Remote Water Pump Monitoring System

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Team #18

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1 Introduction

1.1 Problem & Solution

In remote regions of Indonesia, many rural villages are located very far from clean water sources. Out of 264 million people in Indonesia, 28 million lack safe water and 71 million lack access to improved sanitation systems [1]. Each day, villagers of a specific village named Nibaaf take three-hour trips to get clean water. In order to fight this problem, a non-profit organization called *Solar Chapter*, affiliated by one of our team members, has been building water pump systems that deliver clean water to villages in vicinity. However, they lacked a means to monitor and maintain the water pumps. Any sort of downtime would have adverse effects on the villagers' well-being, therefore constant maintenance is crucial. However, due to the remoteness of the location, having regular inspection is troublesome. Having the local villagers maintaining the pump would not be suitable either, since they have limited knowledge on how to handle the pumps.

Our team is proposing a solution in the form of a remote monitoring system for these water pumps. The system takes the pump's basic operating data such as water flow and up-time measurement to monitor the pump's behavioral trend. The device would also regularly measure safety parameters including vibration and temperature of the water pump. The system would send an alert when it receives undesired values so the operator can send in maintenance. Performing these precautions can extend the longevity of these water pumps and prevent them from breaking down unexpectedly. This would also prevent any downtime and greatly improve the sustainability of the water system. The values measured from the sensors would then be transmitted remotely through a cellular network to a cloud-based database system, which then will be visualized through a website or an app. This will allow high accessibility for the operator. This system minimizes the need of physical onsite personnel presence to only emergency maintenance and longer-term physical inspections, while still keeping the water system dependable.

1.2 Background

The Eastern region of Nusa Tenggara, Indonesia, is still primarily underdeveloped. One specific village by the name of Nibaaf is in an especially tough situation: around 800 villagers reside there, yet the nearest access to the clean water source is located more than one hour away by foot [2]. This situation forces villagers, including children, to spend a big portion of their daily time on a trip for obtaining clean water, instead of spending it on academics or village development. In the long run, it becomes harder for an already undeveloped village to move forward and improve the quality of their lives. With this in mind, it is crucial to relieve some of the villagers' burden by securing them constant access to clean water. Through the monitoring system we proposed, any signs of error can be dealt with swiftly, easing the villagers from any concerns of water shortage.

1.3 Visual Aid & Physical Design

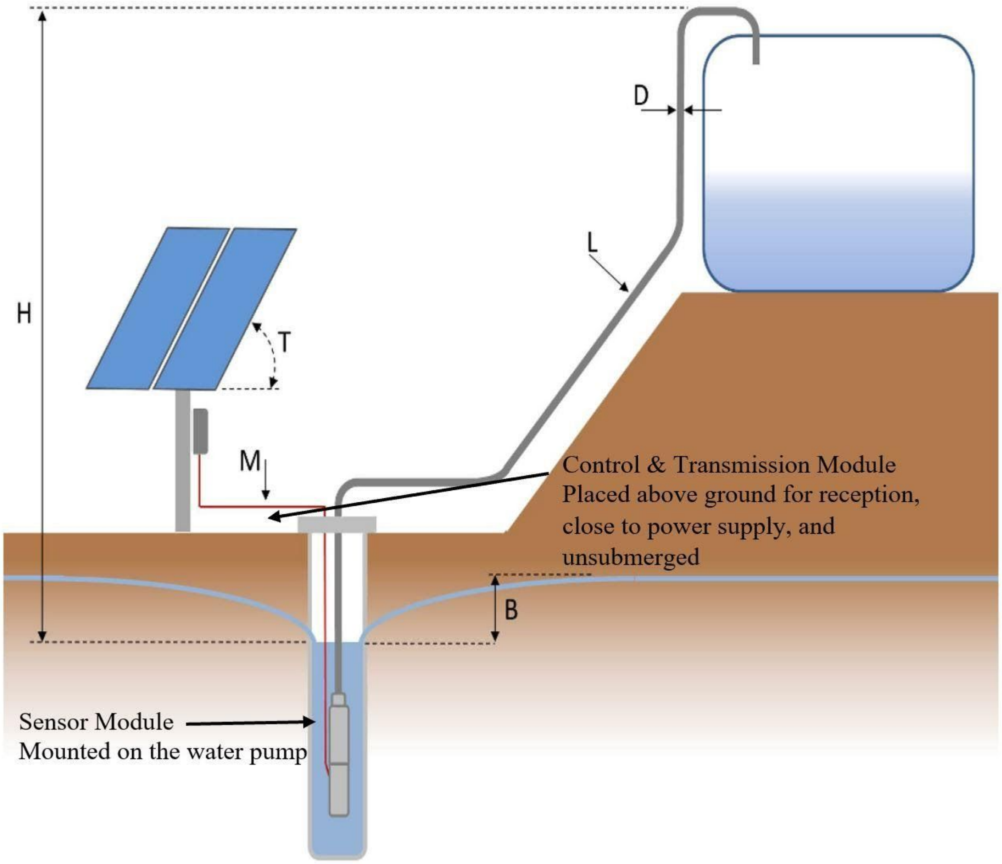

Figure 1. Placement of physical design on water pump system [3]

