

Building a Portable Water Testing Prototype Using Electrical Conductivity Sensing

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Abstract

Many fatal illnesses caused by polluted water are prevalent in poverty-stricken areas where activities such as coal mining occur. Testing the water safety is an efficient way to avoid the exposure of the polluted water. However, current methods of water-quality testing are cumbersome and expensive. We propose a user-friendly device that evaluates the safeness of a given sample of water in an efficient and economical manner. Our device is programmed with Python and can read and interpret electrical conductivity in water via probes. The device accurately returns outputs to the user in the form of LED activation. The device succeeds in displaying red LED lights when polluted water, such as acid mine drainage, had conductivity values of approximately 1430.00 $\mu\text{S}/\text{cm}$, which is above the safety mark of 200 $\mu\text{S}/\text{cm}$. This project endeavors to efficiently determine the safety of drinking water and improve upon the current water testing services, which in turn would improve the lives of many people and families who suffer from the irresponsibility of the coal mining industry.

Keywords: water-testing device, safe drinking water quality, electrical conductivity sensing, LED technology

1. Introduction

Access to safe drinking water is essential to human health in any situation and geographical region. Every year, millions of deaths and diseases occur due to a lack of awareness of contamination as well as a scarcity of clean water. [1] The potential for human exposure to pollution and disinfection byproducts is becoming a widespread health concern. Water quality testing is critical as it provides vital information on the safety of drinking water resources through indication of material concentration. In 2014, the city of Flint, Michigan experienced a water crisis that caused a national outcry. Residents unknowingly consumed water that was contaminated with dangerous levels of various toxins, such as lead, iron, and fecal coliform bacteria, which caused 15 deaths and hundreds of illnesses [2]. In some regions of the U.S., particularly Appalachian region, a cross contamination in migrating ground water by unchecked discharges of acid mine drainage (AMD) from abandoned coal mining and newly emerged fracking has become a major source of health hazard. [3] Effective water testing could have avoided the water pollution catastrophe, which in turn would have saved lives. However, modern water quality testing is often difficult to access and utilize.

1.1 Limitation of the Current Water Testing Methods. Current commercialized water testing methods have two obvious limitations: (1) too long in testing time – the procedure that often involving mailing one’s water sample to a lab and waiting two to four weeks for results, and (2) too narrow in either detecting range of toxins or monitoring microbe concentration. For example, the Oklahoma Department of Environmental Quality conducts a water testing service that involves not

only a one month waiting period but the complexity of instructions to users on how to collect water samples, which are then labeled, packaged, and shipped to laboratories for evaluation. [4] Such inconvenience can increase the risks for those communities living in the regions that are affected by polluted water system as many families may not be able to afford the time and costs for this service. In addition, the recurrent shipment of water samples will create unnecessary surplus expenses for families, not to mention the increased health risks as a household's tap water may fluctuate drastically during the waiting period. To make the matter even worse is that the test results that are returned to the user are oftentimes difficult to interpret, which can defeat the purpose of the test. While many services recognize the essence of clean water, they nonetheless fail to consider convenience on behalf of the user.

Lab-scale methods for water quality testing involve utilizing assays to detect disinfection byproducts and using bacterial indicators to detect pathogenic contaminants. For example, through the utilization of assays, a particular method tests for a multitude of contaminants, such as bromodichloromethane, dibromoacetonitrile, and other specific disinfection byproducts. However, this approach fails to report the low mass concentrations of contaminants that nonetheless exceed the safety regulations set by the EPA¹⁰. Although this type of method can be accurate, it nonetheless returns results in the form of technical and complex terms that the common individual may not easily comprehend.

Furthermore, although efforts have been contributed to making water testing more convenient, many still do not effectively address all contaminants. Water can be contaminated with both pathogenic bacteria as well as harmful chemicals. Prominent methods that are being researched focus on the quick detection of pathogenic bacteria and other types of microbe concentration. For example, a particular method emphasizes the use of bacterial indicators as a means of detecting concentrations of contaminants such as E.Coli in water samples. [5] However, this neglects the detection of toxic chemicals. Microorganisms die from many forms of industrial processing, such as coal mining. Although this method is effective in terms of accessibility, it fails to consider prominent chemicals in polluted water. Water can be contaminated with both pathogenic bacteria as well as harmful chemicals.

