A Minimalist Model of IoT based Sensor System for Sewage Treatment Plant Monitoring

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***Abstract*—This paper presents an effective IoT approach to monitor a Sewage Treatment Plant (STP) status using a small set of critical sensors connected to Arduino microcontroller boards communicating using Wi-Fi networking technology. STP plants are very crucial to maintain environmental safety. The method discussed in this paper applies three critical sensors to measure the sewage plant's status and sends the data to a cloud-based local server in real-time. These three sensors are temperature, turbidity and pH sensors. Besides, STP's power consumption status is also monitored to identify any intentional shutdown of the plant. On the visualization side, a web-based application shows time-stamped data in different time scales of the changing status of the STP. The data are stored in a secured cloud system for further analysis. The sensor set used in the system has been proved effective to monitor operational status of STP plants and gives us a cost-effective decision-making tool for running a STP installation remotely. Our experience shows Arduino based Wi-Fi module used in our system is more cost-effective than a GSM based system for applications at underground levels.**

Keywords—Sewage Treatment Plant monitoring; Effluent Treatment Plant monitoring; IoT based plant monitoring; Water quality monitoring; Arduino; Raspberry Pi; Wi-Fi; PostgreSQL; database; Temperature Sensor; pH Sensor; Turbidity Sensor; STP; ETP

I. Introduction

Protecting the environment from industrial wastes has become one of the most difficult challenges of twenty-first century. One of the most important pollutants is from the untreated wastewater released to the environment. For the health and well-being of the citizens, the wastewater discharge from industries has to be processed and monitored before releasing into the environment. For this reason, it is mandatory in many countries to install a Sewage Treatment Plant (STP) in industries those release water to the environment. The project started with the observation that a significant amount of wastewater in Bangladesh comes from medium and large industrial units located in major cities all over the country. Even though there are strict government regulations requiring local industries to pre-process wastewater before releasing, such directives are frequently ignored. The reasons behind such malpractices are due to the concern of cost savings by plant owners, unawareness to the public good, poor understanding of moral responsibilities and lack of any efficient monitoring system.

A GSM based monitoring system has been proposed in [1]. For monitoring estrogens in STP and river water, [2] has proposed a system to monitor certain estrogens found in STP before decomposing into river water. Due to rapid industrialization in Bangladesh and other alike developing/underdeveloped and also few plants in developed countries, untreated wastewater discharge has become a major problem for localities, agricultural lands, rivers, and water reservoirs. As such, to ensure compliance by these industries, centralized Internet-based real-time wastewater discharge monitoring systems are to be built, which should be user friendly and easy to monitor. Any such monitoring system can be a great help for the government and can have a significant impact on environmental protection. However, to make such system widely deployed, it has to be affordable to the local industries and sustainable in its operation through limited government subsidy or subscription by the plant owners and support from local communities.

This paper is presented as follows: A detailed literature review is given in Section II. Methodology is discussed in Section III. Hardware description and the experimental setup are shown in Section IV and V. System architecture is given in Section VI. Result and validation are discussed in Section VII and system security is described in Section VIII.

II. Literature Review

In recent years, there have been considerable interests in monitoring water quality using sensor networks. Lambrou et al. [3] describe different types of low-cost sensors in the real-time network environment to monitor water quality. Their work shows a detail analysis of sensing parameters and their relationships to water quality. Lambrou et al. also developed algorithms for analog signal conditioning, processing, logging and remote presentation of data. Hangan et al. [4, 5] have built a wireless sensor-network based data acquisition system for water quality monitoring named "Cyberwater Platform". Cyberwater platform has been used to monitor water quality in rivers. Salah et al. [6] and Popescu et al. [7] have developed decision support systems (DSS) for water quality management. Both systems provide useful suggestions to improve water quality. However, the above-mentioned works are focused more on water quality than the monitoring of Effluent Treatment Plant (ETP) plants.

