Sharkya STEM School

IoT Aqua CO_2 Analyzer

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GROUP INFO

Group 22306:

Grade 12 – Semester 1

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ABSTRACT

Increasing levels of CO2 in the atmosphere are causing the oceans to become more acidic, a process known as ocean acidification, which can have a wide of negative consequences on marine life, including coral reefs and shellfish. Building an accurate measurement system using IoT technology can help researchers better understand and monitor the effects of CO2 on ocean acidification, which can inform efforts to mitigate the problem. The measurement system we decide to use is based on accurate sensors like MG-811, NTC 3950 thermistor, and the pH electrode probe sensor to measure the CO2 effect on temperature and pH. The measurement system also features its IoT system that transmits the data collected by sensors to the GUI platform(website). This makes it possible for researchers to easily access and analyze the data in real-time, without the need to physically be at the location where the measurements are being taken. After testing the system's accuracy and GUI performance, it has been found the system could successfully give accurate and precise measurements of the CO2 concentration in air and pH of water with 0.27% and 0.3% percent errors respectively. As for the GUI performance, the loading time was decreased to 0.173ms, which represents an extremely fast loading time.

I. Introduction

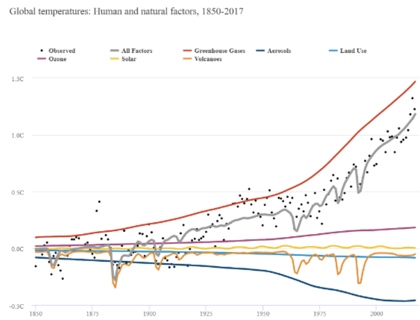

Fig (1)

Egypt is currently facing several obstacles regarding improving the quality of daily life and the country as a whole. These obstacles are demonstrated as the Egypt's grand challenges which, in this case, is reducing and adapting to the effect of climate change, varying through several factors as shown in fig.1. One problem of climate change challenges is its effect on seawater, consequently, air temperature, and water pH. Solving this problem will have many positive consequences like the ability of marine organisms [Bates, 2009] to maintain healthy shells and skeletons, the marine plants [NOAA, 2020] to photosynthesize and produce oxygen, and the health of people would be preserved as it affects them in various ways such as seawater desalination. One way to address the acidification of water is to build an accurate measurement system for monitoring the concentration of CO2 air and its effect on temperature and pH. This information can be used to develop strategies for mitigating the effects of CO2 on water acidification, such as reducing CO2 emissions or developing methods for removing CO2 from the ocean. While deciding on the project idea, the team searched for prior solutions. "Analysis of the Impact of Climate Change on Surface Water Quality in North-Eastern Poland," [Puchlik, 2021] the study investigated the effects of climate on the quality of surface water, showing that the quality of the surface water was affected by each of these seasons and was strongly correlated with air temperature, daily precipitation, and water levels. One of the study strengths is the use of physicochemical analysis to assess water quality, which is a well-established and reliable method. However, study only focuses on two rivers in a specific region of northeastern Poland, so the results may not be generalizable to other regions or rivers. As our project is directed to monitor the effects of climate change, the solution must meet two main design requirements which are, accuracy and precision, and high GUI [CS] performance. The accuracy and precision were achieved by two main techniques, the first one is to select the most accurate sensors. For this purpose, the MG-811 sensor, the NTC 3950 thermistor, and the pH electrode probe sensor were obtained due to their high accuracy and quality. Furthermore, the seniors were calibrated for more accurate results. The second technique utilized is the use of a well-closed system by using a pump to pump the CO2 inside the container to reduce the possibility of gas leakage. After the data was collected from this system, a basic statistical analysis was applied to them (mean, correlation, line regression, standard deviation); the basic statistical analysis can help to reveal underlying patterns and trends in the data, which can provide a better understanding of the information contained in the data. The second design requirement which is high GUI performance was achieved by reducing the time delay in loading the website's content, and animations. This was done by reducing the complexity of code algorithms as possible. Complexity can be represented in the order function notation or Big O notation O(n) as n is the size of the input. This can be achieved by using more simple algorithms to reduce the processor's time in processing the data.

