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IoT based smart water quality monitoring system

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ABSTRACT

Pollution of water is one of the main threats in recent times as drinking water is getting contaminated and polluted. The polluted water can cause various diseases to humans and animals, which in turn affects the life cycle of the ecosystem. If water pollution is detected in an early stage, suitable measures can be taken and critical situations can be avoided. To make certain the supply of pure water, the quality of the water should be examined in real-time. Smart solutions for monitoring of water pollution are getting more and more significant these days with innovation in sensors, communication, and Internet of Things (IoT) technology. In this paper, a detailed review of the latest works that were implemented in the arena of smart water pollution monitoring systems is presented. The paper proposes a cost effective and efficient IoT based smart water quality monitoring system which monitors the quality parameters uninterruptedly. The developed model is tested with three water samples and the parameters are transmitted to the cloud server for further action.

Introduction

Water pollution ensues when lethal materials move into water sources like ponds, rivers, lakes, seas and oceans, gets dissolved and suspends in water or gets deposited on the bed. Pollution will degrade the quality and purity of water. Ensuring pure and safer water is really challenging due to undue sources of chemicals and contaminants. Pollution of water can be instigated by numerous ways; one of the main reasons for pollution is industrial waste discharge and city sewage. Secondary sources of pollution are pollutants that enter the water from soils or from atmosphere via rain or from groundwater systems. Usually, soils and groundwater comprises of residues of modern practices in agriculture and also indecorously disposed wastes from industries. The major pollutants of water include viruses, bacteria, fertilizers, parasites, pharmaceutical products, pesticides, nitrates, fecal waste, phosphates radioactive substances and plastics. These materials will not alter the color of the water always, but they might be indiscernible contaminants.

Hence small quantity of water from such water resources and marine organisms are examined for determining the water quality.

Declining quality of water is detrimental to the health, environment and economy. David Malpass, President of the World Bank cautions about the influence on economy: "Deteriorating water quality is stalling economic growth and exacerbating poverty in many countries". It means that, if the biological oxygen demand, the pointer used for measurement of organic pollution in water, surpasses the threshold, the Gross Domestic Product (GDP) growth of the constituencies surrounded by the allied water basins will decrease by a third. The consequences of water pollution or poor water quality are:

- Destruction of biodiversity: Pollution of water reduces aquatic ecosystems and initiates unrestrained increase of phytoplankton in water resources. Food chain contamination: Fishing carried out in polluted water resources and utilization of waste water for agriculture and livestock husbandry may lead to addition of toxins or contaminants into foods that are injurious to the health after consumption.
- Scarcity of drinkable water: If pollution of water increases or quality of drinking water is not maintained, then there will be no clean water for drinking or public health or sanitization, in rural as well as urban areas.
- Disease: According to WHO (World Health Organization) information, roughly 2 billion people across the world do not have any option for pure water resources, but they have to drink water polluted by excrement, which exposes them to many ailments.
- Infant mortality: As per WHO, diarrhoeal diseases associated with lacking of hygiene results in death of nearly 1000 children per day across the world.

Water quality monitoring is demarcated as the assortment of data at set or desired places and at periodic intervals for providing information

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that might be accustomed to describe present conditions of water. The objectives of smart water quality monitoring system are:

- To measure perilous quality metrics like physical, chemical and microbial properties.
- To find the deviations in measured metrics and give timely warning in recognition threats or hazards.
- To provide real-time analysis of the sensor data and recommend appropriate corrective measures.

The requisite for involvement of the user for sustaining the quality of water and beholding at additional aspects like hygiene, environment sanitation, disposal and storage are crucial components in maintaining the quality of water bodies.

Related works

Pasika and Gandla [1] proposed a monitoring system which consists of a number of sensors used to measure several quality parameters like turbidity, pH value, water level in the tank, dampness of the adjoining environment and temperature of the water. The sensors are interfaced with the Microcontroller Unit (MCU) and additional processing is executed by the Personal Computer (PC). The acquired data will be directed to the cloud by means of Internet of Things (IoT) based ThinkSpeak application for monitoring the quality of the water under test. As a future directive, work should be extended for analyzing some other parameters such as nitrates, electrical conductivity, dissolved oxygen in the water and free residual chlorine.

