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IoT and WSN Based Water Quality Monitoring System

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***Abstract* - SmartCity projects growing with the concept of IoT (Internet of Things) and WSN (Wireless Sensor Network) helps to manage assets and resources efficiently. Nowadays water is getting polluted due to industrialization, use of fertilizers and pesticides, urban development, etc. So we should have a reliable water quality monitoring system. The proposed system based on IoT and WSN gives real-time data of water quality so that the authority can manage and conserve the valuable water resources more effectively. With IoT & WSN, smart monitoring and management is attainable. It helps create more efficient city services and to keep citizens informed. The existing systems of water quality monitoring uses wireless technologies which are short range and much power consuming, which are not suited for sensors nodes in WSN. The proposed system presents a low cost, low power, long range and scalable approach for water quality monitoring using LoRa module based on LoRaWAN protocol which is Low-Power Wide Area Network (LPWAN) technology, which is much more efficient than many existing systems. The design of the proposed system includes integrating sensors to the microcontroller, wireless LoRa module for transmitting and receiving sensor values, and ThingSpeak IoT platform for examining and visualizing water quality sensor values which have been uploaded.**

Keywords—SmartCity, Water Quality Monitoring, WSN, LoRa, LoRaWAN, IoT, LPWAN

I. INTRODUCTION

A SmartCity is an area populated with electronic sensors which provides data that helps to control assets and resources effectively. It is the result of faster development of the new age information technology. Smart cities incorporate information and communication technology (ICT) and sensors together with Internet of Things (IoT) at its core [1]. Also enhances quality and efficiency of municipal services. Smart cities help the authority to connect with the city services and to study the circumstances in the city and how it is evolving.

The proposed SmartCity project helps to improve the quality of water. It helps create more efficient and cost-effective municipal services and keeps citizens informed. Uncontaminated water bodies are an important asset of cities. With the growing population in cities, it is inevitable that wastewater will grow and water sources will get polluted. SmartCity project performs real-time water quality monitoring. Adverse effects of the pollution can be limited by required actions. The SmartCity concept demands the incorporation of information technologies to render the use of energy and other resources more efficiently.

Three major SmartCity features are communication, instrumentation, and intelligence. These are accomplished with the assistance from IoT. IoT computing concept describes the connection of physical objects to the internet and being intelligent to identify themselves to other devices. IoT is composed of three layers; Perception layer which comprises of sensors, Network layer contains standard communication protocol to process information on the required network and Application layer [2]. IoT is important because an object that can symbolize itself digitally becomes something more important than the object by itself. Sensors are installed and are connected to the online network using specific protocols for communication and information exchange. This is done to attain location, monitoring, tracking etc in the urban areas.

The node layer of IoT architecture comprises of Wireless Sensor Networks (WSN). WSN consists of tiny devices known as nodes. These nodes include embedded CPU, limited computational power and sensors which are smart, which form a wireless sensor network providing sensing services and monitoring [3]. It is a scalable network capable of mapping large areas in real-time. The development of the IoT with interconnected devices, improves the adaptability and sophistication of WSN [8]. Distances, power consumption, numbers of nodes are some elements which decide the method of transmitting the collected data.

LPWAN which is a low power wide area network is used in the proposed system. It is best suited for implementing systems which require devices for transmitting small amounts of data to long distances, for a number of years with a single battery [4]. LoRa together with LoRaWAN protocol makes the LPWAN technology. LoRa which is a proprietary modulation technique using chirp spread spectrum (CSS) makes the physical layer of the technology stack enabling the long- range communication link. LoRaWAN describes the medium access control (MAC) protocol in the data link layer [9]. The data link layer detects the changes in the physical layer and establishes a communication protocol to send data in a secure and reliable manner.