1.2. Application of New Water Testing Method Using Electrical Conductivity Sensing

The persistent high rate of illnesses due to using unsafe tap water is a cry for better solutions. The United States Environmental Protection Agency provides a priority pollutant list, which is composed primarily of toxic chemicals and fewer microorganisms. For example, acenaphthene is a chemical compound that the EPA considers among the most dangerous. This chemical cannot be effectively detected through the conventional indication of bacteria such as E.Coli. However, similar to many other water-pollution chemicals, acenaphthene exhibits electrical conductivity, which this device is designed to test for. The advantages of electrical-conductivity-guided water testing device are that (1) it can detect a broader range of toxic pollutants commonly contained in tap drinking water, (2) it is cost-saving and easy to operate, and (3) it is easy to comprehend the test results.

This project can improve upon several drawbacks of existing methods as well as other methods that are either available in market or being researched in academia. Electrical conductivity serves as a critical parameter for water testing since it indicates any amount of mineral concentration. It also fits the analytical method criteria for drinking water that was set by the United States EPA. Many forms of bacteria also exhibit electrical conductivity, which this device can detect. Additionally, LED

technology is widely understood as it is similar to traffic lights in terms of interpretation. I utilized water samples with various pollutant concentrations, and I applied coding methods to interpret the results. This project aims to one day allow families at risk to protect themselves from the consequences of environmentally harmful activities such as coal mining and contaminated water.

Much of the research and preparation for this project was done at the Information and Telecommunication Systems laboratory at Schoonover Center at Ohio University where I took classes and received advising from interested faculty. I purchased all the materials needed for the project.

2. Methods and Materials

2.1. Research Question

Our research question constitutes the hypothesis of this research project: Can the current methods of water-quality testing be improved upon in order to allow for greater accessibility, quicker results, cheaper purchase, and simpler interpretation? Our proposed innovative approach is to apply conductivity values to measure the variations of safety levels in tap water. The conductivity levels in polluted water are expected to be high, which the device will indicate through the activation of an LED.

2.2. Rationale behind Design

To start with, this product is targeted to serve the households of low and middle incomes living in a high-risk water-polluted regions caused by coal and other minerals extractions as well as fracking. Therefore, the primary rationale behind the design follows the four principles: (1) affordable (cost-saving), (2) portable (compact in size), (3) easy to operate (test implementation), and (4) easy to interpret the test results (data comprehension). The above four principles distinguish our water-testing device to be particularly user-friendly from those current commercial ones available on market. For example, The application of LED color sensors to be an integral part of device is to help users to easily understand the test results (like reading traffic lights) of RED (not safe to drink), YELLOW (refrained from drinking), and GREEN (safe to drink).

2.3. Design Criteria

Ultimate design criteria is to successfully create a prototype of the intended device. In other words, it will accurately read and interpret collected data and accurately give outputs to the user in the form of LED activation and precise conductivity values. It should be very easy for the user to interpret the results. As it is a prototype, it is expected to be reasonably refined but by no means resembling the appearance of a final product that all families can use.

2.2. Hardware Setup

I used the following materials to assemble the device: Raspberry Pi (Model B), USB keyboard, USB mouse, 2 breadboards, 3 LED bulbs (red, green, yellow), T-cobbler board, jumper wires (male), electrical resistors (~200 ohms), GPIO ribbon cable, EZO conductivity circuit, HDMI monitor, electrical conductivity probe (5 S/cm – 200,000 μ S/cm)(Atlas Scientific), female BNC connector, Wifi dongle, water samples.

To commence the operation of the project, the hardware components were integrated into a relatively compact device. A Raspberry Pi (Model B) must be booted up and displayed on an HDMI monitor. [6] NOOBS must be installed onto a micro SD card from the Internet (raspberrypi.org). This is the Raspberry Pi's operating system install manager. NOOBS contains a variety of operating systems. For this project, I used Raspbian, which is the Raspberry Pi Foundation's official supported operating system. Raspbian is pre-installed with various software components such as Linux and Python, which were heavily used throughout this project. For this project, our micro SD card contained 32 GB of storage. A minimum capacity of 8 GB is recommended, as many files needed to be saved throughout this project.

