Smart Wastewater Management System Leveraging IoT for Real-Time Monitoring"

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Abstract:
Waste water treatment is the most crucial step towards reducing the degree of waste water pollutants to a manageable level for nature to process. Industrial waste remains the greatest challenge to the treatment process in many sewage treatment plants than any other problem that operators of these plants face handle. Probably, these factories are not built to be able to deal with these pollutants and the quicker degradation. of the structures of sewage treatment plants. In this work, we offer a novel cloud-based industrial IoT model for real-time monitoring and management of waste water. The proposed system monitors the power and readings of the hydrogen's pH, temperature readings from the inflow of waste water that the Treatment Waste water Plant will process, thereby avoiding industrial wastes too large for the facility to accommodate. The system collects and uploads real-timesens or data to the cloud through an Industrial IoT Wi-Fi module. Also, it gives information on observed or unexpected industrial waste water inlets were detected with the help of SMS alerts and sirens, and valves were controlled on all gates. This is necessary because the water should be redirected to the industrial waste water treatment plant that will help able to handle this kind of garbage. Experimental research demonstrates how successful the suggested system is in comparison to relevant work.

Keywords: Industrial IoT (IIoT), Wastewater Treatment, Real-Time Monitoring, Cloud-Based System, Sensor Data, SMS Alerts.

Introduction

Waste water treatment eliminates impurities, making the water both fit for reuse or safeties released into aquifers, rivers, and oceans. These water sources are laden with untreated or under-treated effluent that deprives them of their quality. In an endeavor to protect the waters of the Nile and other streams, Egypt's Law 48 of 1982, in addition to Decree No. 8-1983, man date that only treated waste water should be released into water courses. However, emerging economies face challenges including the lack of infrastructure, finances, and advanced medical science. Biological treatment, which utilizes bacteria to remove pollutants from water, is commonly utilized because it is less expensive than chemical or thermal treatments. For the micro or ganisms within these environments, optimal conditions in pH, temperature, and oxygen levels must be maintained. New technologies, such as the Industrial Internet of Things (IIoT), offer dynamic real-time solutions for waste water management and monitoring. These technologies have advantages in dynamic real-time solutions over conventional techniques and will help to enhance sewage plant pollution control. This research discusses the advantages, difficulties, and potential of an integrated cloud-based Industrial IoT paradigm for wastewater monitoring.

IIOT & Its Contribution in Wastewater Management:

The IoT is also changing connectivity and the interaction between humans and machines and is increasingly fuelling significant social and industrial change. According to forecasts, IoT connections worldwide will grow from 35 billion in 2020 to 83 billion in 2024 largely due to industrial applications. IoT is defined as a network of linked devices that can send, receive, or process data. This defines the Industrial Internet of Things (IIoT), which combines technology, software, and human components in industries to improve efficiency and save costs. With IIoT, sophisticated monitoring and optimization are achievable by using sensors and equipment that measure critical parameters such as pH, temperature, and chemical composition in processes like waste water treatment. Combinations of IIoT with technologies such as computerized maintenance systems can help industries enhance real-time monitoring, efficiently manage maintenance, and ensure adherence to water quality regulations. This game-changing technology ensures that treated wastewater satisfies safety standards before release into the environment and promotes better environmental management while increasing production.

Literature Review

Many research works have discussed IoT and Industrial IoT applications in environmental remote monitoring and control. Water and wastewater quality systems found applications. Other available options for IoT and Industrial IoT middle ware for monitoring and control of water and wastewater quality from a distance are shown below. A real-time low-cost Internet of Things-based water level monitoring device was presented. The ultrasonic sensors collected the water data, and it was hosted by a custom cloud server. On the web- based remote dashboard, the measurements of the water are shown. The earlier system had a Twitter handle and had a buzzer alarm in its alerts system. This device monitors the level of the tank with respect to water but does not control the water flow automatically and reminds the users. There adding of water level from the tank and ultrasonic sensors might not be highlyaccurate. a smart water system with an auto water pump on/off feature was built in order to halt water leaks or overflow. The authors detected the water level using laser sensors, and the sensor results were sent to the Adar-fruit cloud platform via a Wi-Fi module via HC12. The design of the cloud platform was supposed to be able to depict graphically the level of water and the current status of water in real time. Another research paper shown in[25], which intends to eliminate the complexity with high cost implied by current methods through the use of an IoT module to relay data fromthe water parameters. Based on the sense time interval, power consumption of the proposed system was minimized. This method, however, shows the data on the LCD and web server without any graphical representation of data by time. A comprehensive smart monitoring system for detecting water quality is provided in [26].