II. Methodology

II.I. Materials

II.II. Methods

As seen in figure 2, the prototype comprises of three key components.

First, the container. This system comprises of a container in which a closed simulation is conducted. The container has a tube connecting it with a fume hood that has carbon dioxide gas through the water pump. This water pump is a part of the second system as it takes order from the board depending on the readings of the sensors. Second, the circuit board and sensors. The prototype employs three sensors all connected through the esp32 development kit board: NTC thermistor 3950 10k ohm, MG-811, and pH.

Fig (2)

The NTC thermistor is suspended in the container, and it measures the temperature inside the container. The sensor's error is ±0.01.

Temperature affects the resistance of the resistor, as is well knowledge. The MG-811 is pasted to the top of the container. It measures the carbon dioxide content in the air. It measures a reading every 200 milliseconds for ten times and then take the average of these readings every two seconds. The calibration of the sensor that was done at a research facility revealed an inaccuracy of ±1.5ppm. The pH sensor is a sensor that measures the pH of the water. This sensor was used to track the increase in pH as the CO2 concentration increase. The sensor was calibrated in the Zagazig university by an instrument and the error turned out to be ±0.02 as shown in figure 3. Third, the Internet of Things system. The esp32 contains a library that enables it to assign an IP address to a local web server. HTML, CSS, and JavaScript-written code is used to create a GUI [Abdollahi, 2022], which is shown in figure 4, for displaying the sensor readings. The board connects to a Wi-Fi network, and the user may see the sensor's readings by joining to the same network and inputting the board's IP address in any web browser. ngrok is used to make the web server accessible from any location in the world. A command including the IP address and AUTH token of the ngrok account is typed into ngrok in order to create a link for the web server that is accessible from anywhere in the globe.

Fig (3)

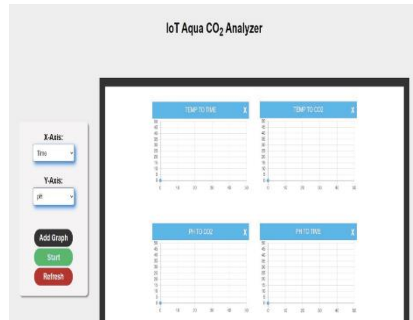

Fig (4)

II.III. Test Plan

Accuracy and perception: Closed system 6-liter water container was used to test system's accuracy and precision, where the sensors to measure data and a pump connected to the container to increase the CO2 concentration. The other side of the pump is connected to a fume hood where the reaction of CaCO3 and HCl [CH.3.01] to generate CO2, while another pump is connected to increase the HCl to, consequently, generate more CO2 when needed, as it should keep the CO2 concentration at a specific level. The pH electrode probe sensor, MG-811 CO2 sensor, and NTC 3950 thermistor are connected to the ESP board to take the average values of CO2, pH, and temperature every 6 minutes, showing these values to the user. After the test was done, the pH of the water was tested in Sharkya Drinking Water Company to measure the accuracy of our system.

GUI: To measure GUI performance, various parameters should be measured: code performance depending on the code complexity, accessibility letting the user utilize the GUI easily and effectively, best practices (security) securing website data from cyber-attacks, and SEO (search engine optimization.) All of these parameters were measured using Google Lighthouse Analysis for both desktop and mobile modes. Additionally, JavaScript loading time was measured by the code itself using "console.time()" and "console.timeEnd()".

