	PC2 (ADC2/PCINT10)
(PCINT19/OC2B/INT1) PD3	5	24	PC1 (ADC1/PCINT9)
(PCINT20/XCK/T0) PD4	6	23	PC0 (ADC0/PCINT8)
VCC	7	22	GND
GND	8	21	AREF
(PCINT6/XTAL1/TOSC1) PB6	9	20	AVCC
(PCINT7/XTAL2/TOSC2) PB7	10	19	PB5 (SCK/PCINT5)
(PCINT21/OC0B/T1) PD5	11	18	PB4 (MISO/PCINT4)
(PCINT22/OC0A/AIN0) PD6	12	17	PB3 (MOSI/OC2A/PCINT3)
(PCINT23/AIN1) PD7	13	16	PB2 (SS/OC1B/PCINT2)
(PCINT0/CLKO/ICP1) PB0	14	15	PB1 (OC1A/PCINT1)

Figure 4: ATmega 32 IC (left) and ATmega32 pin configuration (right)

2.4) pH Probe

A pH Electrode can be compared to a battery in that an electrical voltage is generated between two points that is a function of water chemistry. In the case of a pH electrode the voltage potential is a function of the free acidity or free alkalinity of the solution in which it is immersed.

The pH element is a thin glass membrane that is permeable by H^+ ions. The electrode is filled with a neutral solution, which by definition contains an equal number of H^+ and OH^- ions. When the probe is immersed in an H^+ rich environment (acidic) the glass membrane is permeated by the H^+ ions which exert a positive potential on the sensing electrode. This potential difference is measured by a pH meter and converted to a pH output.

Likewise, when the probe is immersed in an alkaline environment there exists within the probe a higher H^+ concentration than outside of the probe. This causes H^+ ions within the probe to migrate outside of the probe which leaves an excess of OH^- ions within the probe. A negative potential is thus sensed by the pH meter.

The following are the features of the pH probe we are expecting to use.

Features

- 100% Brand new and high quality
- BNC connector, suitable for most pH meter and controller with BNC connector.
- Suitable for wide range of application: Aquariums, Hydroponics, Laboratory etc.
- Measurement range: 0.00~14.00 PH
- Zero-point: 7 +- 0.5PH
- Alkali Error: 0.2PH
- Theoretical Percentage Slope: 98.5%
- Internal Resistance: 250M
- Response Time: 1min
- Operating Temperature: 0-60°C
- Terminal Blocks: BNC plug
- Cable length: Approx. 70cm



Figure 5: pH probe

Chapter 3:

a. Implementation of the project

The following chapter describes how we are going to implement the project.

i. Embedded Systems Design

1) What will you be measuring and/or controlling?

Temperature – It will be measured using a waterproof temperature sensor

pH – It will be measured using the pH probe

Conductivity – It water will be measured with the help of two electrodes

Turbidity – It will be measured by sensing the amount of light passing through water

2) What embedded systems platform(s) will you be using, and why?

ATmega32 – (probably an Arduino – Arduino also contains this IC) the reason for using this is because it comes with already in-built peripherals which can be really useful in this project. They are;

ADC – To convert analog inputs taken from sensors in to digital signals

32 General Purpose Working Registers – Can manipulate a lot of I/O s.

Built in pull up resistors – Extra circuits are not required reducing power consumption

3 timers – Can be used to build events which trigger when certain conditions are met

1KB EEPROM, 2KB SRAM, 32KB self-programmable flash memory – Higher amount of code and data can be stored in the memory

3) How does the system connect to the network?

SIM808 GSM module – This GSM module is used to communicate with the server using GPRS via Internet

4) What peripheral components will you be using, and how do they work?

DS18B20 waterproof temperature sensor –

Why?

Usual temperature sensors are RTDs (Resistance Temperature Detectors), Thermistors, Thermocouples, and semi-conductor IC sensors.

The following table shows the comparison between these sensors.

Criteria	RTD	Thermistor	Thermocouple	IC Sensor
Temperature Range / °C	-250 to 750	-100 to 500	-267 to 2316	-55 to 200
Accuracy	Best	Depends on calibration	Good	Good
Linearity	Good	Worst	Good	Best
Sensitivity	Less	Best	Worst	Good
Circuitry	Complex	Depends on accuracy/power requirements	Complex	Simplest
Power Consumption	Higher when taking measurements		Low to high	Low
Relative system cost	\$\$-\$\$\$	\$-\$\$\$	\$\$-\$\$\$	\$

Table 1: Comparison between the temperature sensors

From the comparison given in the above table, it is evident that semi-conductor ICs are optimum for low power consuming, low cost projects with a reasonable accuracy, linearity, temperature range and sensitivity.

5) How do you interface those components?

Temperature sensor, turbidity sensor, pH probe, conductivity electrodes will be connected to the end node via microcontroller unit. Then the entire end node will be connected to the central server.

6) What are the limitations of those components?

- Temperature sensor– Inability to measure negative temperature under the simple circuit design and will require a much more complex circuit.
- pH probe – Not responding quick changes in the pH of water.
Will not work properly above 70 °C
- ATmega32 – Memory limitations for storing data and the program together.

7) What workarounds can you come up with in order to deal with those limitations?

- It is actually not required to worry about negative temperatures as the temperature of water is typically above zero most of the time as below zero is basically ice

- Have to restrict the time interval of recording data more than the response time of the pH probe.
- Typically, we won't find water resources having temperatures closer to 100°C unless it is a hot water well as found in Trincomalee. Excluding such extreme cases, most of the time temperature of water will lie below the operation temperature of the pH probe.
- Has to limit the amount of code stored in the memory of the microcontroller and regarding the data stored in the memory of the microcontroller they have to be cleared immediately after they are successfully sent to the web server, to gain memory space.

ii. Web and Network Application Design

1) What network protocols and middleware will you use, why, and how do they work?