The attributes of LoRaWAN includes transfer rate of 300bps to 50kbps, low power and low duty cycle, this makes LoRaWAN best suited for IoT applications [10]. The operating frequency of LoRa in India is 433 MHz. The data from the sensors are transmitted to the gateway using LoRa module. It provides long-range coverage of about 8 kilometers in semirural areas and up to 3 kilometers in dense urban areas and up to 30 kilometers range in line of sight measurements [5]. The LoRa receiver shows the received signal strength indicator (RSSI) in dBm during sensor data packet reception. RSSI indicates the received signal power after the transmission losses. RSSI is expressed in negative numbers; the number close to zero indicates a better signal [12]. It represents the quality of the received LoRa signals [13]. An IP based network handles the connection between the gateway and the central server [11]. In this project, the central server is ThingSpeak IoT platform.

II. PROPOSED SYSTEM

The proposed system "IoT and WSN based SmartCity Monitoring System" performs real-time water quality monitoring, air quality monitoring and also incorporates street light energy saving system. Phase 1 includes real-time water quality monitoring and phase 2 incorporates air quality monitoring and street light energy saving system. Water quality and air quality sensor values from different field sites are monitored in real time using LoRa wireless technology. In phase 1 and phase 2 data collected from different sensors in the nodes, are sent to the gateway by LoRa sender via LoRaWAN communication protocol. Water quality sensors include pH, turbidity, temperature, and also performs calculations of the dissolved oxygen content of the water. The gateway here is ESP32 Wi-Fi module. The gateway then transmits the sensor data packets to the ThingSpeak cloud server over internet protocol and we can monitor the sensor values in ThingSpeak API, in internet enabled devices. This paper includes phase 1 of the proposed system.

III. SYSTEM DESIGN

In Phase 1, water sensing node integrates sensors in real-time water quality monitoring and it includes temperature sensor, pH sensor, turbidity sensor, and dissolved oxygen content monitoring. These sensor values from node 1 are transmitted to the gateway via LoRa module RA-02 which is an LPWAN wireless communication technology. The proposed system is shown in Fig. 1.

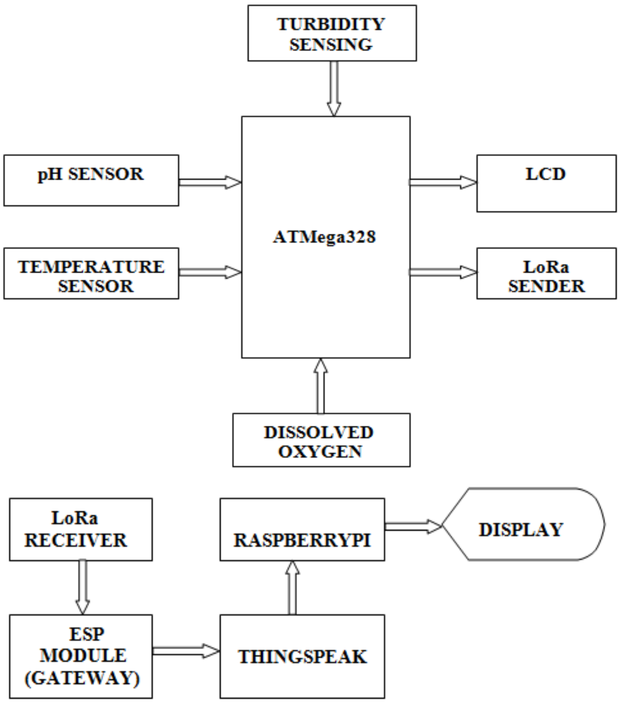

Fig. 1 : Real-Time Water quality Monitoring System

The sensor data values from the water quality nodes are given to ATmega328 microcontroller, and thus to LoRa transmitter module interfaced with ATmega328 by SPI communication. It transmits the sensor data wirelessly to LoRa receiver. The LoRa receiver shows the RSSI value of sensor data packet reception in dBm and passes the data values to ESP32 Wi-Fi gateway module. The gateway then passes the data to ThingSpeak server via IP protocol.

