A Portable Water Pollution Monitoring Device for Smart City based on Internet of Things (IoT)

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Abstract. It has been observed that by 2050 more than 5 billion people could be affected by water crises due to increases in demand and water pollution. Potentially unhealthy conditions will need monitoring. This arising problem can be controlled or overcome by sharing the awareness of water acidity, temperature, salinity/conductivity, turbidity, contaminants etc. of surrounding water sources and then taking appropriate action. The purpose of this study is to design a sensor node and a sensor network strategy to monitor water pollution of a water source. The system is intended to cover a larger water area by implementing multiple portable sensor nodes on same network.

1. Introduction
Water is one of the primary sources and essential for human beings. There is only 0.3 percentage of water available for human use [1]. Therefore, it is important to keep track of available water resources and protect it from getting polluted. If the pollution level or status of water is identified, then it becomes easier to take measure to keep it clean and protect it from getting polluted further. At present there are manual methods for monitoring the water pollution which is not very convenient and requires lot of time and human efforts. As per the information given on the website of Central Water Commission (CWC), India, CWC is monitoring water quality at 552 key locations by collecting the samples by visiting those locations physically and testing it remotely. Therefore, the automated, remote, real-time water quality monitoring system is still needed in India whose performance as per the industry standards. This system can save time and extra human efforts and the water pollution information can be made available remotely any time its needed. In this study we propose and IoT based water pollution monitoring system whose objectives can be summarized in following points

- To design a sustainable, detachable sensor node for water pollution monitoring
- To design a network strategy that will cover larger area of water resources.
- To predict future condition for water sources for preventive purposes.
- To develop a network of devices that would monitor specific parameters (one or more as per the cost) for water pollution and produce the overall water pollution result (that would include all the desired parameter for a specific area)

2. Related Work
Much research has been conducted to identify the major water pollutants in various water areas. In research [2] the use of fuzzy logic algorithms in a broad temporal database have been conducted which
detects the pH level in water due to chemical processes. Islam M M et al [3] proposed a water pollution device based on IoT which can monitor water quality in real time consisting of detection parameters such as pH, Total Dissolved Solids (TDS) and temperature. Lin et al. in research [4] used Internet of Things (IoT) and blockchain technology integrated with Wireless Sensor Network (WSN), directed acyclic graph (DAG) and GIS software for real-time water monitoring. The system can identify various harmful substances in water sources. Chai F et al [5] developed a system to deal with sudden water pollution accidents. Their emergency dispatching system is designed using data mining, database, GIS and other technologies. Tomer et al in [6] proposed a system for ground water pollution monitoring which is based on DRASTIC method. Gupta et al in their study [7] developed a water monitoring system called AquaSight which can detect water impurity with the help of Convolutional Neural Networks (CNN). Duttagupta S et al in research [8] also proposed a groundwater monitoring system for microbial pollution detection. Another IoT based system proposed by Waleed A K et al [9] detects river water pollution using fuzzy logic. Kadir E A et al [10] developed a multisensory system for water pollution monitoring. To detect total dissolved solids (TDS), temperature, and turbidity in water sources Abdulrazzak I A et al [11] proposed an IoT based system. Wang J et al [12] also proposed hesitant fuzzy linguistic based system for water pollution monitoring. In [13] the multiple samples of water quality are collected using the system designed. In [14], another water quality monitoring system is developed using raspberry pi which works on different water pollution parameter. In [15], a low-cost water quality monitoring system is proposed that uses three parameters for monitoring. One more IoT based system with drone has been proposed [16] to monitor water quality. In comparison to above system the proposed system is detachable, portable, low-power and low-cost and can cover larger area. The sensor node in proposed system uses custom circuitry that allow it to consume very less power which makes it work on battery for longer duration of time. It is also easy to add and configure new sensors in the system and the system allows to remotely update the duration of sensing and sleep cycle and threshold value of the sensor [17].

3. Applications of the Proposed System
Following are the applications of the proposed system adopted from the Libelium Smart Water [18]:

3.1. Potable water monitoring
In portable water monitoring the parameters used are pH, turbidity and dissolved oxygen (DO). Identifying DO is an important factor of water quality which indicate the presence of microorganisms from various sources such as sewage, runoff from agriculture and factories etc. Turbidity is also important parameter to identify drinking water purity.

3.2. Chemical detection in Rivers
The system can detect pollution due to chemical leakage in rivers. It can analyze pH level and Dissolve Oxygen (DO) values and can also identify pollution due to sewage treatment plant.