III. Results

After testing the prototype's accuracy and precision for 3 trials, each one for about 9.1 hours, as shown in table 1, for more accurate results and data analysis, the final trial had the most accurate result as the first two has some leaks in the pump hoses. System accuracy and precision in measuring CO2: In the first 31 minutes our system is supposed to keep the CO_2 concentration at 400 ppm, as shown in figure 5; in the next 3 hours, the CO_2 concentration should be 600 ppm; in the next 3 hours, the CO_2 concentration should be 800; and in the final hours of the test, the CO_2 concentration should be 1000 ppm. The mean values were 401,602,801,1004 respectively. As the true values were supposed to be 400,600,800,1000 respectively, the absolute error of each one = | measured value - true value | = 1 ,2 ,1, 4 respectively, and by calculating the percent error for each one using the equation, percent error=(absolute error)/(true value)*100 , the percent error values were 0.25 %, 0.33 %, 0.125 %, and 0.4 %, Hence, the percent error of the system in measuring CO_2 can be calculated by taking the mean of this percent error which equals 0.27 %. This indicates the measured value is 0.27% away from the true value, being very accurate and close to the actual values. Since the standard deviation is the measure of the spread or variation of the data, it can be used to calculate the precision of the data. After calculating the standard deviation values in each period of time, they were 0.54, 0.43,0.39,0.91 respectively, and after taking the mean of these values, it was 0.56, which indicates that the data points are even closer to the mean, so the data would be considered precise. System accuracy and precision in measuring pH: As the final pH of water is supposed to be 6.54 (as measured in the Sharkya drinking water company,) and the mean of the values measured by the system during this time was 6.52, as shown in figure 6, the absolute error = | 6.52- 6.54| = 0.02 Hence, the percent error equals (0.02/6.54) * 100 = 0.3%, which indicates that the system is very accurate in measuring pH. In order to calculate whether the pH measured values were precise or not, the standard deviation values in each period of time were calculated as they were 0.41, 0.43, 0.59,0.21 respectively, and after taking the mean of these values, it was 0.41, which indicates that the data are precise.

Time (m) ± 0.02	CO_2 concentration (ppm) ± 1.5	Temperature(c) ± 0.01	pH ± 0.02
1	401	25.54	7.54
31	399	25.44	7.52
37	602	25.67	7.51
49	603	25.68	7.38
73	601	25.72	7.18
217	805	26.21	7.15
235	804	26.23	6.81
259	800	26.28	6.77
397	1005	26.74	6.75
409	1002	26.72	6.69
421	999	26.77	6.51
535	1005	27.04	6.53

Fig (5)

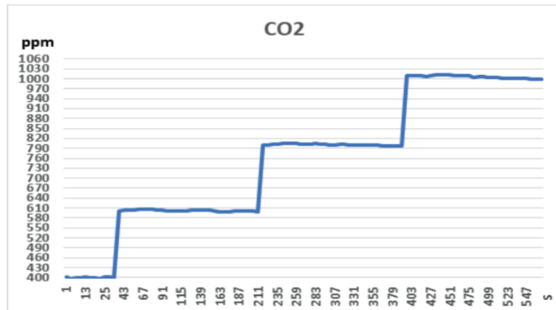

Fig (6a)

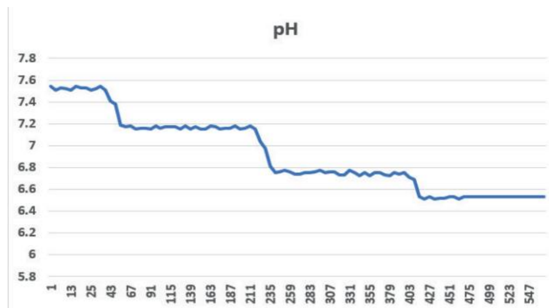

Fig (6b)

GUI performance results must be calculated to know whether it applies the design requirement or does not. GUI performance parameters – code performance which depends on the code complexity, accessibility, best practices (security), and SEO (search engine optimization) – were measured using Google Lighthouse Analysis, applying all the GUI performance parameters with high accuracy and mostly 100% as shown in the figures (7&8) for both mobile phone and desktop respectively; Additionally, the loading time of JavaScript code was measured using “console.time()” and “console.timeEnd()” and getting the difference between them. The result was the mean of three consecutive values:

$$loading\ time_{avg} = \frac{0.18ms + 0.21ms + 0.13ms}{3} = 0.17\dot{3}ms$$

This loading time is extremely fast regarding the data it transmits on the internet, so it wouldn't be an issue within a large scale of amount of data. As can be seen the GUI effectively applied the GUI performance design requirement.