TasikUTeM" is where the system is tested and floated and data is gathered for two assessments using both online and offline measurements. The sensor data sent to "ubidots" platform database via "WeMo's D1" Wi-Fimodule. However, the system theyareproposinghasreliedonthetwoapproaches of recording the data in the database using the Ubidots platform and a graphical representation using the "Wix Webpage" platform for just two parameters using pH and turbidity sensors.

it makes use of cloud computing in industrial environments. It uses the RaspberryPi as a module for communication to be used in remote monitoringandcontroltodevelopasmartindustrial system that can identify anomalous behavior and equipment failure. Their proposed architecture can easily be scaled up to a wide range of Internet of Things applications where fast and accurate decision making may be made possible based on data sets gathered for analysis. The proposed a new SCADA system that employs the use of IoT technologies to monitor real-time water quality.

The SCADA server was in charge of data analytics, which then started to generate reports for the web and a mobileapp. Meanwhile, theytried to overcome the limitations of the already existing SCADA systems, such as the difficulty in implementing a new sensor because the Plc controller and SCADA are connected through a cablenetwork. AGSM modemandan Arduino"At mega 328" microcontroller were used. The technology is inexpensive, lightweight, and compact, but it may work better if the tasks related to control could be automated.

Existing waste water monitoring & Controlling System

Traditional inlet waste water monitoring methods include the collection of water samples through manual means and then the sensor reading through manual observation, which is later analyzed in a laboratory using analytical techniques; these are no longer considered efficient and may take a long time to complete.

Presenting System Elements

The current system for presenting elements that monitor industrial wastewater discharged into the waste water treatment plant comprises the following elements

1. Analog pH electrode: the inflow pH of the waste water is monitored using this electrode.
2. A pH transmitter with a display: this device gives a display of pH values.
3. SCADA system screen: this is used in monitoring in real time all the measurements done from the instruments.

Watches the pH levels on a read out to regulate the system during his shift. If the pH drops below 6.5 or rises above 9, it means that it contains industrial effluent. The worker then sends the water to an industrial waste water treatment plant by closing the intake gates, thus preventing water from entering the facility. The worker reports the incident to managers and observes the pH until its stabilization and reports the time, reading, and action in a daily sheet. Meanwhile, the SCADA operator monitors the SCADA screen's operation and equipment readings. The operator remotely closes the gates and gives instructions to staff to monitor visually until normal pH levels are restored if aberrant readings are found. Every activity, along with time stamps and readings, are recorded in the SCADA report for further review.

Existing System Limitations

Poor Temporal and Spatio Coverage: A spatiotemporal covering is very useful when we need to gather data produced by multiple entities at the same time and place. The effectiveness of wastewater treatment management strategies will certainly be impacted upon through the study of wastewater quality data which must be robustly scrutinized from spatial as well as temporal perspectives. Due to the very small number of sensors, this system currently offers hourly temporal monitoring through individuals with sparse coverage. Due to the very high initial and running installation costs mainly for urban applications, there could be a limit to the locations the sensors could be placed. This means there lacks proper spatiotemporal resolution to understand the extent to which industrial waste water discharges are exposed to the inlet of the wastewater.

Not Scaled Autonomy: Adding more sensors to the current system is difficult because most of them use PLC controllers with analog/digital modules and the installation and connection will be expensive. Scalingis needed for the proposed system so that more sensors can be added in the same area without increasing the price.

A Lack of Critical Decision Making And The Impermissible Wastewater Warning Methods: The system is based on human monitoring and control but if the monitored person is not viewed, then it can be averse to the equipment and the treatment process. There are no other warning techniques that can trigger workers to act immediately in order for them to avoid injury.