III. Methodology

Studying the proposed models, the research team aimed to develop an economic solution for real-time monitoring of wastewater treatment facilities' using wireless sensor networks, modern data processing facility and Internet-based wide accessibility, which is capable to provide information for regulatory compliance and reduce environmental impacts. The STP set up takes raw sensor input from inlet and outlet tanks. The raw data temporarily stored in the Raspberry Pi-based local data concentrator, which is then fetched through Ethernet network by the local server setup by research team. The raw data needs encoding to be interpreted. To do so, STP standard value has been followed which is set by Ministry of Environment of Government of People's Republic of Bangladesh. The research team entered the government approved normative values through a web interface, which also generates graphical presentation of the raw data fetched from the sensors. The graphical representation gives alert if certain sensor value goes above or below the threshold value.

Before conceptualizing the system architecture, the research team investigated remote sensing techniques for monitoring water quality, which includes choice of sensors, dipping method, system security architecture, cost analysis, and longevity of the operating sensors of the treatment plant and algorithms to detect the unusual pattern in the discharged water on the environment. After the primary study, the model presented in this paper is believed to be a low-cost, reliable and secured water quality monitoring system for the industrial treatment plants. To achieve these objectives, the following research tasks had been accomplished:

A. Identification of monitoring parameters:

Different types of water quality sensors have different monitoring requirements. For instance, suspended particles in water flow may change frequently. As such a turbidity sensor (measures cloudiness) needs frequent sampling rate. On the other hand, the temperature of the discharged water may vary slowly and may not have any immediate environmental impact. Hence temperature sensor may not require very frequent sampling. In this phase of our research, we identified and tailored these optimization methods. We also developed techniques to monitor the electrical infrastructure (the running condition of the treatment plant), so that if plant owner suspends the STP's operation, that can be detected on real-time. Our investigation also included error detection and correction during these sensing phases.

B. Internet-based Decision Support Application:

A web-based application has been developed for the monitoring system. The system displays different water quality parameters continuously to give a visual feedback to the users. We have also developed few rules which are incorporated into the database system that generate alerts if any unexpected change of any parameter is detected. The objective has been to identify any compromised state of the plant based on a set of customizable rules. The web application is available round the clock and provides necessary information which could be useful for regulatory control by the government.

IV. Hardware Components Description

The hardware connection is done by using three **Arduino UNOs** which are connected with the aforementioned sensors in this section. The Arduinos are connected with Raspberry Pi using Wi-Fi. Raspberry Pi is connected with the central database using the Internet (through Ethernet network in our setup). The devices are installed into the STP/ETP's wastewater tanks through floating foam support, as the sensors' array has been suggested to float above the surface water for better longevity. If the sensors array gets installed just in front of the opening valves of inlet and outlet tanks, the flow of water keep the sensors safe from garbage clotting and thus from any damage from the accumulation. At the same time the actual value from the freshly received water can be acquired in this procedure. Following Fig. 1 shows how data from the sensor array, collected into the Single-Board Computer (SBC, Raspberry Pi) through Wi-Fi wireless network had been sent through an Ethernet network to a centralized Server.

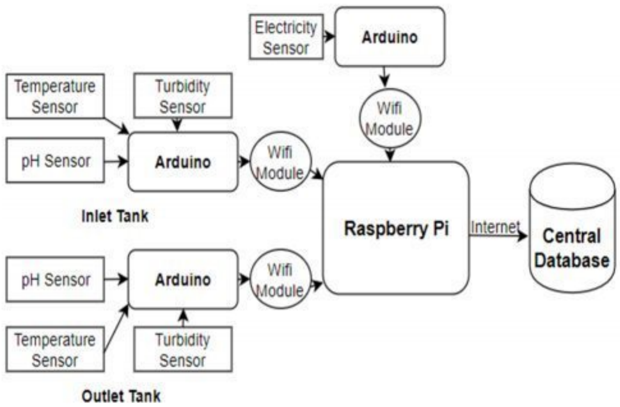


Fig. 1. Implementation of hardware connections for a single Inlet/Outlet sensor array.

We have used six sensors which are connected with Arduino to collect the data from the STP's wastewater. In Fig. 1, we can see that Wi-Fi Module, Temperature Sensor, Turbidity Sensor, pH Sensor and Electricity Sensor, and are connected with Arduinos. Then the Arduinos are connected with Raspberry Pi using Wi-Fi Network. The description of our testing devices is given below:

Wi-Fi Module: ESP8266 Wi-Fi Modules are embedded with **Arduino UNO** and using this network the three Arduino UNOs have been connected to Raspberry Pi. The arrays of sensors which are connected with Arduinos send the data to the Raspberry Pi with the help of Wi-Fi Modules. Raspberry Pi is connected with the central database using the Internet.