The LED code and the EC sensor code files were merged into one file. For example, the GPIO output line was moved to the very top of the merged file. An algorithm that produces binary outputs was designed and tested. A code that allows the LEDs to be controlled by Python was also designed and executed. [A python file was created to allow it to read the console output of another program in Python.] It is important to note that the code is case and space sensitive, etc. For example, the tab key cannot be used as an alternative to 5 space keys. If this occurs, then the code will not be successfully executed. Safety ranges for conductivity values and IF statements were incorporated into the Python file. Certain LEDs get activated when the conductivity levels, which are obtained by the probes, hit certain values.

A GPIO ribbon cable served as a connection between the RPi and the breadboard. This established a circuit within the device. A T-cobbler board was attached to the breadboard to serve as a connection to the ribbon cable. The electrical resistors of around 200 Ω each needed to be placed in close proximity to the LED bulbs on the breadboards. A female BNC connector was needed to incorporate the EC sensor and to resist corrosion on the linkage. The RPi needed a WIFI dongle in order to obtain internet connection, which was necessary for every file execution, primarily for the LED bulbs and sensors.

2.3. Software Setup

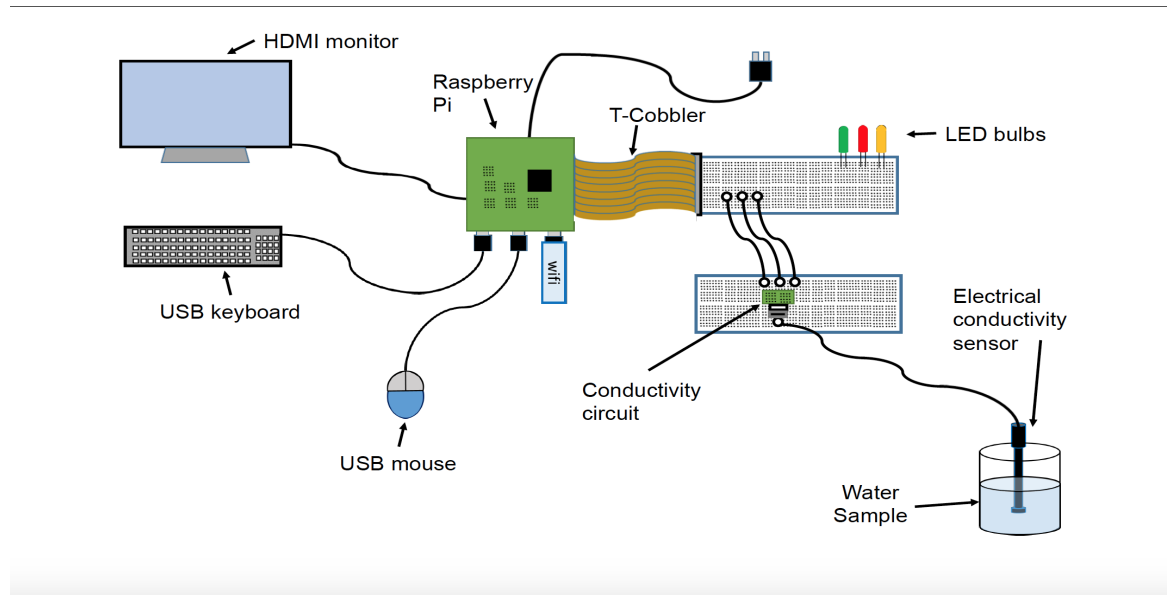
The two files (LED activation and sensor readings) were merged into one. The Raspberry Pi was programmed to collect data when the probe touched a sample of water. This was not automatic, so a command line was needed to collect data with the prototype. [The conductivity sensor must be calibrated before it can collect data using the command "Poll, 5.0"]