IV. TECHNICAL DESCRIPTIONS

A. ATMega328

The ATmega328 is a microcontroller from megaAVR family. It is an 8-bit RISC processor core with a modified Harvard architecture. It has 32KB code space and is a 28 pin IC. ATmega328 shown in Fig .2 has 32KB flash memory, 1KB EEPROM, 2KB SRAM, 23 I/O lines, USART, SPI, 10 bit ADC, programmable watchdog timer, 5 sleep modes for power management. The operating voltage of the device is between 1.8 and 5.5 Volts.

ATmega328 can store the data even on the removal of its power supply. It has 3 Ports, Port B, C and D. Analog Port C have 6 analog pins. Digital Ports B and D own 7 pins each. Thus ATmega328 have 14 digital pins. Serial communication is performed using RX and TX pins. An external crystal oscillator of 16MHz is used with ATmega328.ATmega328 are cost effective and low power dissipating. It also provides programming lock and real timer counter with a different oscillator. ATmega328 is best suited for low power consuming embedded system projects.

Fig. 2: ATMega328

B. DS18B20 Temperature Sensor

Measurement of temperature is the most important physical analysis of water quality. It influences the chemical and biological properties of water and also the quantity of oxygen dissolved in the water. Here DS18B20 digital temperature sensor is used for temperature sensing. The DS18B20 is a waterproof temperature sensor probe with a built-in 12bit ADC. It can be easily interfaced with Arduino and it communicates by one-wire protocol.

DS18B20 sensors are high temperature probes, which is build on a temperature sensor chip DS18B20 having a cable length of one meter. It is handy and used when needed to measure something far away, or in wet conditions, so the probe type sensor is perfect for sensing the temperature of water in our SmartCity project. The operating voltage of the sensor is 3V to 5V. All DS18B20 have different 64-bit serial code, thus many DS18B20 can work on the same one-wire bus. So we can employ a single micro-controller for many DS18B20, scattered over a vast area. The features of DS18B20 also include programmable alarm options, 12 bits of precision, usable temperature range from -55 to 125°C.

C. pH Sensor Module E201-C-9

pH is a measure of acidity or alkalinity of solutions; it is a figure between 0 and 14. The measurement of pH of a water system is of utmost importance. pH of pure water is 7. A pH meter computes hydrogen-ion activity of solutions and shows whether it is acidic or alkaline by a pH value. pH of a solution is expressed as,

$$pH = -\log(H+)$$

pH sensor module shown in Fig. 3 consists of a pH sensor called a pH probe with BNC connector and a signal conditioning board which gives an output proportional to the pH value and can be directly interfaced to the microcontroller. The model used here is E201-C-9. It is a probe type combinational, plastic shell rechargeable acidity meter electrode. It is refillable, round surfaced and appropriate for rugged use in field, schools, labs, where routine pH calculations are required. It is compatible with Arduino. The pH measurement range of this meter is from 0 to 14. The temperature range is 5 to 60 degree celsius and the operating voltage is 5 V.

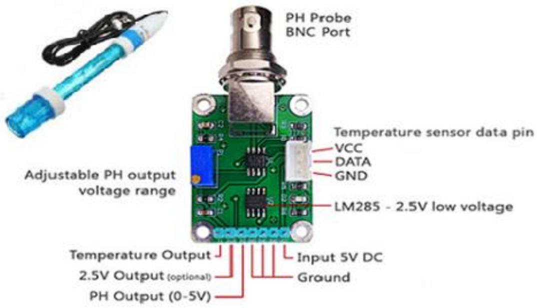

Fig. 3: pH Sensor Module

Even though the process remains at a constant pH, the output of the measuring electrode changes with the change in temperature. So a temperature sensor is necessary to correct the changes in output. The errors due to temperature variations can be rectified using pH meters with temperature compensation. Here a correction factor is applied automatically to the final reading that we get using pH meter and also the pH sensor module is calibrated to minimize these errors.