MQTT (Message Queuing Telemetry Transport) is a messaging protocol that works on top of TCP/IP. It is designed for connections with remote locations where a "small code footprint" is required or the network bandwidth is limited. It is mostly suitable for sensing applications and mobile applications. Moreover, it supports low power usage, minimised data packets, and efficient distribution of packets among several clients.

GTP – GPRS Tunnelling protocols are a set of IP based protocols that are used to send GPRS packets via GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System) and LTE (Long Term Evolution) networks. This is used when packets are sent to the telecommunication tower from the GSM modules.

In addition, typical TCP/IP protocols are used as the rest of the communication, since after the telecommunication towers the remaining part of the packet transfer is done via the Internet.

2) What back-end and front-end technologies will you use, and how do they work?

Front end – HTML, CSS, Bootstrap, Java script, AJAX, Vue js

Back end – Node.js, MongoDB, Mongoose, PHP

- HTML, CSS will be used to generate static context of the front end.
- Bootstrap will be used to make the front end responsive, so that it supports various resolutions and various views on different devices such as laptops, desktop PCs, mobile devices etc.
- AJAX and java script will be used to generate the dynamic contents of the pages.
- MongoDB is free and open source. Uses JSON queries instead of traditional SQL queries. Higher no of JSON queries available and rich data model.
- Node.js is a JavaScript runtime built on Chrome's V8 JavaScript engine. Node.js uses an event-driven, non-blocking I/O model that makes it lightweight and efficient.

- Mongoose provides a straight-forward, schema-based solution to model your application data. It includes built-in type casting, validation, query building, business logic hooks and more, out of the box.

3) What APIs will you use when connecting different parts of the system?

REST API - A RESTful API is an application program interface (API) that uses HTTP requests to GET, PUT, POST and DELETE data. CRUD (Create, Read, Update and Delete) is done via these REST APIs.

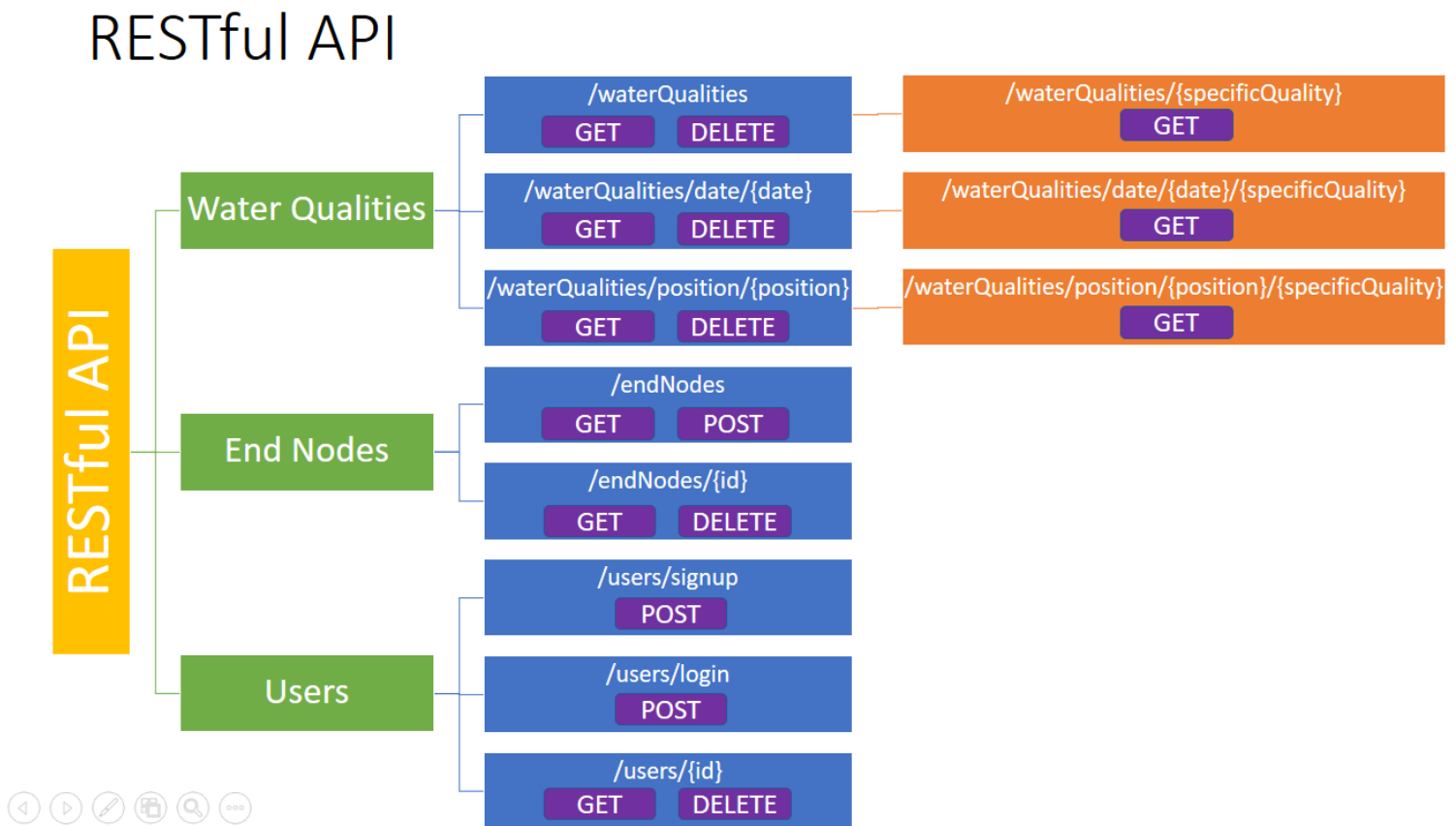


Figure 6: RESTful API

iii. Computer and Network Security

1) Are there any sensitive data in your system that need to be secured?