For the prototype we plan to build, we are not going to concern ourselves with a waterproof design, as we believe that specification is rather trivial to implement. The real-life application also requires a rather long wiring between sensor module and control module, another aspect we are going to ignore in the prototype. The monitoring system we are designing serves as an add-on to an already existing water supply system that spans from the water source to the villages. The pump itself is solar-powered, hence the idea of implementing a self-sustaining monitoring system in the real-life application. Clean water is extracted from the source to be pumped to a reservoir, where further distribution happens to the villages nearby. Thus, several of these monitoring systems need to be deployed on the various pump sites.

1.4 High-Level Requirements

- Microcontroller must process the output signal of each sensor of varying form and translate them to a quantitative value with precisions of 0.1LPM for flow, 0.1A for current, and visible distinction for overheating and excessive vibration cases..
- Collected data must be transferred successfully without corruption through cellular network connection to the cloud based database in an interval of 15 minutes.
- Once the cloud database is updated with new input from the microcontroller, the updated information should also be included in the spreadsheets on the database server. These updates should be reflected on our website in real time.

2 Design

2.1 Block Diagram

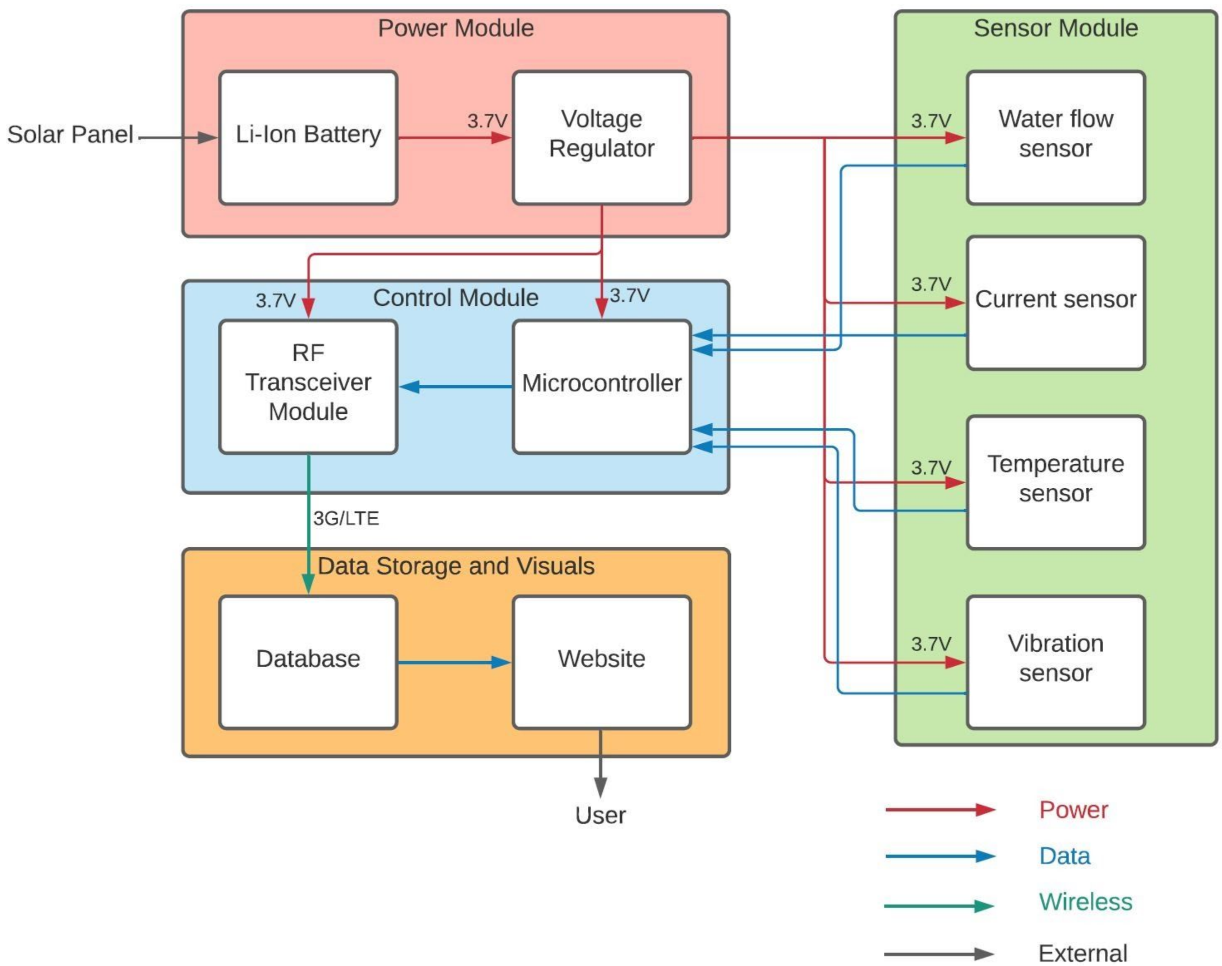

Figure 2. Block diagram of the remote monitoring system

The sensor module as shown in Figure 2 acts as the input to the system and outputs various forms of signals depending on the sensor. The microcontroller will process these varying signal forms and translate them into readable values corresponding to the parameter measured. These data are stored temporarily in the microcontroller memory and then packed into a JSON format for the RF transceiver module to transmit to a database. Once the database receives the data, the website should update and change to reflect the newly received information.