Testing involved acid mine drainage water, conductivity calibration solution, tap water, and distilled water. AMD water, conductivity calibration solution, and tap water were used as samples of polluted or contaminated water. Distilled water was used as the control. Through conductivity, the probes measured the concentrations of toxic metals, such as arsenic, lead, and mercury. If needed, these chemicals may be used to simulate coal-polluted water. The probe collected data once every five seconds until the polling was stopped by the user (press ctrl-c). The probe returned five values for every poll, and the first value of each poll was disregarded, as indicated in the Python file. Instead, the third value was used (this could be modified in the code). If the probe returned a conductivity value in a sample of water that was greater than 500 S/cm, the red LED was activated, indicating that the water was not safe to consume. If the probe returned a conductivity value that was between 200 S/cm and 500 S/cm, the yellow light was activated, indicating that little consumption was safe. If the probe returned a conductivity value that was less than 500 S/cm, the green LED was activated, indicating that the water was safe to consume. If there was an error in the sensor reading, then the

word “Error” was displayed on the screen along with specific line numbers in the code that contained inaccuracies. This indicated that the test must be voided and the source of error must be determined through troubleshooting. Throughout the testing, the device should be at least 80% fail-proof.

The following is a diagram for basic design (Figure 1):

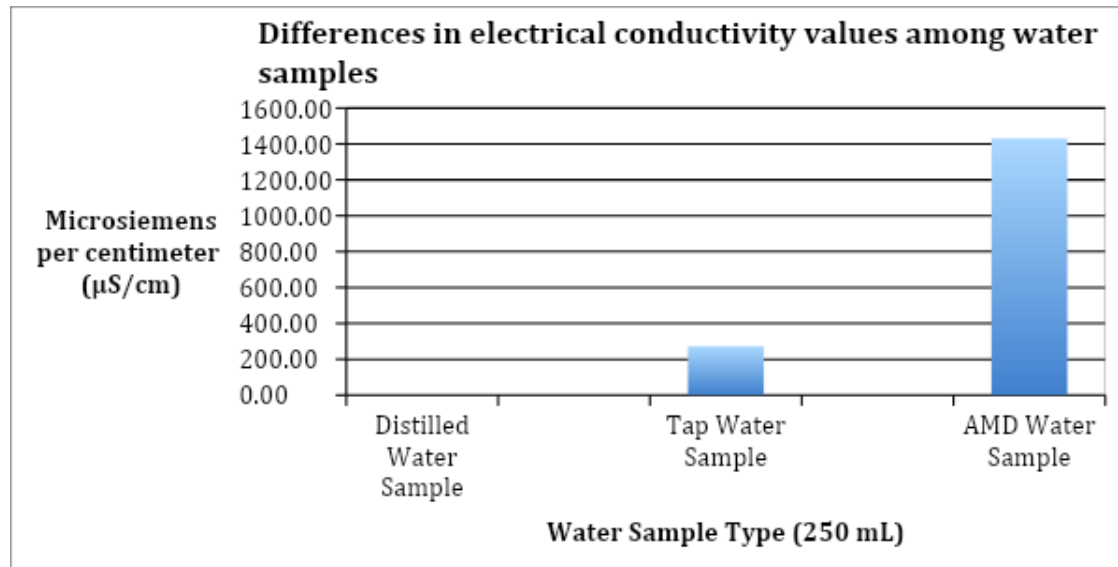
Figure 1: Basic Design Diagram



3. Results and Analysis

The created device was put into test to see if the system was working as designed. The key independent variables of project for our testing and analysis included acid mine drainage (AMD) water, conductivity calibration solution (Atlas Scientific 80,000 $\mu\text{S}/\text{cm}$), tap water, and distilled water. AMD water, conductivity calibration solution, and tap water were used as samples of contaminated water. Distilled water was used as a control variable since it is known for having insignificant mineral concentration and therefore negligible levels of conductivity. Including a variety of water samples ensured that reliable data was collected and demonstrated the correlations between polluted water and EC levels. For the accuracy of water samples, I travelled to vicinities of mining sites in Southeastern Ohio and in Raleigh County, West Virginia to collect samples of AMD water (Figure 2). In some cases, Lab simulations of solutions could be used as an alternative to travelling to field sites to collect real samples.