Temperature Sensor: The temperature Sensors are connected with Arduinos which collect the temperature of wastewater in both inlet and outlet tanks. From both tanks, the temperature data are sent to the server.

Turbidity Sensor: The turbidity sensors are used to measure the amount of light that is scattered by the suspended solids in water. We have used turbidity sensors to measure the quality of the wastewater. Initially, when the wastewater comes across the inlet, the amount of solid materials is higher. We have used turbidity sensor in both inlet and outlet points, so we can measure the turbidity of wastewater both before and after the treatment. Turbidity sensors connected with the Arduino's will send the data to server and the user will be able to see the status of both tanks and also compare the water turbidity quality between the inlet and outlet.

Electricity Sensor: Electricity Sensor (Current Transformer, CT) is connected to the main power supply to calculate how much current it is supplying. From electric sensor we can remotely monitor if the plant is being run or not without being present in the plant physically. If the machines are turned ON then the electricity sensor will show the amount of current it is supplying. At the same time, the sensor will identify the current state when the STP machines are turned OFF. This power status data will be sent through Arduino to Raspberry Pi.

pH Sensor: To measure the quality of the wastewater we have used pH Sensor which show whether the water is acidic or alkaline, and if the desired pH level has been achieved through treatment.. pH Sensors are connected with Arduino and are immersed in both inlet and outlet. The wastewater pH data from both tanks are sent to the server.

V. SYSTEM SETUP

The experimental setup was established in the basement of North South University (NSU), Dhaka, Bangladesh, within their own STP plant which is alike any industrial STP plant. Two sets of sensor modules had been installed for data collection in two locations: 1) inside inlet of the raw STP water container and 2) inside the outlet of the STP treated water.

The actual devices that were built and how those were installed at the STP are shown in the following figures (Fig. 2 to Fig. 4)

Fig. 2: The STP setup at the basement of the NSU

Fig. 3: An STP data acquisition device.

Fig. 4 (a). (Left) An STP data acquisition device in active (on power), (b) (right) An STP sensor module has been floating in the outlet pond (basement 1 of NSU)

Sensors mentioned in Section V had been installed in each of the modules and the sensors communication was set with two separate Arduinos installed outside the tank of the STP plant. The raw data received by Arduinos were sent by the built in Wi-Fi Modules to a Raspberry Pi based local data concentrator which was used as the initial storage for all data points. The Raspberry Pi data were then sent to a local server established by the authority of North South University for online monitoring.

VI. System Architecture

A. System Overview:

IoT based systems as proposed in [8] is ideal for building smart and user-friendly monitoring system. In order to build a good IoT based system, it is highly recommended to look for to use efficient and high life cycled sensors with a user-friendly interface, which would not be hard to be used for non-technical persons. Table I describes the overview of the installed devices in the implemented system, their model no. and the reason of proposing the particular devices**.**

TABLE I. List of installed devices in the system implemented and the objective of the choice.

Device Name	Model No.	Qty	Why is it used?
Arduino Uno + Wi-Fi	ATmega328P +ESP8266	3	It is a customized version of the classic ARDUINO UNO R3 board. Full integration of microcontroller Atmel ATmega328 and IC Wi-Fi ESP8266 with 32 MB flash memory, and USB-TTL converter CH340G on one board. All modules can work together or independently.
Raspberry Pi 3	Model B+	1	it is small in size, and it works as a normal computer at low cost server to handle web traffic
pH sensor	SKU: SEN0161	2	As pH is a vital variable that indicates the water condition. pH closer to 7.00 means the waste water is safe as normal water.
Turbidity Sensor	SKU: SEN0189	2	As water clarity is a vital variable that indicates the water condition. Turbidity sensor measures water clarity in NTU. Lower the NTU value means clearer the water.
Temperature Sensor	DS18B20	2	To measure the temperature of the water.
Current Sensor	SKU: 101990029	1	To check whether the ETP plant is running or not.