3.3. Remote measurement
The system is designed to perform remote measurement. By the measurement of pH levels, Chloride levels and oxidation reduction potential (ORP) of water it can be determined if the water quality in water resources, such as swimming pools and other man-made resources, are safe for use.

3.4. Pollution levels in the Rivers, Ponds
The system can be implemented to monitor rivers and ponds. The system can measure pH, temperature, DO, salinity and nitrates and reports the water quality index of river (i.e., Ganga river) water.
3.5. Fish Tank Monitoring, Hatchery, Aquaculture, Aquaponics
The system can monitor the water sources which is the home for fish, prawns or any other water animals. The parameters used for detection are pH, DO, Ammonia (NH4), Nitrate (NO3-), Nitrite (NO2-) and temperature.

4. Methodology
The sensor nodes are deployed at the various locations at the target area. Sensor nodes upload data to cloud via network/internet. The following are the steps involved in the operation:

Step 1 – Sensor devices continuously sense the water pollution at target area.
Step 2 – Data collected by sensors at predefined time. This time may be adjusted remotely.
Step 3 – Data is uploaded to the cloud server for storage & analysis.
Step 4 – In case of pollution detection, alert is generated which can be notified via app or email.
Step 5 – If sensor node detects any anomaly in functioning, it is immediately reported to cloud with the help of ML on the edge. These anomalies may relate to sensor functionality attached in the sensor node or any other functioning of sensor node itself.
Step 6 – Stored data can be utilized for further research and prediction on future condition is also made by the system. The operations performed by system are as stated below. The system consists of 4 major components which are monitoring, reporting, analysis and sustainability. In addition to the above, the proposed system performs following standard operations as described by Lim W Q et al [19].

4.1. Monitoring
The system can monitor following parameters (the parameters are customizable. It means that new sensors can be easily added to sensor node and can be configured via application dashboard.) The current parameters for measuring are Acidity, Temperature, Turbidity, and Conductivity.

4.2. Reporting
The system uploads data collected by sensors to the cloud server. The system also keep track about the amount of data published by each sensor node. The Choropleth Map or Heat Map is provided in app for visualization purpose. The proposed system uses Low Power Wide Area (LoRa) as wireless communication network protocols. The reason for using LoRa is that it allows long-distance transmissions (which can cover approx. 10 km in rural areas) at very low power consumption. LoRa is based on peer-to-peer communication system which enables long distance direct communication between sensor nodes. This allows each sensor node participating in the network communication to send and receive data signal at the same time. Using this technique, a network chain is formed, and the data may be transferred even from the location that does not have internet connectivity. The data from sensor nodes will be transmitted to base station which decrypt the data and upload it to the cloud over Internet. The data packets contain information of the coordinate of nodes and water quality.

4.3. Analysis
The data collected from the sensors will be sent to Cloud for analysis. After analysing the data, the result is converted into visual that is user-friendly. For example, a Choropleth Map can be used to display the polluted area and graphical representation of various parameter values can indicate the pollution levels. System also has a feature, which can be used by end user, to report any pollution that they found on the waterway.

4.4. Self-Sustainability
The sensor node has been designed to monitor and report once two hours to reduce the power consumption (although this timing of sensing may be configured remotely from the application dashboard). Rest of the time device will remain in sleep mode thus consuming less power and live on
battery for a longer period. The system also able to capture and report status of malfunctioning devices in real time so that the necessary action can be taken.

5. System Architecture

![Figure 1. Block diagram of the Sensor Node](image1)

The overall system can be subdivided into three subsystems.

5.1. Sensor Node

Sensor node sense the water pollution based on described parameter and uploads the data to the cloud. The sensor node not only monitor the water pollution but it also performs some other tasks required for the functioning of the system such as charging the battery using solar energy for self-sustainability and analyse any anomaly with the help of machine learning on the edge.
Figure 3. Prototype of Sensor Node

5.2. Gateway Node
The gateway node receives data from all sensor nodes. The gateway node performs the protocol translation before transmitting data to the cloud. Gateway node receives signals from LoRa powered sensor nodes and sends the MQTT data to cloud server over Internet.