- The recorded data sent to the server from each node has to be secured. For instance, one might be able to change/modify the actual data sent to the server by intercepting.
- The personal details of the members logging in to the system through the frontend UI.
- Login requests to the central server.

2) How might an unauthorized third party obtain data from your system?

- A third party may intercept the actual data sent to the server while packets are transmitted via GPRS or Internet and then modify the data and send the modified data to the server.
- Personal details of the members logging in to the system can be retrieved by hacking the server database.
- Sending replay attacks by listening to logging in of members to the server.

3) How might an unauthorized third party manipulate your system?

- A third party may send modified data to the server hiding the real data.
- A third party may take over the system by hacking the central server.

4) What security features are you able to implement, and how?

- Modern encryption techniques can be used when sending data from an end node to the server.
- Validation of access to the central server.
- Maintaining initial password protected login and having access levels to access the system.
- Add SSL in Transport layer to ensure the safety of packet transfer via Internet.

User Authentication

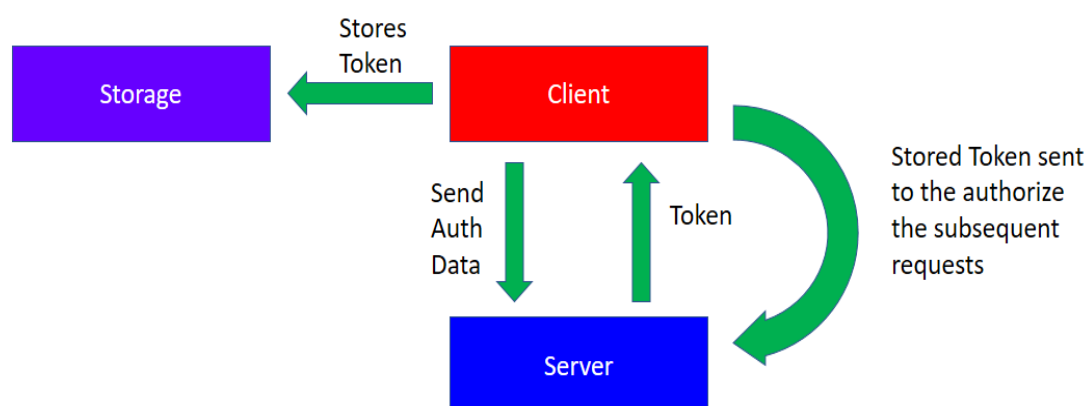


Figure 7: User authentication diagram

b. Block diagrams & Circuit diagrams

b.1. pH Sensor

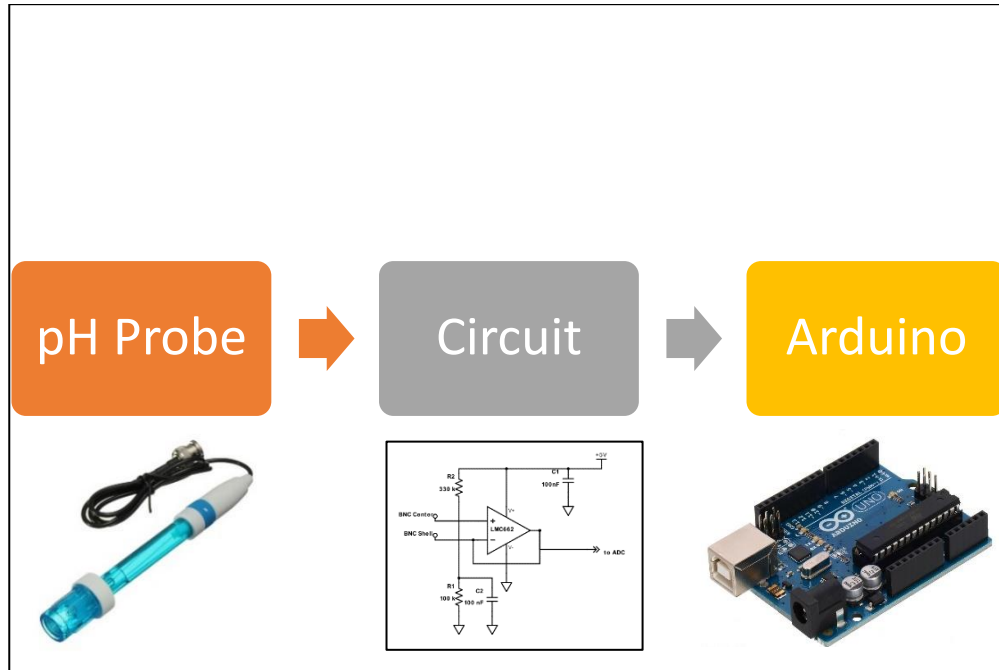


Figure 8: Block Diagram of pH sensor

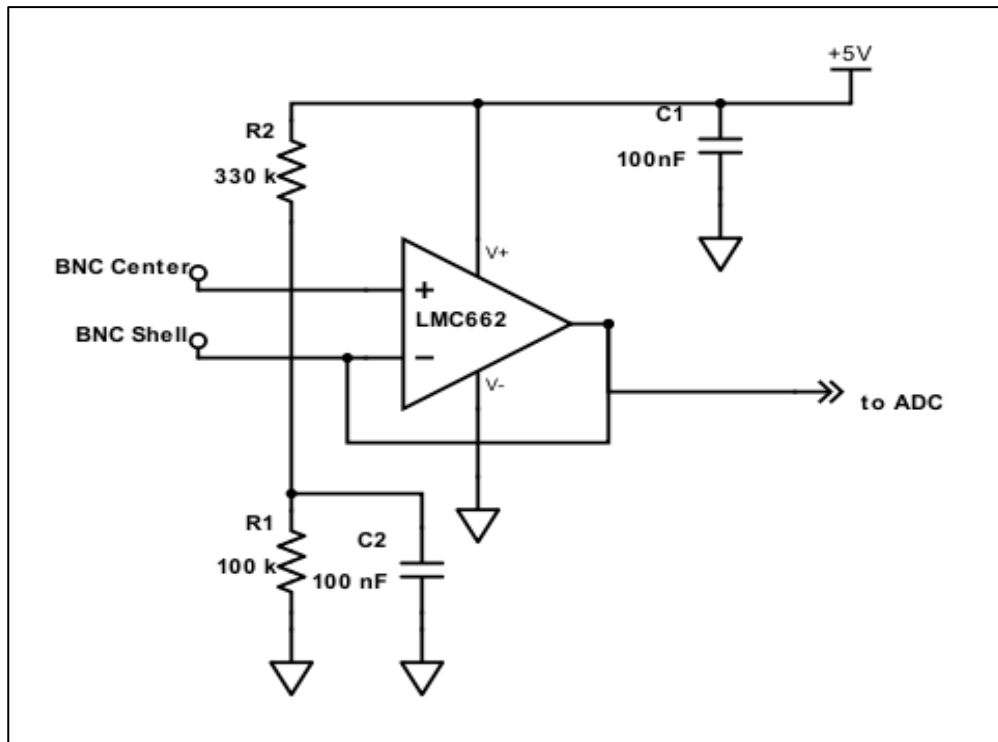


Figure 9: Circuit which is using to connecting the pH probe

pH probe plug is a BNC. Therefore to connect the pH probe to the Arduino there should be some intermediate connection. This is the circuit that using to connect the pH probe to the micro controller.