Mukta et al. [2] developed an IoT based Smart Water Quality Monitoring (SWQM) system which helps in incessant measurement of quality of water on the basis of four different parameters of water quality i.e., pH, temperature, turbidity and electric conductivity. Four different sensors are coupled to Arduino Uno in order to sense the quality parameters. The data collected from all the four sensors are communicated to a desktop application which is developed in .NET platform and the extracted data are matched with the standard values. On the basis of the collected data from sensors, the developed SWQM model will efficaciously examine the water quality parameters by employing fast forest binary classifier for classification of the sample of water under test is whether potable or not.

Konde and Deosarkar [3] proposed a method for developing a Smart Water Quality Monitoring (SWQM) system with reconfigurable sensor interface device using IoT environment. Sensors, Field Programmable Gate Array (FPGA) board, Zigbee based wireless communication module were used in the proposed model. Six different water quality parameters like turbidity, pH, humidity, water level, water temperature and carbon dioxide (CO_2) on the surface of water were considered in real-time. The proposed method will provide assistance in guarding the safer and balanced environment of water bodies. The SWQM system reduces the cost and time in determining the quality of water in water resources as part of managing environmental and ecological balance. In the suggested future work, WSN network will be developed involving of additional number of nodes to encompass the coverage area.

Deployment at different locations

Amruta and Satish [4] proposed a Solar Powered Water Quality Monitoring system by employing wireless Sensor Network. Underwater Wireless Sensor Network (UWSN) is the elementary component in the water quality monitoring using wireless sensor network (WSN) technology which is powered by photovoltaic panels or solar panel. For monitoring quality of water in real-time over various locations, exceptional system architecture is proposed that consists of a base station and distributed sensor nodes. All the nodes and base station are linked with the use of Zigbee WSN technology. Designing and implementing a prototype model by using a node which is power- driven by solar panel and WSN technology is a perplexing task. The collected data at each node such as turbidity, oxygen level and pH values from different sensors will be sent to the base station through WSN. The collected data from the different locations can be shown in some readable form and analysis can be done at base station using various simulation tools. This developed novel water quality monitoring system has various advantages like consumption of less power, no carbon emission and higher limberness for Sughapriya et al. [5] developed a method for determining the quality of water using IoT and different sensor modules. This system uses different sensors for monitoring the water quality by determining pH, turbidity, conductivity and temperature. The Arduino controller used will access the sensor data. With the use of IoT, the collected data is analyzed and the pollution of water can be investigated by a stringent mechanism. Additionally, the developed system sends alerts and notifications to the people and apprehensive authorities about the quality of water. The task of water quality monitoring could be achieved by with people having less training also. Installation of the water quality monitoring system could be achieved effortlessly adjacent to the water resources (target area). The proposed developed model comprises of different sensors that computes quality parameters of water in real- time for immediate plan of action. Also the developed model is accurate, economical and requires less manpower.

Unnikrishna Menon et al. [6] proposed a method for water quality monitoring in rivers which is developed based on wireless sensor networks that aids in incessant and remote monitoring of water quality parameters. In this system, wireless sensor node is designed to monitor the pH of water continuously, which is the key parameter that affects the water quality. The sensor node design primarily consists of a processing module, signal conditioning module, power module and wireless communication module. The sensed data from the pH sensor is communicated to the base station with the use wireless communication module i.e., using Zigbee module after the necessary signal processing and signal conditioning techniques. The circuit is developed for the sensor node by designing, simulating and the hardware prototype is built with the use of suitable circuit components. This minimizes requirement of power for the system and a low cost platform is provided for monitoring the water quality of water resources.