Inequality: If the industrial effluent is discharged, the existing system requires instant decision-making and ongoing monitoring. Traditional approaches in the existing system require large numbers of personnel who are qualified to handle various types of waters for continuing monitoring and control, which comes at an expensive cost for this number of workers. An automatic control option selected in monitoring and operating the discharging gates and managing the collected data will need high-precision equipment.

Proposed System

As mentioned earlier, the existing system has several disadvantages to the efficiency of the station concerned in these wage treatment. For overcoming all these constraints, our proposed system needs the following: (1) scalability through the addition of several sensors at the lowest possible cost; (2) temporal and spatial coverage through monitoring data; (3) further security options for guarding against attacks; (4) data analysis with a facility of generating reports, thus increasing system efficiency; and (5) Provision for a warning system that should enable such email, voice alarm, and SMS alerts.

SYSTEM OVERVIEW

The proposed industrial wastewater monitoring system architecture aggregates the information about such variables as temperature and pH and transmits them to a remote web server that can be accessed from any location in the world. When the industrial wastewater is detected, an SMS message is sent to the monitoring centre, and the inlet gates are shut off by the solenoid valves, and the water then finds its way into an industrial treatment facility. A database server maintains a record of temperature and pH data from pumping stations and treatment facilities to aid in predicting when and where industrial waste might enter the system. The three major components in the system consist of an IoT cloud platform, an IoT gateway device, and IoT sensing devices. Sensors collect data, which the IoT gateway then sends to the cloud platform through a wireless or cellular connection.

This data is stored in a database for processing. To ensure effective data collection, processing, and accessibility, the core elements of this system comprise a power source, sensing devices, connectivity with the cloud, data management, and a user-cloud interface.

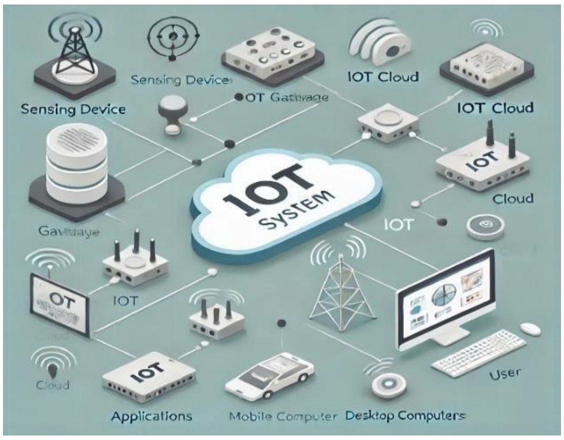
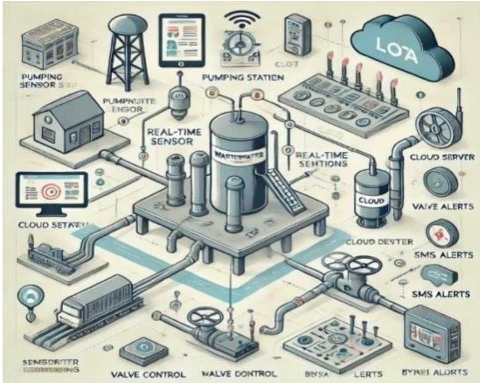


Figure 1: Overview of the Wastewater Monitoring and Management System.

The received data from the sensor are stored in the database for further data processing or application development. Using an application programming interface to allow a user to send a specific command to the IoT cloud, the IoT cloud should use an IoT gateway in relaying this to an IoT device. The five main components include Power Source, Sensing Devices, IoT Device to Cloud, Data Management and Cloud-to-User Interface. The collected sensor data, that have reached the cloud system, are harvested by the data



storage component.

Figure 2. General environment of the IoT Wastewater Monitoring and Management System.

System Architecture: The activity flow of the system is shown in Fig. 4. Figure5 depicts the structure of the system: central server and modules with many sensors for communication. In the design, there are measurements of pH and temperature conducted by sensors at the inlet of the wastewater plant. After that, the sensed data will be transmitted bythe IoT Module to a server monitored inrealtime and then will be shown on an LCD near that location. The IoT module will regulate the plant's intake valves through sensor data so that industrial effluent is not permitted to enter. When the sensors' reading exceeds and goes below the setpoint, an alarm message is sent to the phone through a GSM module, while the plant plays a sound alert. The valves return to its normal function until the sensor readings stabilize; that is, to allow waste water to go in. The user can predict when the industrial wastewater is going to reach the treatment station by sending an order through the monitoring screen to the server, which receives it and forwards it to the IoT module to remotely control the inlet valves when he identifies alerts from one of the pumping stations. The information collected on the server aids in preparing various reports to the concerned authorities.