b.2. Turbidity Sensor

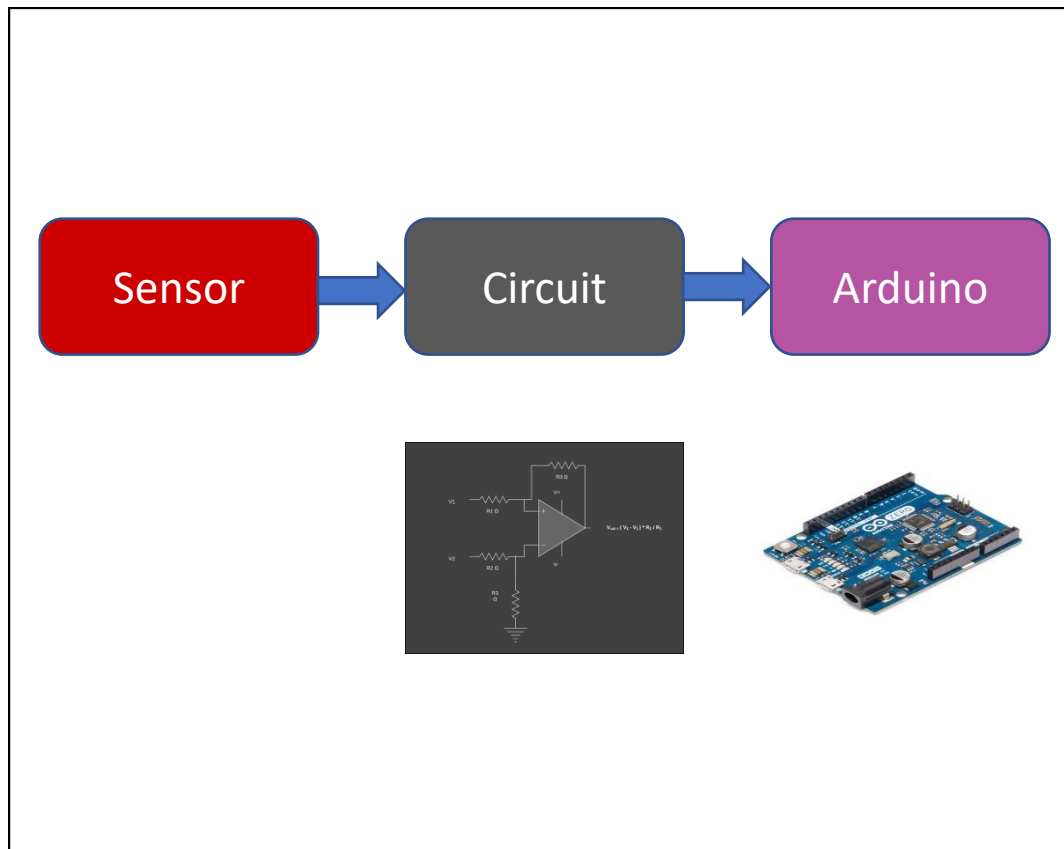


Figure 10: Block diagram of turbidity sensor

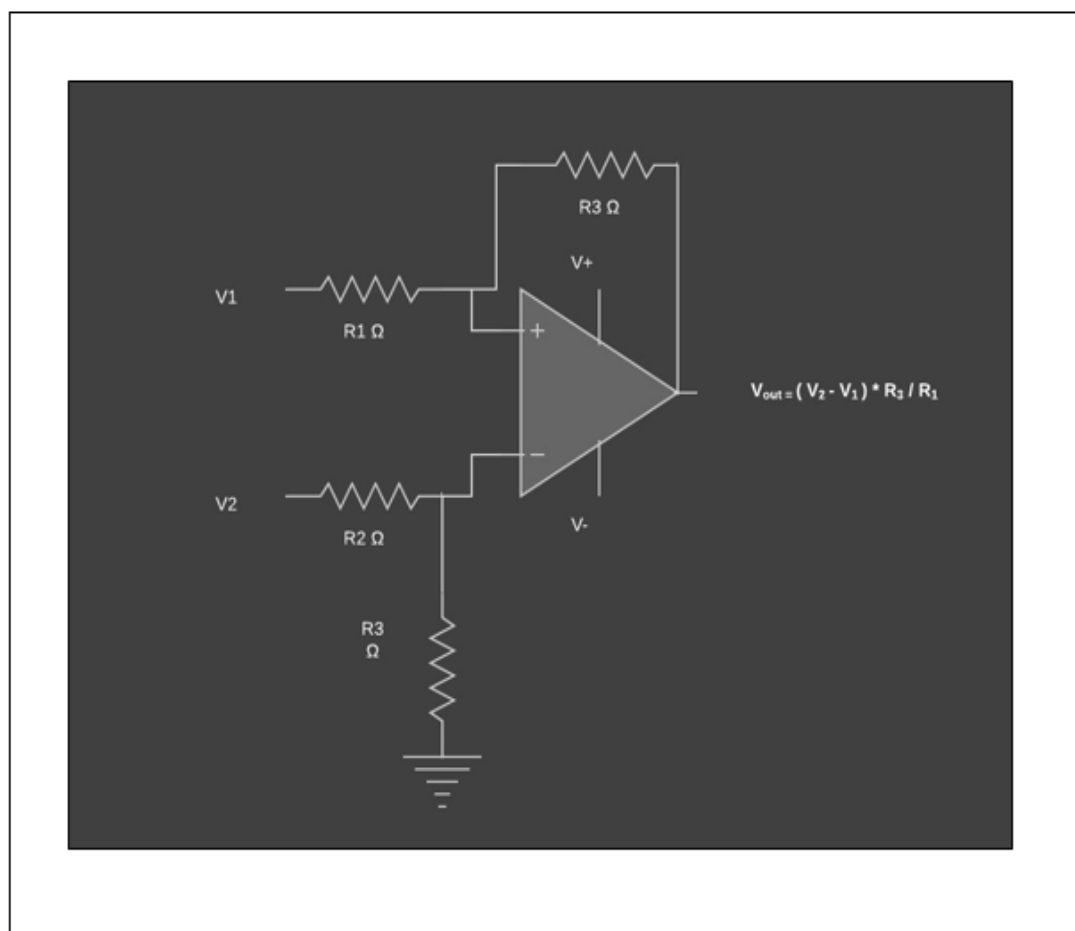


Figure 11: Circuit diagram of the turbidity sensor

b.3. Conductivity Sensor