D. LDR and LED Setup for Turbidity Sensing

Turbidity calculations are used as a measure of water quality based on clarity and total suspended solids (TSS) in water. It also indicates the presence of high bacteria levels and pathogens. Water quality monitoring system constantly monitors turbidity levels to ensure that it does not exceed safe levels. Light scattered by small solid particles in water is measured by the turbidity sensors. Turbidity level of water increases with the increase in solid particles. Turbidity sensor used in the proposed system is a circuit made of LDR and white LED as shown in Fig. 4. Arrangements are made such that water sample comes between the LDR and LED. Light emitted by LED is partially transmitted and partially scattered by the particles in water. If the sample has high turbidity, the amount of light from the LED that reaches the LDR will be less and the resistance of LDR will be high and vice versa. Here LDR and LED are sensor and light source respectively.

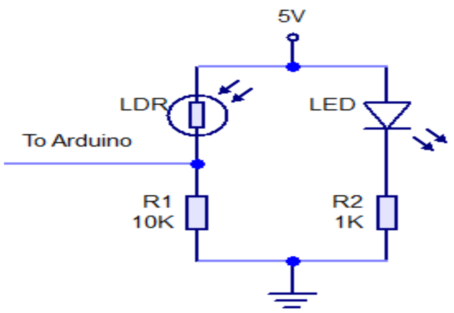

Fig. 4: LED and LDR Circuit for Turbidity Sensing

The LDR and LED are given a 5V supply as shown in Fig. 4. LDR outputs an analog voltage which changes proportional to the intensity of light falling on it. If the intensity of light reaching LDR is greater, the turbidity sensor circuit outputs a high voltage to ATmega328 micro-controller.

E. Lora Module RA-02

LoRa is a proprietary long-range wireless data communication technology developed by Semtech for sending data to orders of kilometers, with extremely low power requirement. This led to the introduction of the IoT implementation using LoRa technology. It adopts CSS modulation with a spreading factor ranging from SF7 to SF12 [14] and has a data rate ranging from 30bps to 50Kbps. It has high interference immunity and high reliability, thus brings a solution to the issues caused by conventional design schemes which cannot deal with interference, distance and power consumption simultaneously. LoRaWAN is a modified form of LPWAN which specifies the protocol on how LoRa in a physical layer should be used to send and receive data among the nodes, gateways and to the internet.

SX1278 Ra-02 LoRa module operates on 433MHz in Asia and it is mandatory to operate the LoRa module with an antenna; else the output transmitting power will damage the module. The LoRa module consists of 16 pins with 8 pins on each side as shown in the Fig. 5. Six pins out of 16 pins are used as GPIO pins ranging from DIO0 to DIO5. The working voltage of the module is 3.3V. Data communication between LoRa Ra-02 and ATmega328 is SPI communication. By using two LoRa modules we can send sensor data wirelessly from LoRa transmitter and receive it on LoRa receiver which is kilometers apart.

Fig. 5: LoRa RA-02 [15]

F. ESP32 Wi-Fi Module

ESP32 is used in low power IoT sensor application. It is a 32 bit, 2.4 GHz Wi-Fi created with very low power technology. ESP32 microprocessor has a 520KiB of SRAM and 4MiB of flash memory. It is a 48 pin IC supporting SPI and I2C interfaces. The board layout of ESP32 is shown in Fig. 6

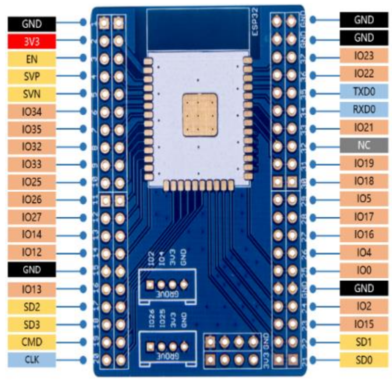

Fig. 6: Board Layout of ESP32 [16]

G. Liquid Crystal Display (LCD)

LCD electronic display unit has a large range of applications. 16x2 LCD shown in Fig. 7 displays characters in 2 lines, with 16 characters in a line. It has an operating voltage ranging from 4.7V to 5.3V. LCDs can be programmed easily and are economical. It can display special, custom characters and animations.

The 2 registers of LCD are command and data register. LCD can be used to display information from arduino or any other micro-controller connected to it. In this project, LCD is used to display the sensor values from the water quality monitoring system.