2.2 Block Descriptions

2.2.1 Power Module

The power module is responsible for powering the whole system. In the real application, ideally a Li-Ion rechargeable battery should be used to utilize power from the solar panel, but in our testing stage there are no solar panels so a 3.7V DC Li-Ion battery will be used. The battery will be interfaced with a voltage regulator before providing power to the components, to ensure all the components receive a steady supply voltage of 3.7V DC which is in compliance with their device specifications.

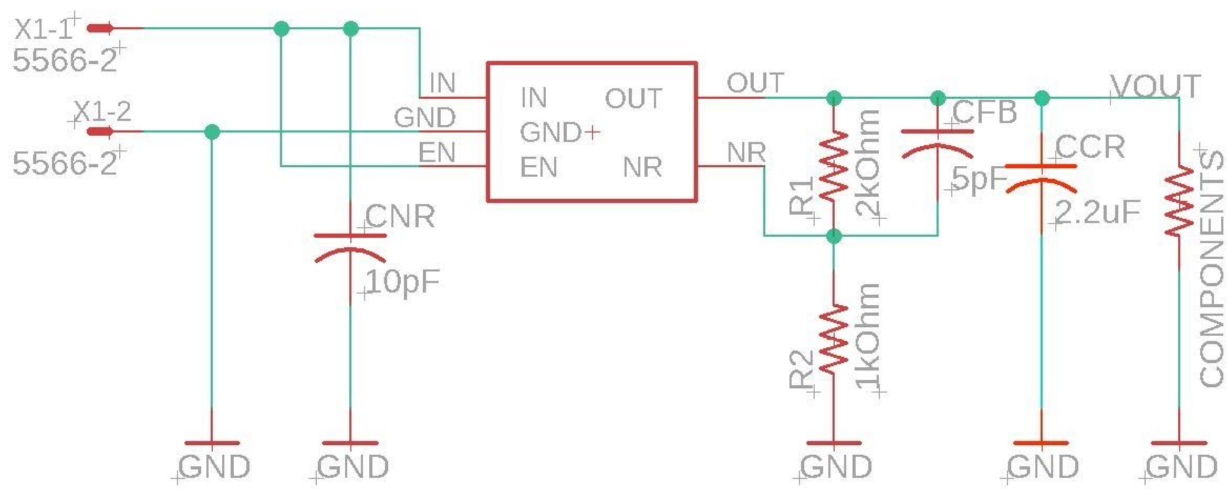

Figure 3. Circuit schematic for the power module

Figure 3 above shows the circuit schematic for the battery-voltage regulator interface. Signals X1-1 and X1-2 will come from the battery, the power provider of the system. The configuration in Figure 3 shows an adjustable voltage application of the voltage regulator, with the output voltage formulated as:

$$V_{out} = \frac{(R1+R2)}{R2} * 1.193 = 3 * 1.193 = 3.579V$$

$$error\% = \frac{3.7-3.579}{3.7} * 100\% = 3.27\%$$

The actual V_{out} deviates by 3.27% from the expected V_{out} of 3.7V, which is still within the tolerance value we are using for this project (<5%) and still falls within the working voltage range for all our components. Capacitor values are chosen based on the manufacturer's experimental data [4].

Lithium Ion Battery

The Li-Ion battery acts as the power source for the monitoring system. We will be using a battery rated at 3.7V, as all of our components can run with a 3.7V DC power supply.

Requirements	Verification
Battery can run from fully charged for 3 hours without the output voltage falling below 3.4V.	1. Fully charge battery and check charge limited voltage of 4.2V±5%. 2. Connect battery with 200Ω resistor as load, and probe the load with oscilloscope. 3. Let run for 3 hours, noting voltage value periodically. 4. Confirm that output voltage is still >3.4V.