Prasad et al. [7] developed a method for smart water quality monitoring system in Fiji, by employing remote sensing and IoT technology. The quality parameters used to analyze water are Oxidation and Reduction potential (ORP) and Potential Hydrogen (pH). With efficacious implementation of this approach of monitoring, an early warning system for water pollution will be developed with a completely implemented system using numerous monitoring stations. The study of water quality in Fiji Islands is also presented which necessitates recurrent data collection network for water quality monitoring using IoT and Remote Sensing. The comparative study is presented for various parameters like Turbidity, pH, temperature and Conductivity. The developed system has demonstrated its effectiveness by providing precise and reliable values in real-time water monitoring. Four water sources were examined at hourly intervals over a stipulated time interval of 12 hours for validating the accuracy of measurement of the developed system. The obtained results are compared with the probable values. The relationship between temperature with conductivity and pH are also witnessed for samples of all four water sources. GSM technology was efficaciously implemented for sending alarm on the basis of reference parameters to the end user for instant action intended for ensuring water quality. Furthermore, the reference parameters acquired from all the four various water sources are used for building classifiers that are used for performing automated analysis of water through Neural Network Analysis.

Jerom B. et al. [8] proposed a Smart Water Quality Monitoring System based on IoT using Cloud and Deep Learning methods for monitoring the water quality of various water resources. In traditional methods, the procedure of monitoring implicates collecting the sample of water manually from different water resources, trailed by testing and analysis in the laboratory. This process is usually ineffectual since this process is strenuous and consumes more time and it will not give results in real-time. There should be continuous monitoring of quality of water for ensuring safe supply of water to the end users from any water resources or water bodies. Henceforth, designing and developing a cost effective system for real-time monitoring water quality using the IoT is a requisite. Monitoring quality of water in water resources using IoT aids for combating issues related to environment and improves the wellbeing and standard of living of all living beings. The developed system helps in monitoring the water quality persistently by using IoT devices and Node-MCU. The built-in Wi-Fi module associated with Node-MCU facilitates connectivity of internet, and transmits the data measured from the sensor to the Cloud. The designed prototype monitors a number of contaminants present in the water. Various sensors are utilized for measuring different parameters for assessing the water quality from water resources. The obtained results are stowed in the Cloud and deep learning techniques are employed for predicting if the water under test is potable or not.

Geetha and Gouthami [9] developed a low powered and naiver solution for monitoring quality of in-pipe water based on IoT. The developed model is used to test samples of water and the data collected from the sensors is uploaded over the internet is analyzed. This model is less complex and low cost smart water quality monitoring system with a core controller having built-in Wi-Fi module for monitoring quality parameters like turbidity, conductivity and pH. The developed system comprises of an alerting facility for informing the users on deviance of water quality parameters. The implementation facilitates sensors to provide data over the internet to the end customers. The setup used for experiment can be enhanced by integrating algorithms for incongruity detection in quality of water.

Sengupta et al. [10] proposed a cost effective technique for monitoring water quality and controlling in real-time using IoT. The proposed system comprises of different sensors like temperature sensor, turbidity sensor and pH sensor that are interfaced with Raspberry Pi via an Analog-to-Digital Converter (ADC). Based on the data obtained from various sensors and processing of data by the Raspberry Pi, the solenoid valve will be directed to either continue or stop the flow of water from the overhead tank to houses using relay mechanism. This entire process takes place automatically without human intervention thus saving the time to handle the situation manually. Finally its checks for weather water quality parameters are desired range or not. These all devices are low cost flexible and high efficiency.

Kumar and Samalla [11] proposed a cost effective system to monitor quality of water in real-time using IoT. The designed system used various sensors to measure the chemical and physical parameters of the water. This smart water quality system consists of a Raspberry pi controller interfaced with various sensors like CO_2 sensor, pH sensor, turbidity sensors, temperature sensor and water level sensors. These sensors control the entire operation and monitoring is done by Cloud based wireless communication devices.

Demetillo et al. [12] proposed a cost effective and water quality monitoring system in real-time that can be used in remote lakes, rivers and other water resources. The major hardware in the system comprises of a microcontroller, standard electrochemical sensors, a customized buoy and a wireless communication system. The developed system is capable of detecting pH, dissolved oxygen and water temperature at preprogrammed periodic intervals. The developed system transmits the collected data in tabular and graphical formats over a personalized web-based portal and registered mobile phones for serving better to the appropriate end-users. For checking the efficiency of the system, the stability of the buoy in punitive environmental circumstances, energy consumption of the system, transmission efficiency of data and display of information in web based portal were evaluated prudently. The results of the experiment proved that the developed system has higher anticipation and could be employed for monitoring environment practically by giving end-users with pertinent and well-timed information for better action plan. Extension of the coverage range using autonomous surface vehicle is continuing for covering huge areas such as rivers, lakes and other such water resources that needs continuous monitoring owing to its prominence to both nature and humankind. Use of lithium-ion batteries as a source of power and the inclusion of heavy metallic ion as parameters of concern is furthermore deliberated for the extension of the work [14,15].