Fig (7)

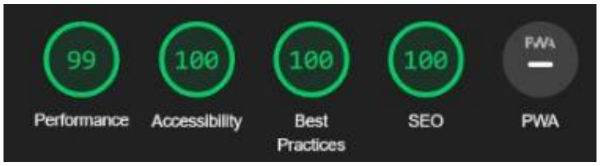

Fig (8)

IV. Analysis

After analyzing the data obtained in the test plan, it has been found that our closed system could make accurate and precise measurements with a high user interface performance. Further analysis can be applied to the data to draw conclusions about the behavior of the system during the test plan as follows,

CO_2 and temperature:

Fig.9 shows the relation between CO_2 concentration and temperature.

According to the graph, it can be observed that an increase in CO_2 concentration by

(1002 ± 1.5 – 401± 1.5) = 600 ± 1.5 ppm led to an increase in temperature by

(25.5 ± 0.01 – 27.2 ± 0.01) = 1.7± 0.01 C,

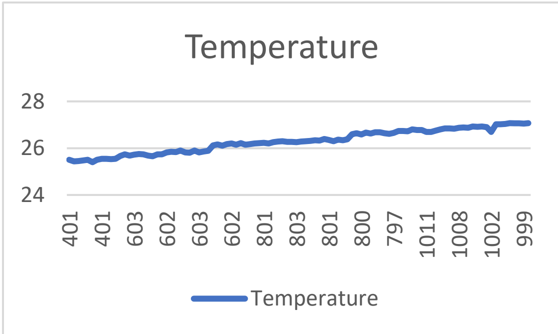

Fig (9)

As prediction is an important aspect of statistical analysis, a regression line [ST.3.03] was created to predict the relation between temperature and CO_2 as in the following equation $y = 0.0023x + 24.532$, where y represents the temperature and x represents the CO_2 concentration.

After calculating the correlation between the temperature and CO_2, it was 0.94412 which indicates that there is a strong positive relation between CO_2 and temperature, as the CO_2 increases, the temperature increases.

CO_2 and pH:

Fig.10 shows the relation between CO_2 concentration in the container and the pH of the water. According to our experiments, it is safe to say that an increase of 200 ± 1.5 ppm in CO_2 can decrease the pH of water by 0.4 ±0.02 to 0.2 ± 0.02, this percentage can change depending on other factors like temperature.

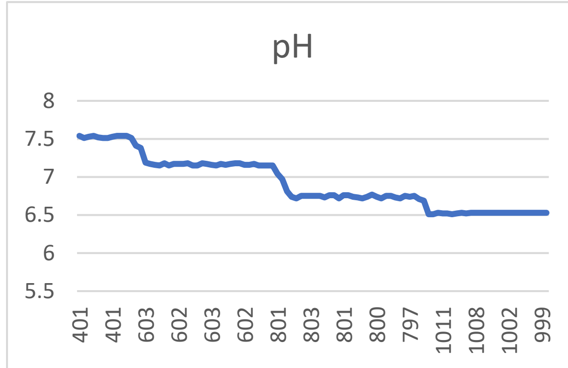

Fig (10)

In order to predict the rate of change of temperature according to the change in CO_2 concentration, a regression line was created to predict the relation between pH and CO_2 as in the following equation: $y = -0.0016x + 8.1617$ in which y represents pH and x represents CO_2.

The correlation between the CO_2 and pH was -0.95721, which indicates that there is a strong negative relation between CO_2 and pH, as the CO_2 increases, the pH decreases.

Analyzing the GUI [Abdollahi, 2022] performance, code and algorithm complexity is related to the performance itself and the loading time it takes. Consequently, we need to calculate the complexity of the code and reduce it as possible as we can so we can reduce the loading time it takes. Complexity is represented in Big O Notation or O(n), in which while the parameter of the function increases the loading time it takes increases. For example, there are O(n),O(log (n)),and O(n^c), and, as can be seen, we seek to reduce the value of c.