Table 1. RV table for battery

Voltage Regulator

The voltage regulator acts as a medium between the power source and the components, to ensure that the components receive a stable voltage supply that falls within the acceptable range.

Requirements	Verification
Output voltage is within the range of 3.7V±5% and draws 400mA±5% of current.	1. Connect the output to a 9.25Ω resistor load. 2. Probe the oscilloscope across the load and ammeter in series between the load and the ground. 3. Power on the regulator with 3.7V supply voltage. 4. Confirm that voltage is within 3.7V±5% and current is within 400mA±5%.

Table 2. RV table for voltage regulator

2.2.2 Sensor Module

The sensor module contains an array of sensors to act as inputs to the monitoring system. Four parameters classified into operational and safety are measured and then the output signal will be processed by the control module.

Water Flow Sensor

A Seeed Technology 1-25LPM water flow sensor will be used for the prototype, because choosing a sensor that matches the operational data [3] will require one that can measure up to 100LPM, which would be unnecessarily costly and hard to test for the prototype. The sensor operates based on the Hall effect, where a rotor rotating due to water flow magnetically induces a voltage, outputting a square signal of varying frequency based on the flow rate [5].

Despite the datasheet stating that the working voltage is 5~15V DC [6], experimentation was conducted using a different model sensor with the same working voltage values. The sensor was provided with a 3.7V DC power supply, and pouring water into the sensor still outputs square signals, albeit a lower amplitude (matches power supply). This result means the flow sensor can use the same power source as all the other components, a 3.7V DC supplied by the voltage regulator.

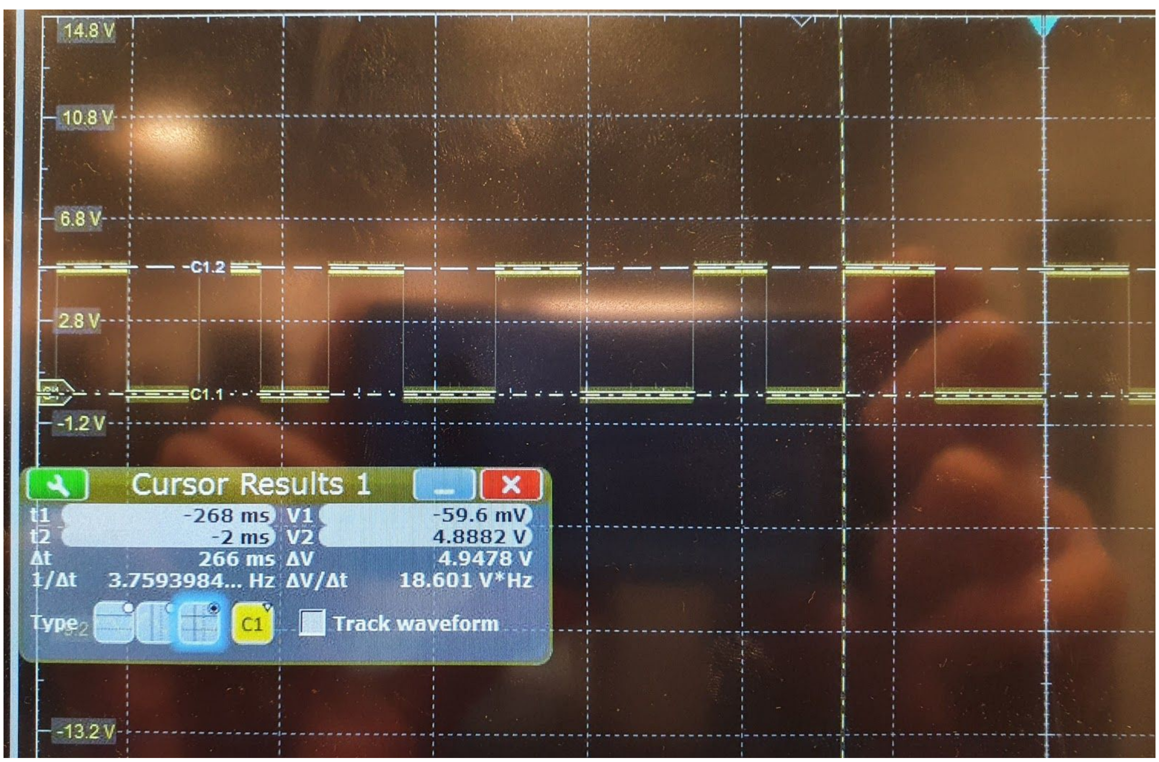

Figure 4. Output of flow sensor operating at 5V DC power supply

Further experimentation was done to test the mathematical model relating the pulse frequency and flow rate in LPM. The sensor used in this experiment has a flow rate ranging from 0.3LPM to 6LPM, and exposing it to water flow resulted in oscilloscope readings as shown in Figure 4. The pulse signal is inconsistent in frequency because it is impossible to give the sensor a steady flow of water with the equipment and environment of the lab, which also complicates in verifying if the model is right. However, a simplification is done by simply checking if the resulting flow rate is within the range described by the datasheet. One full cycle of a pulse signal is taken as sample, and the frequency F is obtained by:

$$T = t_2 - t_1 = 266ms \qquad F = \frac{1}{T} = 3.759Hz$$

Assuming the same model for this sensor as the one we chose for our project, the model relates frequency F with flow rate Q as F=11*Q, so solving for Q yields:

$$Q = \frac{F}{11} = 0.3418LPM$$

And this value falls between the range of acceptable flow rate values, providing stronger evidence of the accuracy of the mathematical model. Absolute proof of the model's viability needs a more elaborate testing environment to minimize the risk of water spill and electrocution, thus for our interest we decided to simply perform basic tests to reinforce our argument.

Requirements	Verification
Functions for supply voltage 3.7V±5% DC.	1. Connect sensor output to oscilloscope. 2. Connect sensor to 3.7V power source. 3. Pour water through the sensor. 4. Confirm that the oscilloscope shows output in the form of square waves.
Flow rate readings fall between the range of 1~25LPM.	1. Connect sensor output to oscilloscope. 2. Connect sensor to 3.7V power source. 3. Pour water through the sensor. 4. Calculate the frequency of the output square waves. 5. Convert to flow rate by Q=F/11 (Q=LPM) and confirm that the value falls between 1~25LPM.

Table 3. RV table for water flow sensor

Ammeter

The ammeter here indicates if the pump is running at any given time, and also gives information about power consumption.

Requirements	Verification
Functions for supply voltage 3.7V±5% DC.	1. Connect sensor output to oscilloscope. 2. Connect sensor to 3.7V power source. 3. Run current through the sensor. 4. Confirm that the oscilloscope shows output in the form of voltage readings.
Current measurement sensitivity is 45mV/A±5%.	1. Connect sensor output to oscilloscope. 2. Connect sensor to 3.7V power source. 3. Run a current sweep from 10A to 15A, increasing by 1A at a time. 4. Confirm that the oscilloscope output voltage shows increment by 45mV/A±5% for each step.
Current measurement is accurate up to a 5% margin.	1. Connect sensor output to oscilloscope. 2. Connect sensor to 3.7V power source. 3. Run a 15A current through the sensor. 4. Confirm that the oscilloscope shows an output voltage of 675mV/A±5%.

Table 4. RV table for ammeter

Temperature Sensor

The temperature sensor serves as a safety precaution to indicate if the pump is overheating.

Requirements	Verification
Functions for supply voltage 3.7V±5% DC.	1. Connect sensor output to mock microcontroller. 2. Connect sensor to 3.7V power source. 3. Probe the air for its temperature. 4. Run a mock code to check if the sensor outputs any values.
The sensor can differentiate between pump normal operating temperature and pump overheating temperature.	1. Connect sensor output to mock microcontroller. 2. Connect sensor to 3.7V power source. 3. Probe room temperature water to

	simulate pump in normal operating temperature. 4. Run a mock code and note the output value. 5. Probe boiling water to simulate pump overheating temperature. 6. Run a mock code and note the output value. 7. Confirm that both readings' values are visibly distinct.

Table 5. RV table for temperature sensor

Vibration Sensor

Vibration sensor acts as a secondary safety precaution to indicate if the pump is shaking excessively, which is likely to cause pump failure if prolonged.

Requirements	Verification
The sensor can differentiate between pump normal operating vibration and pump excessive vibration.	1. Connect sensor output to oscilloscope. 2. Connect sensor to 3.7V power source. 3. Shake the sensor moderately to simulate pump normal operating vibration. 4. Note down the output voltage on the oscilloscope. 5. Shake the sensor harder to simulate pump excessive vibration. 6. Note down the output voltage on the oscilloscope. 7. Confirm that both readings' values are visibly distinct.

Table 6. RV table for vibration sensor

2.2.3 Control Module

The control module manages sensor data processing and data transmission. Data from sensor modules needs to be processed into the format that is suitable for transmission, and the data needs to be transferred through cellular networks.

Microcontroller Subunit

The microcontroller, ATmega328PB, will act as the brain of the system, handling the output signal of sensors and translating them to readable values, then sending them to the cellular network module to be transmitted into the database. This microcontroller can be programmed in C through Atmel Studio.