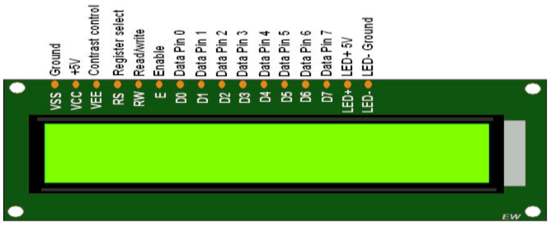

Fig. 7: 16*2 LCD Display

V. SYSTEM WORKING

A. Temperature Sensing

DS18B20 temperature sensor uses Dallas one wire protocol to send accurate temperature readings directly to the board without the need of an analog to digital converter. When the sensor is connected to the microcontroller, we use a 4.7k resistor to the sensing pin, as a pull-up from the data to the Vcc line. It gives an output which is an actual temperature value in degree Celsius and the readings are displayed on the LCD and transmitted wirelessly to LoRa receiver.

B. pH Sensing

E201-C-9 pH sensor module is calibrated using solutions of known pH, 4 and 7.0. pH sensor is connected to analog input of ATmega328 microcontroller. Using the solutions with pH 4.01 and 6.86, an analog voltage of 3.04V and 2.54V is obtained respectively. As the sensor is linear, by using these values, an equation converting the measured voltage to pH value is deduced as given in the hardware manual of pH sensor with arduino, which is given by

$$\text{pH Value} = -5.7 * (\text{measured Voltage}) + 21.34$$

The graphical relation between measured voltage from pH sensor module and the pH value is as shown in Fig. 8.

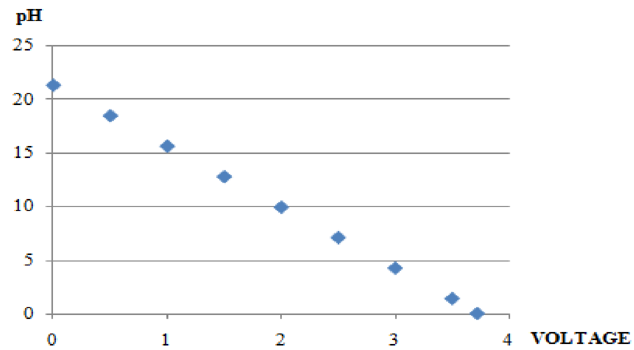

Fig. 8: Voltage – pH graph

The pH sensor module outputs an analog voltage proportionate to the pH of water sample and is given to the microcontroller. The voltage is converted to the corresponding pH value as per the equation and graph shown in Fig. 8. The pH value of the water sample is displayed on the LCD display and transmitted wirelessly to LoRa receiver module.

C. Turbidity Sensing

The turbidity sensor circuit using LED and LDR outputs a voltage which is proportional to the turbidity of the water sample. This analog voltage is converted to NTU (Nephelometric Turbidity Unit) as per the below equation [6].

$$\text{Turbidity in NTU} = -111.25 * (\text{Voltage}) + 506.67$$

For pure water, light reaching the LDR is high, so turbidity sensor circuit outputs a high voltage of 4.55 volts to the microcontroller as per the circuit shown in Fig. 4 and for highly impure water, no light reaches LDR and the sensor circuit outputs a voltage of 0 volts to the microcontroller. The graph of the relation between voltage obtained from turbidity sensor circuit and turbidity value of water sample in NTU is given in Fig. 9.The turbidity value in NTU is displayed on the LCD and transmitted wirelessly to LoRa receiver.