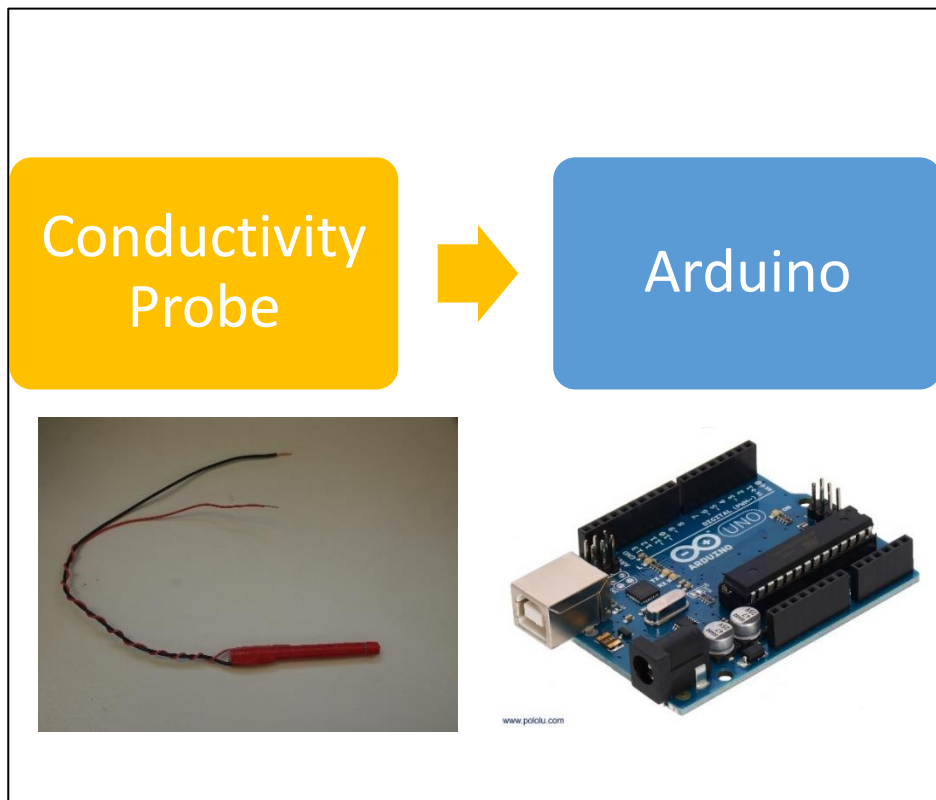


Figure 12: Block diagram of the conductivity sensor

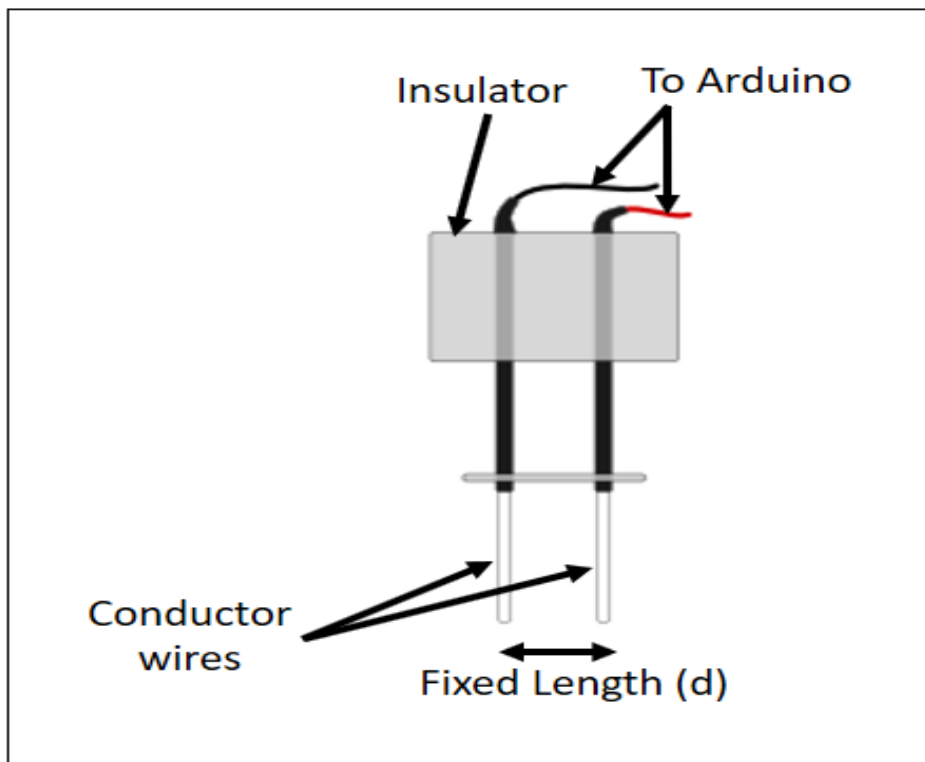


Figure 13: Circuit diagram of the conductivity sensor

b.4. Temperature Sensor