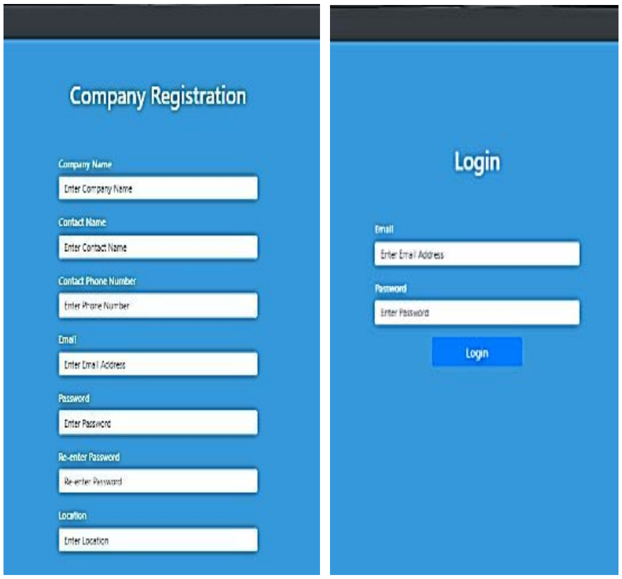
The application architecture has been built with a web interface, which is easy to monitor and configured as secured and protected. The raw data received from the plant gets interpreted in meaningful visuals for better understanding by the authority. The system alerts the admin panel as soon as any anomalous data is received by the system.

For the safe storage of data, two steps back up method has been adopted. The raw data first gets to the Raspberry Pi which keeps running 24 hours and collecting data points at 10 second intervals. The raw data from Pi server gets transferred to the central database for data analysis, web projection and other works. As a result the chances of data loss are very minimal.

B. User Interface to monitor the system:

To visualize the sensors' interpreted values and understand the state of the STP, a user interface has been developed. In the implemented method, it is suggested to show the data in graphical format through line graph presentation. The raw data, upon the test performed in laboratory, following the standards of Ministry of Environment of the country has been interpreted to get the standard value and threshold values which are 7.0 for pH sensor and 5.0 for Turbidity sensor [3]. Upon these values, the web interface works.

Fig. 5: Sensors' list to shown to the user with respect to time period expected by the user.



(a) (b)

Fig. 6: (a) ETP/STP plants registration page, (b) Login page to monitor one STP plant.

For monitoring a number or STP plants the interface has the option to register other plants in the system to be monitored. Fig. 5, 6(a) and 6(b) demonstrates the user interface.

VII. Result and Validation

The system had been tested at North South University's own Sewage Treatment Plant (STP). Data from the sensors are validated at the Environment Science and Management Department's (ESM) lab of the same institution. Turbidity is indirectly relatable with Total Suspended Solids (TSS) found in water samples. Such turbidity-based monitoring has been suggested in [9] which has inspired us to use in the model. Besides the proposed model in [10, 11] has also done relatable work using turbidity and TSS values. The lab test conducted by the research team found relatable data with TSS and Turbidity values comparing unprocessed and processed data. The research team reviewed the correctness of the results and found that the implemented system acquires data consistently. As our data acquisition rate is very high (every 10 sec), to ensure precise monitoring, a huge data stack is built up in the server. The raw data is stored in csv format and authorized accessed can be given any time if needed. Fig. 7 and Fig. 8 demonstrate the snapshot of ten second interval stored data values for 100 seconds.

	A	B	C	D	E
1	temperatu	turbidity	PH	oxygen	dateTime
2	25.19	44.48	10.29	2	2/19/2019 12:1
3	25.19	5.34	10.31	2	2/19/2019 12:1
4	25.19	17.79	10.29	2	2/19/2019 12:1
5	25.19	37.89	12.14	2	2/19/2019 12:1
6	25.19	16.7	12.3	2	2/19/2019 12:1
7	25.13	18.77	7.94	2	2/19/2019 12:1
8	25.19	6.35	9.86	2	2/19/2019 12:1
9	25.19	5.35	9.09	2	2/19/2019 12:1
10	25.25	48.71	9.04	2	2/19/2019 12:1

Fig. 7. Data points acquired for 100 seconds from Inlet Tank.