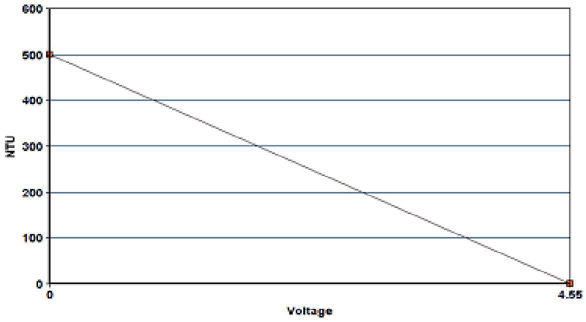

Fig. 9: Voltage to NTU Conversion

D. Dissolved Oxygen Calculation

Dissolved Oxygen (DO) is the measure of non-compound oxygen that is mixed in water. It is a major parameter in determining the quality of water. Too large or too small DO level can cause damage to aquatic life and degrades the quality of water. High level of turbidity, increase in water temperature and salinity, all leads to the reduction of dissolved oxygen level of water bodies.

The most influencing parameter on dissolved oxygen content is the temperature of the water body. We can use DO meters, Winkler's Azide modification technique based on APHA or use the temperature dependency relation on DO. The DO level is expressed in mg/L. Good dissolved oxygen level is 7.3mg/L to 9.5mg/L.

In this project, Temperature - DO dependency relation is used for the calculation of DO of the water sample. The relation between the temperature and dissolved oxygen content of the water sample is as shown in TABLE 1 [7].

TABLE I: DO – TEMPERATURE RELATION

TEMPERATURE (Degree Celsius)	DO (mg/L)	TEMPERATURE (Degree Celsius)	DO (mg/L)
0	14.61	23	8.57
1	14.20	24	8.41
2	13.82	25	8.25
3	13.45	26	8.10
4	13.10	27	7.96
5	12.76	28	7.82
6	12.44	29	7.68
7	12.13	30	7.55
8	11.84	31	7.42
9	11.56	32	7.29
10	11.28	33	7.17
11	11.02	34	7.06
12	10.77	35	6.94
13	10.53	36	6.83
14	10.30	37	6.72
15	10.08	38	6.62
16	9.86	39	6.52
17	9.66	40	6.42
18	9.46	41	6.32
19	9.27	42	6.23
20	9.08	43	6.14
21	8.91	44	6.05
22	8.73	45	5.96

DS18B20 measures the temperature of water sample and the DO content proportional to this real time temperature is calculated using TABLE 1 and the value is displayed on the LCD and transmitted wirelessly to LoRa receiver.

VI. RESULTS AND DISCUSSIONS

The water quality monitoring system presented a good performance. Simulation is done in Proteus. The simulation result of Phase 1 water quality monitoring system is shown in Fig. 10. All the sensors together with LCD display of sensor values are included in the simulation. The PCB design of water quality node is done in Proteus ARES.

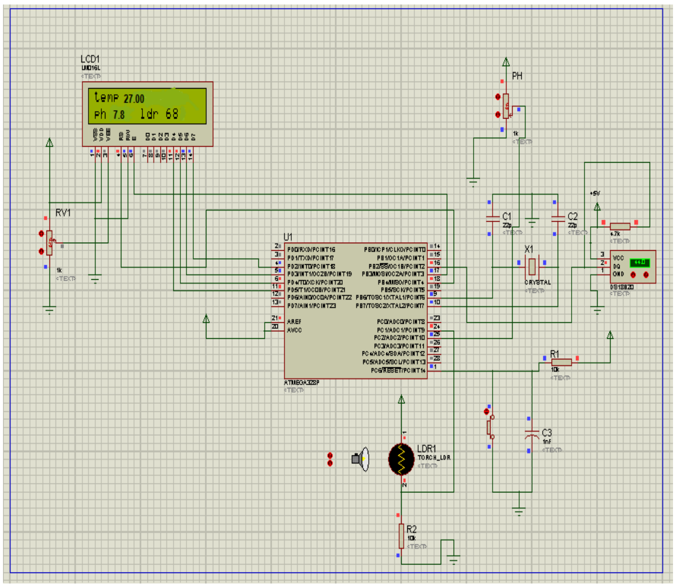

Fig. 10: Simulation of the Project

Hardware of the water quality monitoring system is implemented. Temperature, pH, turbidity and DO of the water sample are displayed on the LCD as shown in Fig. 11. Also, the sensor data from the water quality sensing node are given to the LoRa sender module. LoRa sender is interfaced with ATmega328 by SPI communication.