Figure 2:



Through electrical conductivity testing, the probes measured the concentrations of various chemicals and other toxic metals, such as arsenic, lead, and mercury. If needed, these chemicals may be used to simulate coal-polluted water, although this was not used in this case study. The probe collected data once every five seconds (as shown in code: Poll, 5.0) until the polling was stopped by the user (ctrl-c).

The probe returned five values for every poll, and the first value of each poll was disregarded, as indicated in the Python file. Instead, the third value was used (this could be modified in the code). If the probe returned a conductivity value in a sample of water that was greater than 500 S/cm, the red LED was activated, indicating that the water was not safe to consume. If the probe returned a conductivity value that was between 200 µS/cm and 500 µS/cm, the yellow light was activated, indicating that little consumption was safe. If the probe returned a conductivity value that was less than 500 µS/cm, the green LED was activated, indicating that the water was safe to consume. (Figure 3)

If there was an error in the sensor reading, then the word "Error" was displayed on the screen along with specific line numbers in the code that contained errors/inaccuracies. This indicated that the test must be voided, and the source of error was determined through troubleshooting (further analyzing the code). Throughout the testing, the device was 80% fail-proof. As shown through the graphs (Figure 2), the readings were fairly consistent as long as the temperature in the setting did not fluctuate significantly.

RPi collects signals that probe gives to it. Code tells RPi how to process the signal. CPU helps transmit processed information to the LED bulb.

Figure 3:

Recorded Values for Each Sample Set				
Conductivity Solution (µS/cm)	Distilled Water (µS/cm)	Tap Water (µS/cm)	AMD (µS/cm)	*
33578.39	0.50	273.57	1429.93	
33578.35	0.53	273.53	1430.01	
33578.29	0.53	273.51	1429.93	
33577.98	0.51	273.55	1429.89	
33578.15	0.50	273.51	1429.84	
33578.09	0.51	273.48	1429.78	
Average	Average	Average	Average	
33578.21	0.51	273.53	1429.90	
STDEV	STDEV	STDEV	STDEV	**
0.16	0.01	0.03	0.08	
Red - Dangerous	Green - Safe	Yellow - Use little	Red - Dangerous	
* Independent variables				
** Extent of fluctuation from the average values				
Note: Electrical conductivity fluctuates with respect to the temperature of its surroundings.				

Discussion and Conclusion:

While there is no doubt that various forms of mineral concentrations in drinking water can cause severe health problems, many of the available testing methods do not succeed in effectively addressing issues relating to water pollution. Many methods are either too complicated or are too narrow in the contaminants that they test for. This device tests for a broader range of water contaminants through electrical conductivity sensing. The results of this project were used to show that the device functions effectively and that more polluted water has higher levels of conductivity. The hypothesis and design criteria were validated and fulfilled as the test results show respectively.

It is important to note that conductivity values increase as temperature increases and that the safety ranges of this project are based on standard conditions (25°C).

An improvement in the experimental procedure could be to stabilize the jumper wires in order for them to remain intact with the breadboard. This could be done through adhesives. As stated in the design criteria, this project could be further improved by becoming more user-friendly, more compact, and more economical. It could also test for more water-quality parameters, such as pH.

The development of this device included many complicating factors. Accurately arranging the hardware components, such as the GPIO pins on the RPi and the jumper wires on the breadboards, for the correct LED activations was among the most challenging tasks for this project. A displacement of a jumper wire by a single “hole” can clutter an entire circuit and the code would be unable to be executed.

Regarding the project's social significance, this is the first step towards creating a device that would allow families from all backgrounds to confidently evaluate the water that they consume. As stated in the design criteria, this project could be further improved. Easier use, more compact, more independent variables to test for, etc. The device could even be improved to where it can purify water rather than just evaluating its quality.

For a future project, the general hardware setup could be compacted and manufactured into a more refined handheld device without the necessity of many hardware components such as jumper wires and breadboards. Specifically, the electrical conductivity sensor could be made smaller and the use of an HDMI monitor would no longer be necessary. Furthermore, the code could be modified so that a command line would no longer be necessary for return values and data collection. I am currently working on developing a polymer network that can treat a broad range of pollutants, including inorganic arsenic. In the future, the command-line should function at the push of a button rather than through typing.

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