The GUI code appears to be a simple implementation of a data visualization tool, as shown in figure 4, that allows the user to plot graphs of different data sets. The user can add multiple graphs by clicking the “Add Graph” button and can start the data visualization by clicking the “Start” button. The data for the graphs is generated by incrementing the values of the “time”, “temp”, “co2”, and “ph” arrays, which stores the sensors’ data, by a fixed amount on each iteration.

The complexity of the code will depend on how many times the “draw()”, which plots the graphs, function is called, which in turn depends on how many times the user clicks the “Start” button and how many times the “Add Graph” button is clicked to add additional graphs.

If we assume that the “Start” button is clicked once and the “Add Graph” button is clicked a fixed number of times to add a fixed number of graphs, the complexity of the “draw()” function can be characterized as follows:

1- The “time”, “temp”, “co2”, and “ph” arrays are incremented by a fixed amount on each iteration, so the complexity of this operation is constant, O(1)

2- The “draw()” function calls itself recursively, so the overall complexity of the function is O(n) where n is the number of times the function is called.

3- The “eval” function is called once on each iteration of the “draw()” function, so the overall complexity of this operation is O(n).

Therefore, the overall complexity of the “draw()” function can be characterized as O(n), where n is the number of times the function is called.

In a previous version of the code there were two “eval” functions in the “draw()” function, so it was calculated as O(n^2) as it will be called twice. However, we managed to combine these two functions together in one function editing the algorithm we used before.

V. Conclusion

The project was able to achieve the design requirements: accuracy and precision, measuring CO_2 concentration, water pH value, and air temperature and GUI performance which included code performance, accessibility, security, SEO, getting and visualizing the data from the IoT system. By achieving these design requirements, project can be applied through various real-life systems. One of them is to give a simulation about what can the greenhouse gases change in the temperature and pH using the analysis made for prediction such as the regression line equation. Additionally, GUI system can be used as a platform for increasing people’s awareness and educate them of the climate change problem, especially on the seawater. Also, IoT system could be useful in controlling the measuring system from anyplace in the world once one has the access to its server. Furthermore, the ability to accurately and precisely measure these environmental factors can be useful in a variety of settings. For example, it can be used in agricultural settings to monitor greenhouse conditions and optimize plant growth. It can also be used in industrial settings to monitor emissions and ensure compliance with regulations. In both cases, the system's ability to provide real-time data and alert users to potential problems can help prevent costly errors and ensure the health and safety of both plants and people.

VI. Recommendations

The investigation revealed an analysis of greenhouse gases impact on temperature, water quality parameters, and climate change. On this basis, future research should examine the potential consequences of climate change. After a thorough analysis of the data, the following recommendations are hereby made:

o Improving the accuracy and precision of the sensors used to measure pH, temperature, and CO2 levels. This could involve using more advanced sensors or implementing calibration and correction algorithms to improve the quality of the data collected.

o Developing algorithms or machine learning models to analyze the data collected by the sensors and identify patterns or trends that may not be immediately apparent. This could include identifying correlations between different environmental variables and predicting future changes in pH, temperature, or CO_2 levels.

o Expanding the range of environmental variables that the system is able to monitor. In addition to pH, temperature, and CO_2 levels, you could consider adding sensors to measure other factors such as humidity, air pressure, or light levels.

o Investigating the potential for using the IoT [PH.3.05] system to support research and development activities. For instance, the system could be used to conduct experiments or simulations to study the effects of different environmental conditions on plants, animals, or other organisms.

o Providing more greenhouse gases measurements; as we have just measured CO_2 gas, even though measuring the rest of the greenhouse gases, such as (N_2O, CH_4 & H_2O ‘Water Vapor’,) to be able to get in-depth with clear vision on their impact on the climate change.

In the light of the above-mentioned recommendations, we believe that a focus on these key areas will help to advance our understanding of climate change and support the development of effective solutions to this pressing global problem.

VII. Literature Cited

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