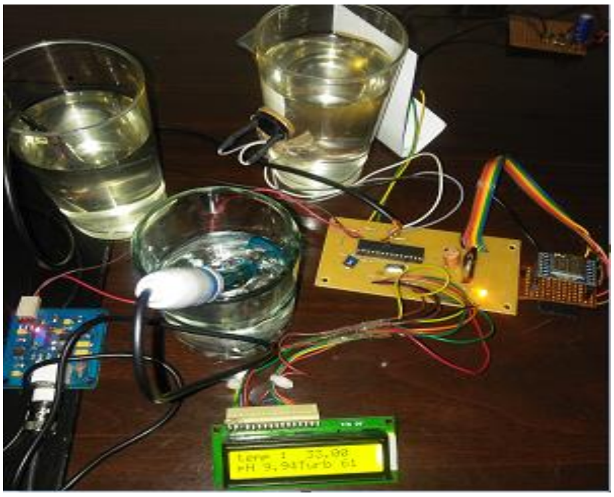

Fig. 11: Water Quality Sensor Values on LCD Display

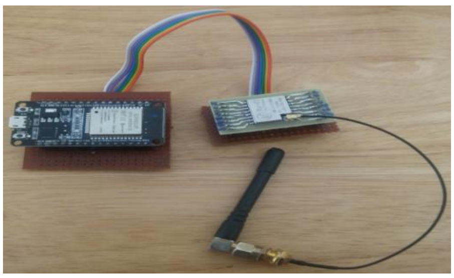

Fig. 12: ESP32 Gateway with LoRa Receiver

The LoRa sender module in the water quality sensing node performs wireless transmission of sensor data to LoRa receiver which is several kilometers away from the water quality node. LoRa receiver connected to ESP32 gateway via SPI communication shown in Fig. 12, received the data from LoRa sender and displayed temperature, pH, turbidity and DO of the water sample, in the arduino serial monitor. Gateway ESP32 Wi-Fi module pick up the sensor data from the LoRa receiver.

The water quality sensor data packets are received by the LoRa receiver placed at varying distances. Fig. 13 shows the temperature, pH, turbidity and DO of the water sample received by LoRa receiver, with a distance of 1 kilometer between LoRa sender and receiver, with RSSI value near to -57. Fig. 14 shows the sensor values received by LoRa receiver with a distance of 1.5 kilometers between the LoRa sender and receiver, with RSSI value near to -105. Both Fig. 13 and Fig. 14 are the experimental results in dense urban area. In dense urban areas LoRa provides a maximum of 3 kilometers coverage. The coverage range of LoRa can be significantly improved by the higher positioning of LoRa receiver. This long range low power wireless data communication cannot be achieved in the existing systems which uses Zigbee, Bluetooth, WiMAX,etc