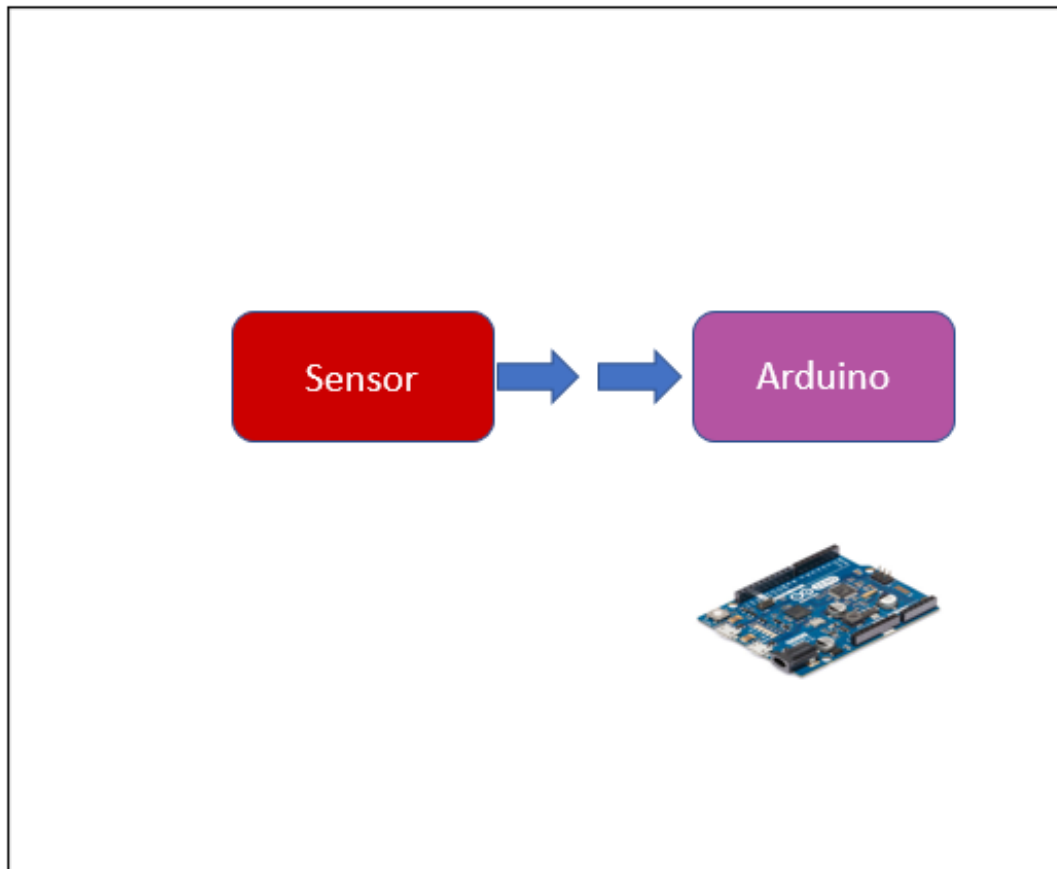


Figure 14: Block diagram of the Temperature sensor

b. Overall design of the system

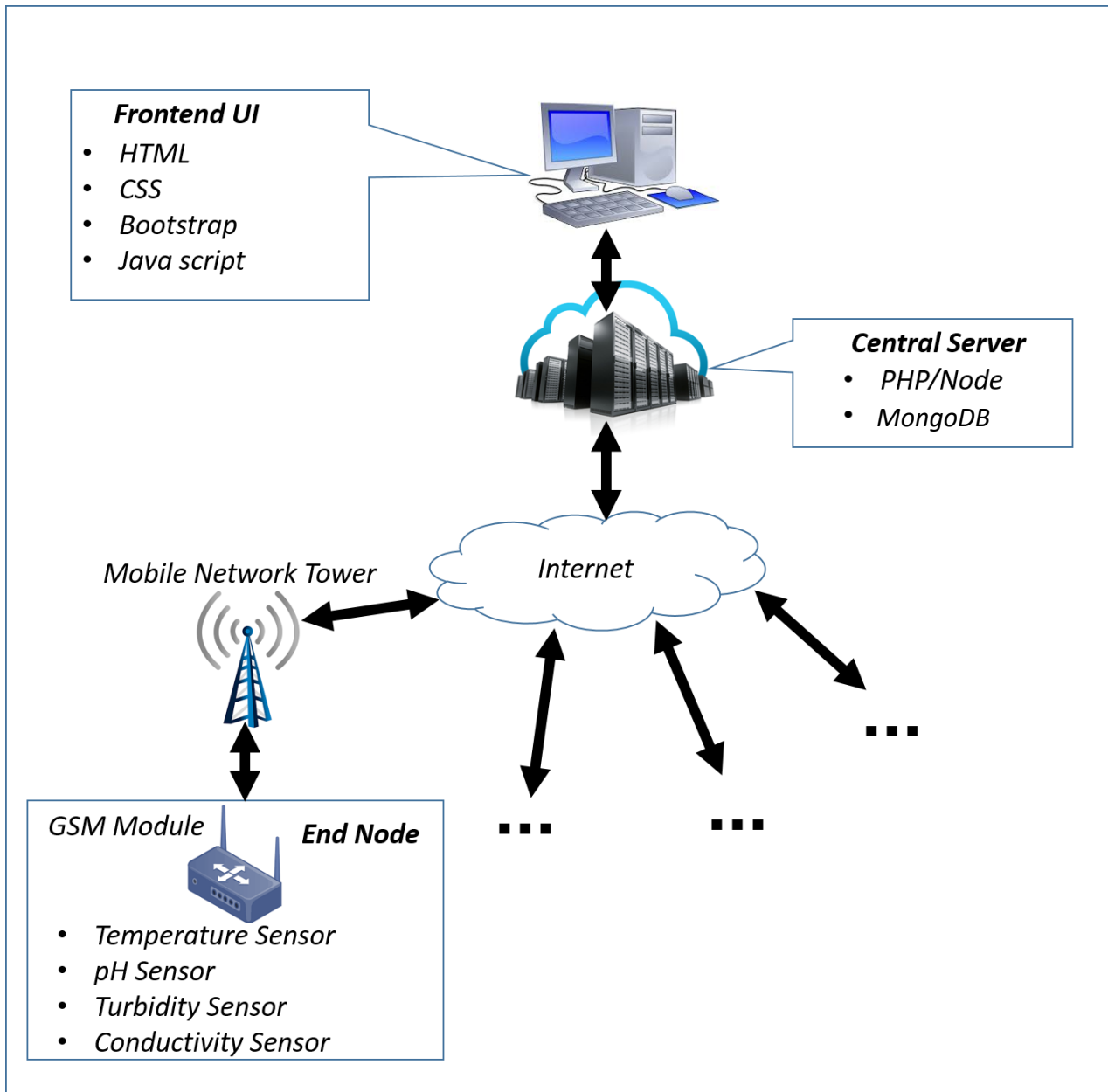


Figure 15: Overall design of the RTWQ system