	A	B	C	D	E
1	temperatu	turbidity	PH	oxygen	dateTime
2	24.63	4.06	8.14	2	2/19/2019 12:14
3	24.63	4.07	8.14	2	2/19/2019 12:14
4	24.63	4.07	8.14	2	2/19/2019 12:14
5	24.63	4.08	8.13	2	2/19/2019 12:14
6	24.63	4.08	8.14	2	2/19/2019 12:14
7	24.63	4.07	8.14	2	2/19/2019 12:15
8	24.63	4.08	8.14	2	2/19/2019 12:15
9	24.63	4.07	8.14	2	2/19/2019 12:15
10	24.63	4.07	8.14	2	2/19/2019 12:15

Fig. 8. Data points acquired for 100 seconds from Outlet Tank.

The web application shows the water quality parameters in the form of line graphs as mentioned before are presented in Fig. 9 and Fig. 10. This interface projects the minute-average of acquired data set for comprehensive user reading.

Fig. 9: Monitoring Interface of pH Data.

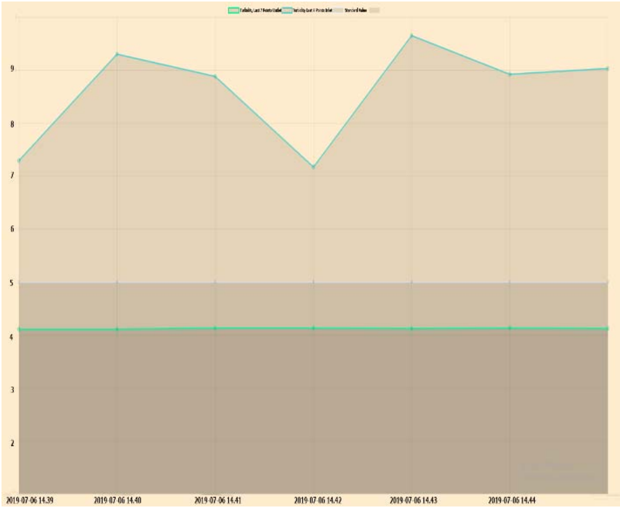


Fig. 10: Monitoring Interface of Turbidity Data.

TABLE II. SENSOR ACQUIRED AVERAGE VALUES FROM INLET AND OUTLET POINTS OF THE FACILITY.

Time	Temp: Inlet	Temp: Outlet	Turbidity Val: Inlet	Turbidity Val: Outlet	PH Inlet	PH Outlet
3/9/2019 6:28	21.44	25.81	9.03	4.03	13.44	9.41
3/9/2019 6:31	21.38	25.81	8.15	4.02	13.40	9.84
3/9/2019 6:41	21.13	25.81	8.82	4.02	13.89	9.55
3/9/2019 7:03	21.19	25.81	8.56	4.03	9.49	9.52
3/9/2019 7:59	21.38	25.81	8.80	4.03	15.28	10.29
3/9/2019 8:12	21.31	25.81	9.72	4.03	17.57	10.97
3/9/2019 8:22	21.25	25.75	6.79	4.03	22.31	9.06
3/9/2019 8:23	21.50	25.81	9.03	4.03	16.44	9.41

The acquired values mentioned in Table II can be interpreted to understand how the system is working. The inlet temperature value and outlet temperature value indicate the system environment. Sudden rise in temperature may indicate any of the machineries has been damaged or even fire alert in the system. Outliners in the acquired result indicate the sensors are not working properly. Turbidity sensor values indicate the cleanliness of the water. The lower the value read by the sensor, the cleaner the water is. The difference of the value is quite noticeable which interprets that the system is exhausting cleaner water in the outlet tank. The pH indicates the acidity and basic property of the water. Dirty water is more basic than cleaner water. For this reason, the inlet pH sensor is reading more basic water than the outlet tanks, which also indicate that the system is working and cleaning the water.

For interpreting the acquired data, the research team observed both inlet and outlet tanks' received values for confirming the plant is working.