IoT Cloud: Integrating the Internet of Things (IoT) with cloud computing optimizes their capabilities, leveraging the cloud's vast storage and processing power to handle IoT's distributed networked devices. While platforms like Blynk, ThingSpeak, and Google Cloud offer such integrations, they can be costly and complex, requiring extensive knowledge of APIs and third-party services. To simplify this, a custom IoT dashboard was developed, allowing for device connectivity, data tracking, and storage without relying on third-party solutions. This approach gives full control over hardware, coding, and linking devices, using programming languages like PHP, C#, and ASP.NET. The dashboard manages sensor data, active devices, and commands sent to IoT modules via GSM or Wi-Fi, storing and analyzing data for visualization and prediction. Key features include listing active devices, adding new device details, generating daily and weekly sensor and fault reports, and remotely controlling IoT devices through a web server integrated with an Arduino-based IoT module.

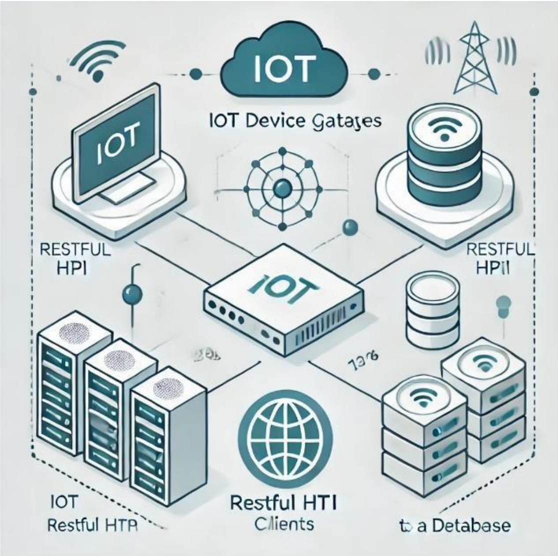


Figure 3: REST Full interface design

This may be further managed according to our needs. From data gathering to the final user experience, everything remains at our discretion to be modified, integrated, and maintained. Security is always the utmost priority; in our opinion, this is the riskiest aspect, but we will definitely overcome it. There are five major parts of the proposed system which are the cloud-to-device interface, data management, authentication, and cloud-to-user interface. The cloud-to-device interface is just an endpoint for data transmission between the cloud platform system and its equivalent IoT device.

Once in the cloud, the interface of communication makes contact with the authentication component in order to verify the legitimacy of the relevant IoT device. The elements of the components of an IoT building block comprising of identification, sensing, networking, computation, services, and semantics is discussed.

Results & Discussion: The plant has temperature and pH sensors; the latter collects data every 15 minutes. The data are received by an Internet of Things module, then analyzed and uploaded to a web server for real-time viewing. As stated, although the sensing period can be changed based on the operational needs, the system runs continuously since it renews every five seconds. The live graphs by the web server enable monitoring and analysis using data gathered from many pumping stations. For example, the pH at Pumping Station 1 reduced from 7.82at4:20PM on September 28, 2024 to 5.18 at 4:36 PM on the same day, while at the treatment plant, it reduced from 7.92 to 5.42 at 5:05 PM, indicating the release of industrial effluent. To prevent industrial effluent from penetrating the plant, the system may respond by diverting input gates. In order to ensure effective monitoring and management, all measurements are taken for later review.