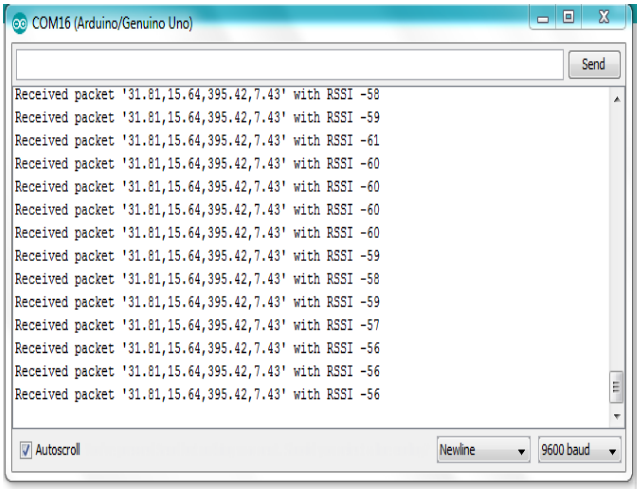

Fig. 13: LoRa Receiver Displaying Sensor Values with RSSI -58

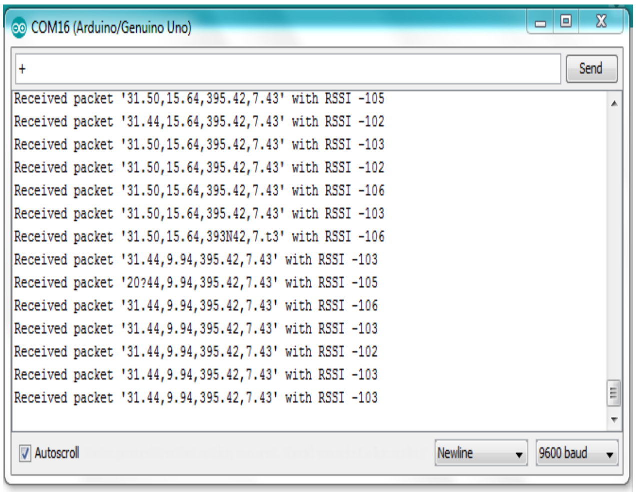

Fig. 14: LoRa Receiver Displaying Sensor Values with RSSI -105

Sensor nodes and the base stations (gateway) communication goes over the wireless channel utilizing the LoRa technology. Gateways connect to the internet and relay the water quality sensor data to server using the standard IP protocol.

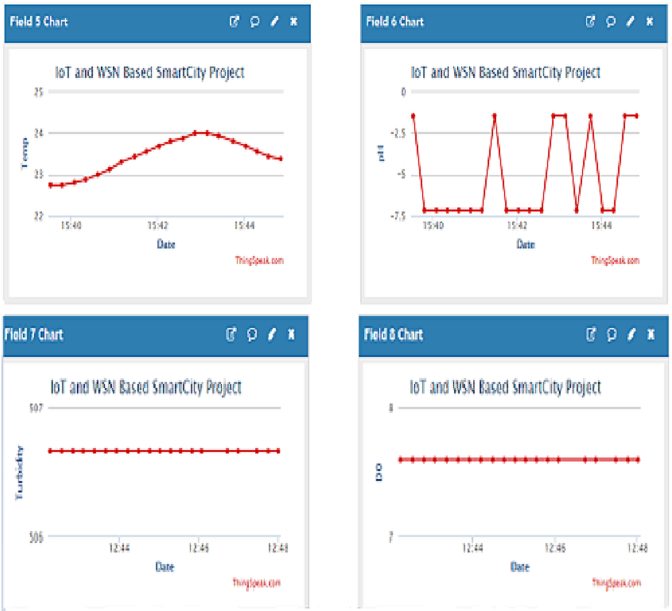

Fig 15: Water Quality Sensor Data Visualized in ThingSpeak

The server used here is ThingSpeak IoT platform. In this both data analysis and visualization can be done. By having a ThingSpeak account, we can create channel in it. Each channel can store data in 8 fields. Here 4 data fields of the channel are used to save water quality sensor data. Fig. 15 shows the live visualizations of temperature, pH, turbidity, and DO sensor data of water quality monitoring system in 4 data fields of ThingSpeak server. We can monitor the sensor data in any internet-enabled devices by login to ThingSpeak account.

VII. CONCLUSION AND FUTURE SCOPE

IoT and WSN based water quality monitoring system is designed and implemented successfully. The system monitors pH, turbidity, temperature and DO of the water sample. The system performed well as per the design. The LoRa receiver efficiently received water quality sensor values from LoRa sender, several kilometers away. This long range wireless communication cannot be achieved in many existing water quality monitoring systems using ZigBee, Bluetooth, and WiMAX etc. By analyzing various technologies it is better understood that LoRa is the best technology for wireless communication between the sensor nodes and the gateway. Unlike the above mentioned wireless technologies, LoRa is long range, low power radio technology providing long battery life for the sensor nodes and is best suited for low data rate WSN applications. The water quality sensor data is sent to ThingSpeak IoT platform, by ESP32 Wi-Fi module and the live visualization of sensor data is performed. As a future scope the system can be extended to IoT and WSN based SmartCity project which includes air quality monitoring and street light energy saving system.

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