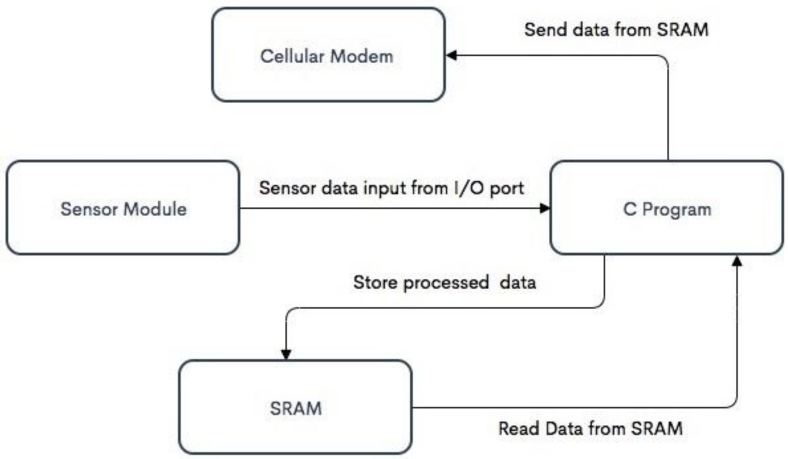

Figure 5. Data flow diagram

Requirements	Verification
The C program on the microcontroller should be able to process data from the sensor module into a format that is suitable for transmitting data. This will be JSON.	1. Run test C program to check if signal/data from I/O pins can be recognized by the software. 2. Write test data within the C program to check if it can process data into the correct format. 3. Test the C program with sensor input to check if the data is processed correctly.
The C program successfully stores processed data into RAM.	Design and run test C program in Atmel Studio to print RAM contents after processed data is stored. Check if it is the intended value or not.
The C program can send correct data to the RF transceiver module for transmission within 1.5 to 2.1 V range.	Design and run test C program in Atmel Studio to output test data. Measure signal from I/O pin to check if data matches. Also check if the voltage of the output signal is between 1.5 and 2.1V which is input voltage specification of cellular networks modem.

Microcontroller flags successful data delivery to RF module with a green LED.	Run C program to send a signal to light up the green LED and confirm that the green LED lights up.

Table 7. RV table for microcontroller

RF Transceiver Module

This module receives data from the microprocessor and sends data to the database through cellular networks. AirPrime HL6528RDx is the cellular networks modem we plan to use.

Requirements	Verification
Module receives data from the microcontroller, flagged by a blue LED.	Connect this module to microcontroller and test data delivery; the blue LED should light up after the green LED does.
The module can send data through cellular networks without corruption.	Input test signal to UART and check if server receives test data.

Table 8. RV table for RF transceiver module

2.2.4 Data Storage and Visuals

This module receives data that is sent from the cellular network module. It also processes and stores the data into a database. The website should display data and warnings of the water pump.