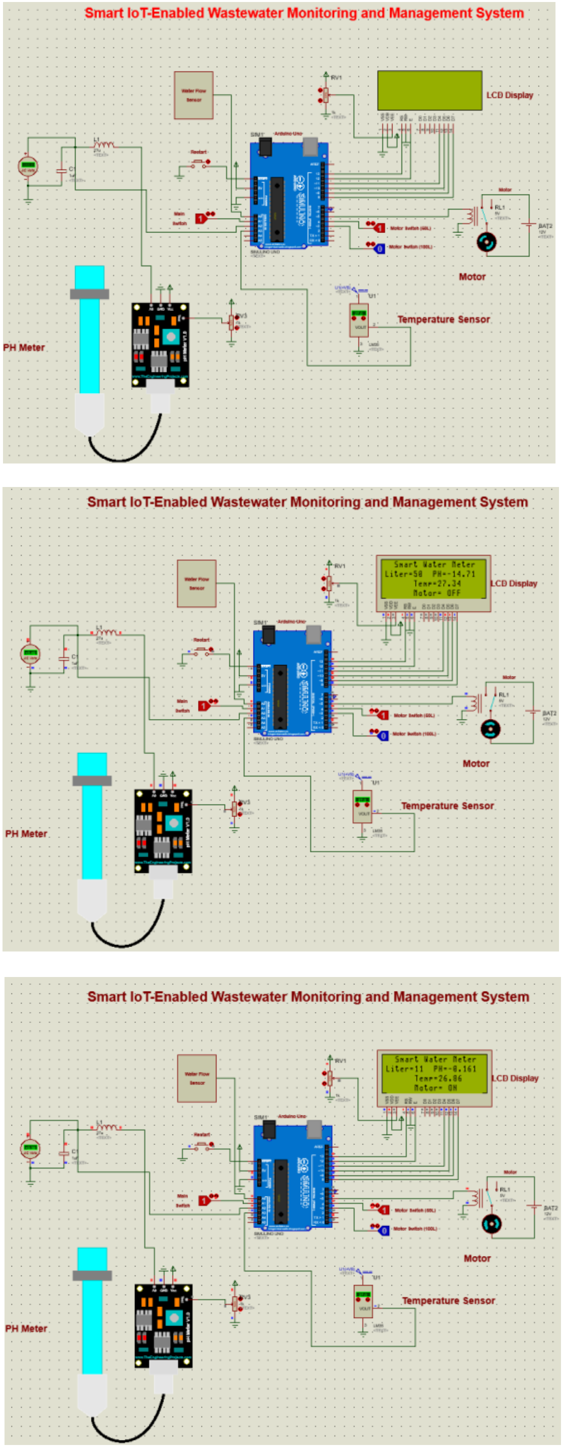


Figure 4,5 & 6: Outputs of the Wastewater Monitoring and Management System

Due to the enormous quantity of industrial wastewater discharged, the OFF gates with buzzer alarms, red LEDs on its alarm notification, SMS notification to the supervisor, and alarm notification on the monitoring dashboard were triggered bythe sensors in the treatment plant. The supervisor can monitor the inlet water visually and detect the color of the water, which by experience informs us about the kind of industrial water.

Thanks to the notification alarms by the pumping stations (SMS, web notification), the supervisor may foresee when the water would arrive at treatment plant, depending on distance and follow-up between the pumping station and the treatment plant.

Conclusion & Future Work: A compact, affordable, adaptable, easy to configure, and portable system that would be capable of monitoring and regulating the discharge of industrial wastewater into treatment facilities, protection of the equipment and process of treatment from damage, as well as the employees who are not equipped to handle such water, were the major objectives of this research project. The system verifies the alarming messages and the water parameters, therefore the dependability and feasibility for the monitoring processes could be achieved, making it more adaptable and controllable. This research protects the natural eco system of the water resources. The comparative study states that the proposed system is more superior to the present system and related work. Hopefully, other factors of water will be incorporated into future research so it is possible to analyze every water parameter. For such an application in consumer networks, additional creativity will be required to develop a custom dashboard using the mobile application. Extra sensors would be used in adding physical metrics including DO, turbidity, conductivity, residual chlorine, and waste water flow to the system for presenting a comprehensive SCADA system that combines with IoT technology to have real-time monitoring of all pumping stations and treatment facilities. All of the equipment was automatically controlled based on results, and users were notified by SMS when values were aberrant and what was to be done. Moreover, in wireless networks used for transferring sensor data, avoidance of unauthorized access is of much importance. The incorporation of machine learning to the system will be a great addition.

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