Server Side Overview

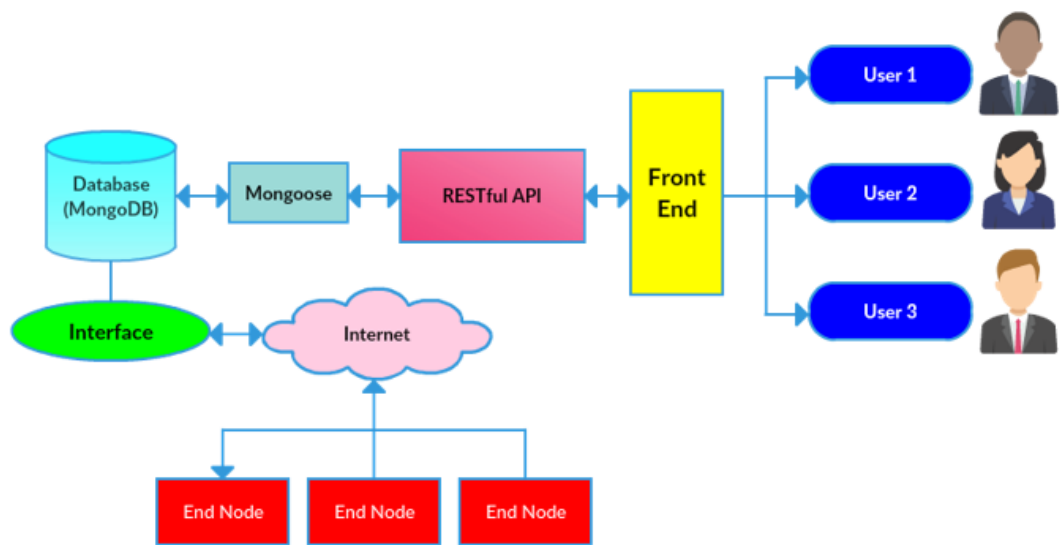


Figure 16: Server-side overview

Database

Temperature	Turbidity	pH	Conductivity	Position	Date
-------------	-----------	----	--------------	----------	------