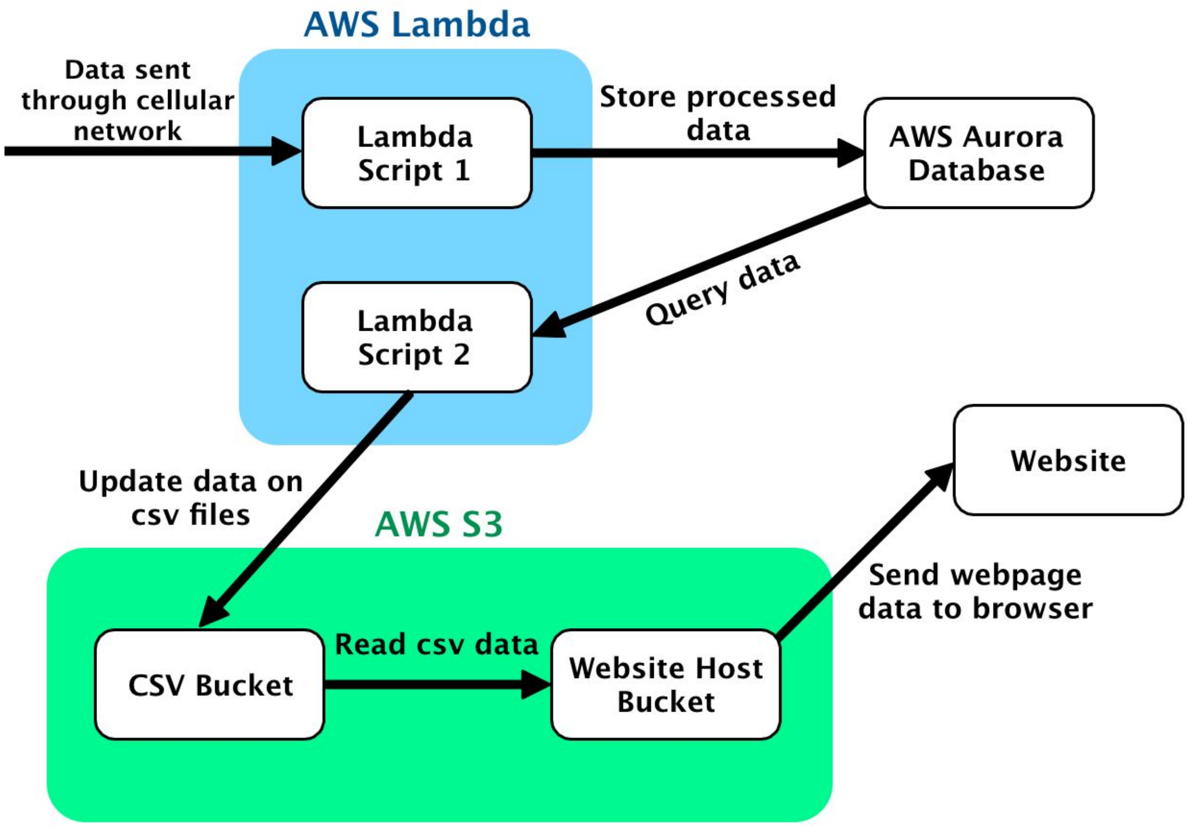

Figure 6. Database and frontend architecture

Database

AWS Lambda will be used for processing data sent from the RF transceiver module, and store data into a database. This will be done using a relational database: Amazon Aurora. Since the website is static, it cannot read data directly from the database. Thus, csv files on AWS S3 bucket needs to be updated whenever the database is updated.

Requirements	Verification
AWS Lambda receives data given that the transmission module successfully sent data.	Send test data from hardware, and log the input received. Check if log matches with test data sent from hardware. Test this after

	cellular modem is tested.
Data is processed by script on AWS Lambda correctly, and processed data is stored into the database without corruption of data.	1. Create dummy data input within the script and log the processed data. Check if it is successfully processed. 2. Check database table after processed data is inserted to database. Make sure it does not affect past data, and new data is inserted without alteration.
Whenever the database is updated, AWS Lambda script should be executed to update csv files in AWS S3 bucket.	Send a single data packet every minute and check if the csv files in AWS S3 bucket updates.

Table 9. RV table for database

Website

The website is a static website hosted on AWS S3. It will be used to visualize data and warnings in real time.

Requirements	Verification
The Javascript component of the website can read and process data from csv files on AWS S3 through ajax in real time.	Upload dummy csv file with dummy data to S3. Log the read data on console, and check if data matches with dummy data on csv.
Warnings should be generated through analysis of data read from csv files.	Create dummy csv files. One has data satisfying warning conditions, and another does not. Test warning analysis part of code with both of csv files. Check if warnings are generated if only if the csv file has data that satisfies warning conditions.
Data and warnings can be visualised on the website using d3.js.	Given the csv file, check if the website can display all data in graph and highlight the data with warnings.

Table 10. RV table for website

2.3 Tolerance Analysis

The RF transceiver module has the highest risk in our design because collected data cannot be viewed by the user if data cannot be sent through cellular networks. Considering the background problem of this project, the "remote" part of this project is a significant factor, thus the status of the RF transceiver is the biggest concern that could risk the project's success.

For our RF transceiver module, the lowest baud rate it supports is 1200bit/s [7], while our project monitors four parameters in a 15-minute interval. Assuming each parameter value is contained within 16 bits:

$$\#\ of\ bits\ /\ period\ =\ 4 * 16 = 64 bit/s\ \ <<\ \ 1200 bit/s$$

Even the lowest baud rate is more than enough to support our monitoring system, which means data transmission rate should not be an issue.

Regarding power consumption, since we are planning to use the E-GSM 900 RF band, the RF transceiver module's maximum power consumption is 2W [7]. Our voltage regulator, though, with a voltage of 3.7V, has a maximum current rating of 0.6A [4], which means:

$$P_{max,\ supply} = 3.7V * 0.6A = 2.22W\ >\ 2W\ = P_{max,\ consumed}$$

The maximum power consumed by establishing a GSM connection is still lower than the maximum power able to be supplied by the voltage regulator, so it should be within our system's capabilities to establish that connection. The monitoring system also runs serially, meaning that when it is time for data to be transmitted, the only active component is the RF transceiver module while other components remain idle. Furthermore, the maximum value stated is simply an absolute maximum rating, typically a connection to the E-GSM 900 only takes 0.22A [7], so this current consumption should give more leniency to the system's power distribution.

In terms of environmental factors, the average humidity of Indonesia is around 70% to 90% [8]. It is imperative that our RF transceiver unit stays functional under this condition since our whole system depends on it. According to the datasheet of our HL6528RDx, the transceiver has gone through a humidity test under 95% humidity, at a temperature of +65°C for 10 days [7]. It also has gone through the Moist Heat Cyclic Test, where the chip was placed under a cyclic temperature change ranging from +40°C with 93% relative humidity to +25°C with 95% relative humidity [7]. The test setting is well above the average high temperature of Indonesia of around 30°C to 31°C and the aforementioned humidity level of 70% to 90% [8].