Anuradha et al. [13] developed a cost effective system for monitoring the quality of water in real- time using IoT. The developed method is a sensor based Water Quality Monitoring System that is used to measure chemical and physical parameters of water. The parameters like pH, temperature, turbidity and Total Dissolved Solids (TDS) of the water are measured using sensors and are processed by Raspberry Pi controller. Lastly, the measured sensor data is seen on the internet by using ThingSpeak API. The distinctiveness of this work is that the water monitoring system is having many advantages such as high mobility, high frequency and the developed model uses low power. Quality parameters like ammonia, hardness, conductivity, fluoride, iron, chloride content can be also deliberated for measurement of quality of water and the measured values are used for checking the cleanliness of the water for numerous applications like daily requirements for industries and drinking water.

S.A. Hamid et al. [16] designed and developed a Smart Water Quality Monitoring System (SWQMS), and the evaluation factors such as temperature and pH value of swimming pool was continuously monitored based on statistical tools such as Design of Experiment (DOE) and Analysis of variance (ANOVA). The findings of the experiment divulge that time, volume of the pool and the interaction aspects will not affect the value of pH, and time of day will have an effect on temperature of the water of swimming pool. It was witnessed that the developed system is proficient to update the water quality status of the pool automatically by means of IoT and adjust the pH level. The proposed system is also proficient to offer monitoring in real-time and needs less maintenance.

Gupta et al. [19] proposed model which automatically evaluates water quality parameters such as turbidity, pH and temperature. For underwater communication, ESP32 was used due to its low power consumption and inbuilt Wi-Fi. Communication modules, turbidity meter and pH sensor were integrated to develop the IoT based model. In addition, machine understanding algorithm using K Means was used to analyze the quality of water on the basis of pre-cogitated values. The developed model is locomotive and it monitors the water quality continuously in large and local water bodies. The readings are displayed on the website that can be retrieved by central pollution control board. Monitoring of water quality can be done from anyplace by using a robot. The developed model is of low cost and by using high speed Wi-Fi, the robot can communicate from underwater which makes this project self-reliant and efficient.

Taxonomy of research

In general water quality monitoring system consists of various sensors such a pH sensor, turbidity sensors, temperature sensors, conductivity sensors, humidity sensors and many other sensors. Fig. 1 shows the general block diagram of smart water quality monitoring system. As shown in the figure, core controller forms the heart of the system. All the sensors are connected a core controller and this controller controls the operation, gets data from sensors, and compares it with that of the standard values and sends the values to the concerned end user or authorities through wireless modules [17,18].

With the advances in IoT technology, the water quality monitoring system is becoming smarter with reduced power consumption and ease of operation. Fig. 2 shows the operating flow chart of smart water quality monitoring system.

The core controller is integrated with various sensors such as pH sensor, conductivity sensor, temperature sensor, turbidity sensor and many sensors. The sensor leads are placed in the water to be tested. The sensor values will be processed by ADC and the core controller reads the value and it will be uploaded on the cloud. The values will be monitored continuously by checking whether the sensor value is greater than threshold or not. If the sensor value is greater than threshold, then it will be

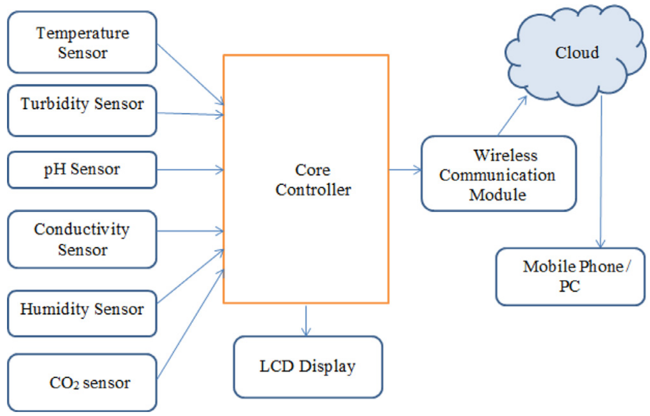

Fig. 1. Taxonomy diagram of water quality monitoring system.

communicated to the concerned end user for further action. If sensor value is lesser than threshold, then the parameters are again checked for different water source.