Table: Readings Table

First Name	Last Name	Email	ID	Password	Contact No
------------	-----------	-------	----	----------	------------

Table: Users Table

ID	Position
----	----------

Figure 17: Database overview

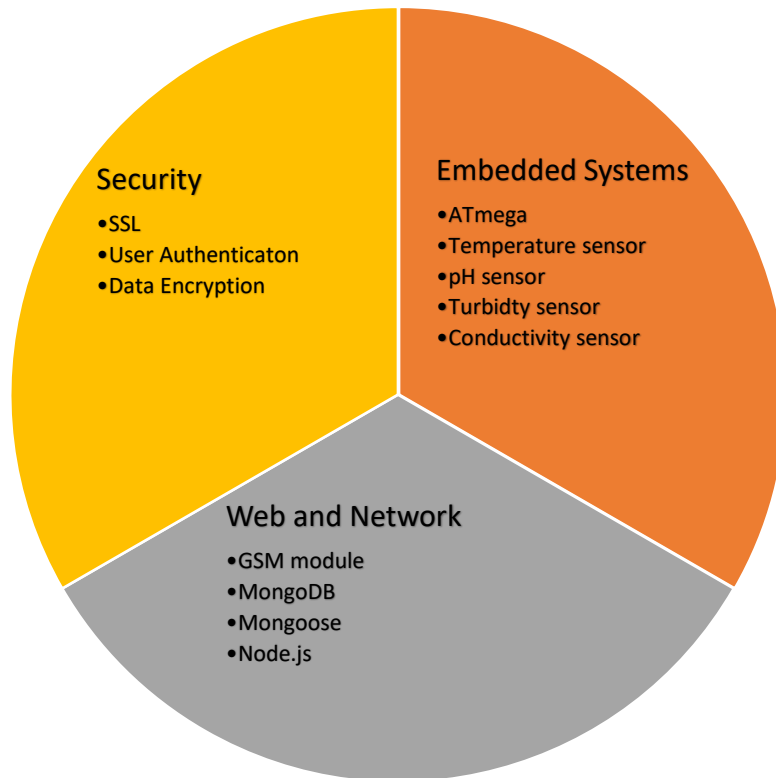


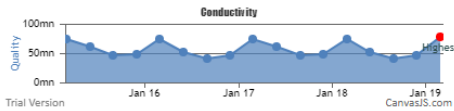
Figure 18: Aspects of the system relevant to the courses

d.Designed GUI



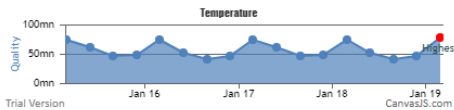
Conductivity

01-02-2018	Peradeniya	555.0
------------	------------	-------



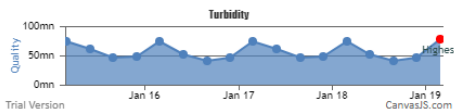
Temperature

01-02-2018	Peradeniya	555.0
------------	------------	-------



Turbidity

01-02-2018	Peradeniya	555.0
------------	------------	-------



pH Value

01-02-2018	Peradeniya	555.0
------------	------------	-------

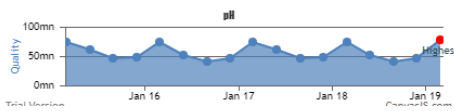


Figure 19: Designed GUI

Chapter 4:

a. Project Information
Expenses

Description	Qty.	Unit Price/Rs.	Amount	
Sensors				
1) Waterproof Temperature sensor	1	1600.00	1600.00	
2) LDR	2	10.00	20.00	
3) LED	5	2.00	10.00	
4) pH sensor(pH probe/pH pen meter + circuit)	1	1400.00	1400.00	
GSM module	1	3750.00	3750.00	
Additional (Unforeseen)			2000.00	
Sub Total				<u>8780.00</u>

Table 2: Expenses

Estimated Timeline

Description	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
1) Introduction to project														
2) Project proposal														
3) Project proposal review and feasibility study														
4) Project Design														
5) Project Development commencement														
6) Project Development Review(Mid evaluation)														
7) Project Development														
8) Final Project Development Review														
9) Project Development														
10) Completion and Demonstration														



Figure 19: Timeline of the project

References

- 1) Waterproof temperature Sensor DS18B20 (1 Wire Digital Thermometer) Data sheet
<https://cdn.sparkfun.com/datasheets/Sensors/Temp/DS18B20.pdf1>
- 2) https://www.itead.cc/wiki/SIM808_GSM/GPRS/GPS_Module
- 3) SIM808 GSM module data sheet, adafruit industries
https://cdn-shop.adafruit.com/datasheets/SIM808_Hardware+Design_V1.00.pdf
- 4) ATmega32 datasheet,
<http://datasheet.octopart.com/ATMEGA32-16AU-Atmel-datasheet-13403916.pdf>
- 5) <http://mongoosejs.com/>
- 6) <https://www.mongodb.com/what-is-mongodb>
- 7) <http://searchmicroservices.techtarget.com/definition/RESTful-API>

- 8) Li Zhenan, Wang Kai, Liu Bo, "Sensor-Network based Intelligent Water Quality Monitoring and Control", International Journal of Advanced Research in Computer Engineering Technology, Volume 2, Issue 4, April 2013
- 9) Steven Silva, Hoang N ghia Nguyen, Valentina Tiporlini and Kamal Alameh, "Web Based Water Quality Monitoring with Sensor Network: Employing ZigBee and WiMax Technologies", IEEE Conference on Local Computer Networks, IEEE 2011.