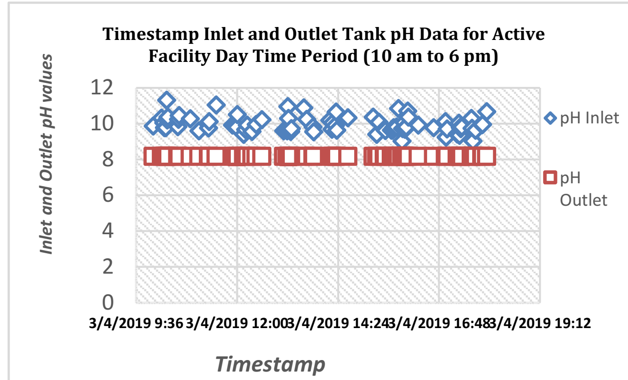


Fig. 11. Observation of 100 data points from Inlet and Outlet Tank pH Values from an active facility day 8 hour period where steady pH values in the outlet tank water had been observed.

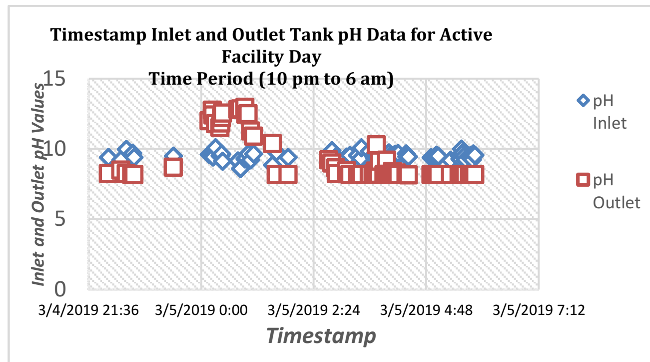


Fig. 12. Observation of 100 data points from Inlet and Outlet Tank pH Values, for an 8 hour slot, with some anomalous data found during hour 3rd-4th.

Fig. 11 and Fig. 12 demonstrate the data nature received from the sensors. Observing the values of pH, it can be determined whether the plant is working properly or not. A working facility should project steady outlet pH values of processed cleaner water. If any anomaly is found in the data stream, it appears in the interface demonstrated in Fig. 9 and Fig. 10 almost real time, which can trigger an alert so that a manual checkup team can be dispatched at the site. Sudden jump or fall in pH level of the wastewater might indicate any unconventional discharge and may suggest adjusting the treatment process to address this deviation.

VIII. SYSTEM SECURITY

For such a monitoring system, it is highly recommended to maintain the online data security. As the whole system may physically cover a vast area, the sensors are highly vulnerable to physical breaches and false data can be injected at any time. For ensuring system security, the research method has proposed certain data and system web security measurements to prevent it from vulnerable activities. The web interface and the database had been hosted in within a private network for statistical analysis and system monitoring. The database was maintained by PostGRE SQL with web application written in PHP. Also the database was backed up in another server inside Raspberry Pi which is run on MySQL database.

The server was always kept up to date and security patches of the most vulnerability that get exploited have been known for over a year minimizes the risk of data being stolen. As the implemented system can have multiple users, it is needed to restrict and manage the database access permission. Regular monitoring to login audit had been set for the database and for multiple failed logins, which can indicate a possible attack, a notification feature has been set, and the users' passwords encryption has been enabled for the system when storing in the database.

All the data are initially backed up before storing into the database. An additional feature had been added to back up the existing database periodically and also to lock down the backup directories, restrict access to the server or storage hosting data when the website had been hosted on the private network of ECE Dept. of North South University, Bangladesh.

Lastly the web interface had been designed to make it secured from getting SQL Injection, where any form of raw SQL queries will not be accepted from any user side.

IX. Conclusion

The STP monitoring system we built is based on an idea to get a cost-effective and easy to implement system that can be implemented globally. Our method has been found effective to monitor ETP/STP plants and may have potential applications in other sectors, such as medical waste, tannery and power plant waste management systems. The visualization technique we found in the conventional tabular approaches does not show time-series data behavior effectively over a time period. So, we have chosen graphical display technique which enables any user without any past to understand the sensor-based system's operation. Scalability is another critical feature of this model, as the array of sensors can be extended and ETP plants can be based on multiple locations, which will be addressed in our future research.

The acquired data may also provide much valuable information through using different data mining techniques and may be useful for new research, such as finding correlations among the data features and generating any statistical function to predict STP/ETP workloads for any certain time. For this reason, the research team has interest to analyze the acquired data further and generate mathematical functions (possibly for multiple ETP/STP application) and fit into a possible to machine learning model to predict important changes.

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