Schematic analysis

The schematic diagram of the proposed work is as shown in Fig. 3.

The work consists of two parts, the first one is hardware & second one is software. The hardware part has sensors which help to measure the real time values, another one is arduino ATMEGA328 converts the analog values to digital and LCD shows the displays output from sensors, Wi-Fi module gives the connection between hardware and software. ATMEGA328 has inbuilt ADC and Wi-Fi modules.

The water quality parameters are checked by one by one and updated in the cloud server as well as the values are displayed in the LCD display [20–22].

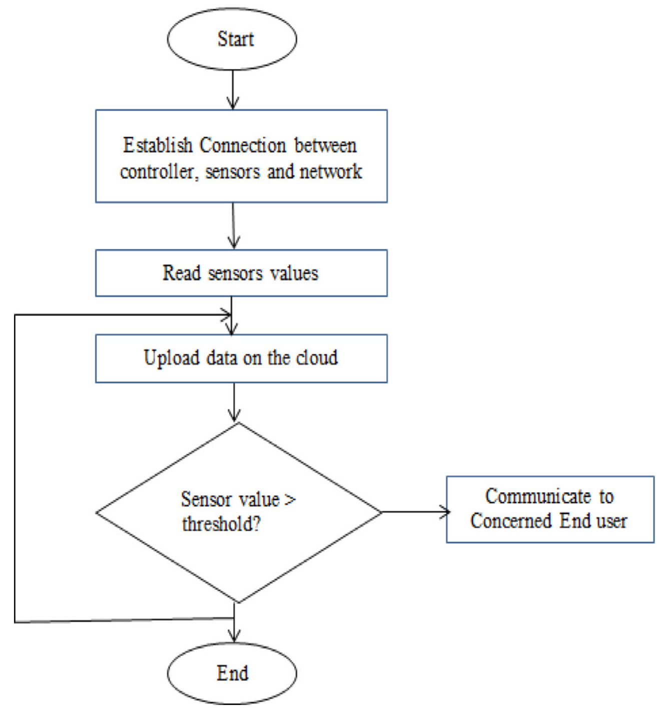

Fig. 2. Working of smart water quality monitoring system.

Table 1
Water quality parameter range for drinking water.

Parameter	Range
pH	6.5 to 8.5
Turbidity	< 5 NTU
ConductivityCarbon DioxideHumidity	200 to 800 µS/cm< 2.0 mg/L40% to 100%

Discussion

Due to the limited drinking water resources, intensive money requirements, growing population, urban change in rural areas, and the excessive use of sea resources for salt extraction has significantly worsened the water quality available to people. A smart water quality monitoring system is an essential device which monitors the quality of water continuously. Fig. 4 shows the developed model of smart water quality monitoring system.

As per the literature review, the range of different quality parameters for safe drinking water is tabulated in Table 1.

If the above listed parameters are in the specified range, then the water is safe for drinking. If these parameters are out of specified range, then the water is not safe for drinking purpose.