	Temperature(°C)	Humidity(%)
Humidity Test	N/A	95%
Moist Heat Cyclic Test	40°C - 30°C	95% - 93%

Environment	31°C - 30°C	90% - 70%

Table 11. Summary of humidity and temperature under different tests vs Indonesia

2.4 COVID-19 Contingency Planning

In case of full online transition due to elevated risk of the COVID-19 virus, our project should not deviate much from the planned implementation. It is likely that we will finish interfacing the power, sensor, and control modules in the next three weeks. After finishing those tests that require the use of a testbench, later works should focus on software. The software tasks can be done remotely where we will run simulation codes with mock environments for each sensor and check the data transmitted to the database.

3 Cost and Schedule

3.1 Cost Analysis

3.3.1 Labor

Name	**Hourly rate (USD)**	**# of Hours**	**Cost (USD)**
Raynaldi Yose Iskandar	35	100	3500
Masaki Sato	35	100	3500
Yun Mo Kang	35	100	3500
Total			10500

Table 12. Table of labor cost distribution

3.3.2 Parts

Description	**Manufacturer**	**Part #**	**Qty**	**Cost (USD)**
Battery	SparkFun Electronics	1568-1491-ND	1	4.95
Voltage Regulator	Texas Instruments	296-17776-1-ND	1	0.92
Water Flow Sensor	Seeed Technology Co., Ltd	1597-1520-ND	1	6.02
Ammeter	Allegro MicroSystems	620-1482-1-ND	1	1.41
Thermocouple Wire	BFRobot	1738-1311-ND	1	6.97
Vibration Sensor	TE Connectivity Measurement Specialties	MSP1006-ND	1	5.37
Microcontroller	Microchip Technology	ATMEGA328PB-AURCT-ND	1	1.42
RF Transceiver Module	Sierra Wireless	1645-1072-ND	1	25.23

Total				52.29

Table 13. Table of component cost

3.3.3 Total

Type	**Cost (USD)**
Labor	10500
Parts	53.21
Total	10553.21

Table 14. Table of total cost

3.2 Schedule

Week	Task	Members **Y**un, **M**asaki, **R**ay
10/5	Sign up for Design Review, Set up AWS lambda server Test power and sensor module interface on breadboard Complete design review	M, Y R ALL
10/12	Interface with the RF transceiver Design initial frontend website Interface the sensors to the microcontroller	M Y R
10/19	Interface the transceiver to AWS server Design & finalize PCB orders	M, Y R
10/26	Connect the AWS backend to the frontend Order PCB	M, Y R
11/2	Install the sensors to the PCB Add functionalities on the frontend	R M, Y
11/9	Mock Demonstration sign up Interface everything together & complete mock demonstration	Y ALL
11/16	Complete Demonstration	ALL
11/23	Thanksgiving Break	ALL
11/30	Complete Mock Presentation Complete Presentation Write up final papers	ALL
12/7	Finish and submit final papers Lab checkout	ALL

	Submit lab notebooks	

Table 15. Summarized work schedule

4 Ethics and Safety

4.1 Ethics

This project is mainly focused to help maintain a clean water source for undeveloped regions of Indonesia. Our effort is a direct practice of the IEEE Code of Ethics #1: “To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment” [9]. Despite our efforts to assist the villagers, we realize that errors can be made, and in the case of hazardous side effects taking place due to our project, we swore to not keep any confidentiality and tend to the error immediately. This project will not only ensure clean water to the villagers, but will also allow children to attend school instead of taking hour-long trips to gather water. This will enable them to pursue better lives and break the cycle of poverty. Furthermore, by the IEEE Code of Ethics #5: “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others”, we realize that we are still at a learning stage, where we occasionally make mistakes and need the guidance of other, more professional personnel. Therefore, being humble and honest about our mistakes, listening to feedback, and crediting the people that helped us in the project, is a necessary step for us to improve as an engineer and, more importantly, as a person.

4.2 Safety

Corrosion on the sensor modules is a serious safety concern. Since this module will be underwater, parts can corrode and dissolve into water, which can contaminate the water. The Environmental Protection Agency states that the maximum allowable for copper and lead are 1.3 milligrams/liter and 0.015 milligrams/liter, respectively [10]. This problem can be solved by building a cover that can insulate hardware from water. Any water damage to the power source is another major safety concern. Although this part will not be submerged, the weather tends to be rainy in Indonesia. Therefore, building a quality water-proof system for the monitor will be important.

The lithium-ion battery also may be a safety concern. If it is not handled properly, it may explode and cause severe damage to hardware and possibly anyone near it. Any physical damage or high temperatures above 130°F may cause damage to the battery [11]. If the battery breaks or explodes and drops debris into the water, it could become a cause of contamination. To counter this concern, we will build a casing for the batteries so that they are well-protected against external impacts and fluids.

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