5.3. Cloud
Cloud server is responsible to store data uploaded by sensor node and perform data analytics. The Machine Learning algorithms on the cloud predicts the future conditions of the target area. The sensor node can be monitored and controlled via the application hosted at cloud.

| Table 1. Hardware components of the system. |
|---------------------------------------------|
| **Component** | **Description** |
| 1 | Sensor Node | ARDUINO MKR WAN 1300 or Arduino UNO + LoRa Module |
| 2 | Gateway Node | ARDUINO PRO Gateway for LoRa |
| 3 | Sensors | pH, Conductivity, DO, Turbidity, Temperature |

In the proposed system architecture sensor nodes, equipped with LoRa, can transmit the sensory data to the gateway node over LPWAN. The gateway node collects the data and further transmit it to the cloud server via MQTT protocol. The use of MQTT protocol makes the communication faster and reliable and both LoRa and MQTT protocol makes system energy efficient because it consumes less energy in transmitting data.

6. Results
The prototype of the proposed systems has been tested against the standards specified by WHO in following table. The system was tested in various conditions. The figure 4 and 5 shows the data stream visualize by application which has been developed for monitoring water pollution.

| Table 2. Limits specified by WHO for safe drinking water |
|---------------------------------------------------------|
| **Parameters** | **Quality Range** | **Units** |
| pH | 6.5 – 8.5 | pH |
| Turbidity | 5 - 10 | NTU |
| Conductivity | 300 - 800 | microS/cm |
The three parameters, as specified by WHO, have been taken to test water using the proposed device. Other parameters are also being added to the system. The pH measures amount of acid, Turbidity measure the cloudiness, and Conductivity measures salt content in the water. Using conductivity, we can also identify whether the water has ability to carry current. Using proposed system, various sensor data samples have been collected from 10 to 21 January 2021. The samples were collected on different test conditions on parameters such as pH, DO, conductivity, and turbidity. The system has been tuned to collect sample every two hours. In the above graphs, the samples with maximum values for each day have been displayed.

As a first test condition, water sample from home water filter has been taken. For the second test condition the samples from tap water have been taken. The prototype has also been tested by adding contaminants such as liquid and powder detergent, soil, and salt. The experiments have been conducted as described in research by Geetha S et al [20]. The following table shows the results.

### Table 3. Device testing in filtered water

|         | Sample 1 | Sample 2 | Sample 3 |
|---------|----------|----------|----------|
| pH      | 6.4      | 6.5      | 6.5      |
| Turbidity | 3       | 4        | 3        |
| Conductivity | 410     | 421      | 418      |

### Table 4. Device testing in tap water

|         | Sample 1 | Sample 2 | Sample 3 |
|---------|----------|----------|----------|
|         |          |          |          |
| pH   | 7.3 | 7.6 | 7.9 |
|------|-----|-----|-----|
| Turbidity | 5   | 6   | 5   |
| Conductivity | 523 | 535 | 518 |

**Table 5.** Device testing in water with soil contaminants

| Sample 1 (5mg soil) | Sample 2 (10mg soil) | Sample 3 (20mg soil) |
|---------------------|----------------------|----------------------|
| pH                  | 6.6                  | 6.9                  | 7.3                  |
| Turbidity           | 8                    | 11                   | 16                   |
| Conductivity        | 589                  | 610                  | 723                  |

| pH   | 7.6 | 8.4 | 8.9 |
|------|-----|-----|-----|
| Turbidity | 5   | 6   | 8   |
| Conductivity | 380 | 410 | 540 |

**Table 6.** Device testing in water with salt contaminants

The data in the above tables shows that the system has been tested in various conditions and is giving satisfactory results. The system has been designed to work in remote locations therefore it is operated on a battery and implements energy efficiency techniques [17]. The system collects the data at specified intervals and sends the data to cloud server. If the system detects anomaly in water, it immediately reports by sending alert.

7. **Conclusion & Future Scope**

The proposed system can monitor water pollution using various parameters and report in real time. If the pollution level is critical, it generates the alert. The system is easily customizable. The most important features of the system include less power consumption, adjust duration of sensing remotely and easy to configure new sensors etc. In future the system will have other features such as energy harvesting, which will make the sensor node sustainable for long time duration. As a part of energy harvesting the system will include solar and wind energy which will charge the battery. The solar panels, wind turbine is also detachable. The second feature would be self-monitoring in which if any part of device is damaged or malfunctioning of sensors and other components occur, the device will send a distress signal to cloud. The signal will include its current position of device and details of the problem occurred. The problem is identified by device itself by on-device intelligence. Lastly the
system would also predict the future pollution condition based on historical and current data of water sources.

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