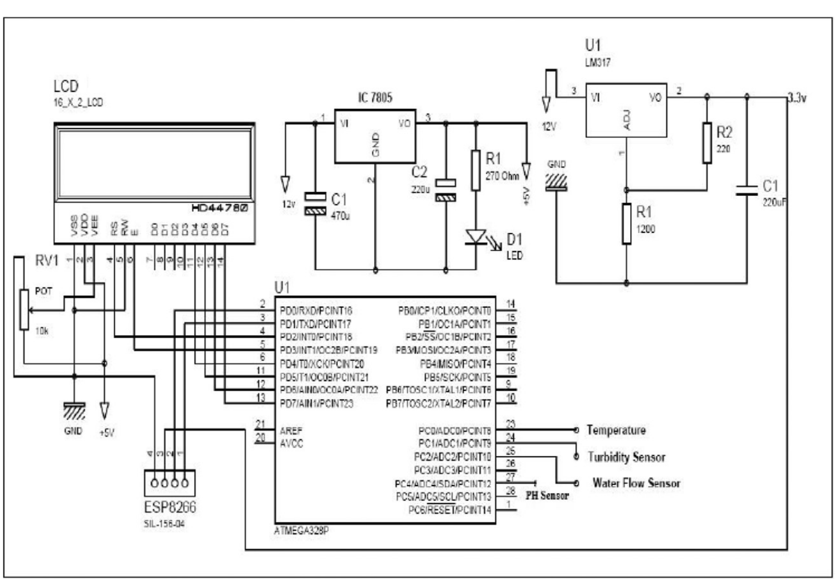

Fig. 3. Schematic diagram of water quality monitoring system.

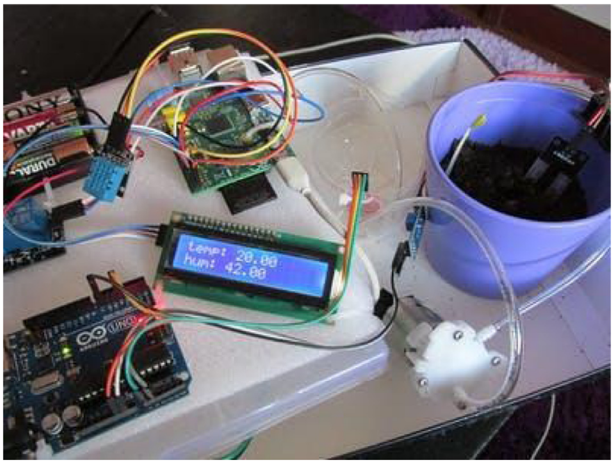

Fig. 4. Developed model of smart water quality monitoring system.

Table 2
Water quality parameters for different samples.

Sample	Parameter	Measured Value
Water Sample 1	pH	7.5
	Turbidity	4 NTU
	Conductivity	450 µS/cm
	Carbon Dioxide	1.20 mg/L
	Humidity	42%
	Temperature	20° C
Water Sample 2	pH	9.3
	Turbidity	5.6 NTU
	Conductivity	600 µS/cm
	Carbon Dioxide	1.820 mg/L
	Humidity	60.44%
	Temperature	29.4° C
Water Sample 3	pH	9.72
	Turbidity	5.33 NTU
	Conductivity	709 µS/cm
	Carbon Dioxide	1.89 mg/L
	Humidity	64.67%
	Temperature	26.4° C

The developed model is tested with three different water samples and the results are tabulated in Table 2.

From the analysis, water sample 1 is drinkable and other two samples are not drinkable.

Conclusion

Water Pollution is a major threat to any country, as it affects health, economy and spoils bio- diversity. In this work, causes and effects of water pollution is presented, as well as a comprehensive review of different methods of water quality monitoring and an efficient IoT based method for water quality monitoring has been discussed. Although there have been many excellent smart water quality monitoring systems, still the research area remains challenging. This work presents a review of the recent works carried out by the researchers in order to make water quality monitoring systems smart, low powered and highly efficient such that monitoring will be continuous and alerts/notifications will be sent to the concerned authorities for further processing. The developed model is cost effective and simple to use (flexible). Three water samples are tested and based on the results, the water can be classified whether it is drinkable or not.

As a future directive, the suggestion is to use latest sensors for detecting various other parameters of quality, use wireless communication standards for better communication and IoT to make a better system for water quality monitoring and the water resources can be made safe by immediate response.

Declaration of Competing Interest

We, the authors of the paper titled "IoT Based Smart Water Quality Monitoring Systems" hereby declare that the work included in the above paper is original and is an outcome of the research carried out by the authors indicated in it. Further, we declare that the work submitted has not been published already or under consideration for publication in any Journals/ Conferences/ Symposia/ Seminars. We also declare that the work does not infringe on any copyrights, property rights of others including licences and it is free from plagiarism. The authors hereby assign all copyright rights of the paper to Science Direct.

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