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IoT based smart water management systems: A systematic review

Manmeet Singh [a], Suhaib Ahmed [b]

[a] Department of Information Technology and Engineering, Baba Ghulam Shah Badshah University, Rajouri, Jammu and Kashmir, India
[b] Department of Electronics and Communication Engineering, Baba Ghulam Shah Badshah University, Rajouri, Jammu and Kashmir, India

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A B S T R A C T

Water is an all-important need of all living beings. With the exponential growth of the human population, the need for conservation of water resources is gaining greater importance. Many water management systems have been proposed in the past using different technologies to address the issue which are high in cost and energy consumption. With the advent of the Internet of Things (IoT), the pursuit of the smart water management system is gaining momentum. This study first discusses the architecture and various components of IoT based water management system in detail followed by in-depth survey of all existing IoT based water management systems. Various measurement parameters such as water level, pH level, turbidity, salinity, etc. used in different water management systems proposed in the literature have also been identified and a comparison of various systems based on these parameters has also been presented. Finally, based on the survey, list of various essential attributes of these systems are framed which must be incorporated in future designs. In addition to this, an architecture of a smart water management system based on IoT and Machine learning has also been proposed as future scope which addresses all these essential attributes and also uses machine learning based predictions which can increase the efficiency of the smart management system.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Innovations in Clean Energy Technologies.

1. Introduction

Water is an essential component for survival of human life on earth. A wide variety of living beings depend heavily on water for existence. With the increase in water consumption due to an increase in the human population, there are growing concerns of water scarcity [1]. Besides the general concerns of freshwater scarcity for drinking purpose, there are rising concerns for scarcity of water for agricultural purposes [2,3]. In order to tackle the challenges of water scarcity, an effective water management system is vital. Water management is possible primarily by real-time monitoring of water level and quality. Real-time water level monitoring can significantly reduce wastage of water due to overflow from tanks. The water management system can also help detect water leaks in a smart home by analyzing water levels during different hours of the day. A smart water management system as such is a dire need for a smarter planet.

One of the main reasons for the low adoption of smart water management system is its high cost. In recent years, with the advent of the Internet of Things (IoT) for smart cities [4], the cost has come down significantly. Internet of Things is a system of connected devices with the ability to transmit data. The water management system based on low-cost Internet of Things has gained momentum in the last few years. Devices in an IoT ecosystem can transfer data without human interaction thereby making them ideally suitable for real-time water level monitoring.

In recent years, efforts have been made to monitor water quality by studying parameters like pH value, conductivity, dissolved oxygen, temperature, biochemical oxygen demand and total dissolved solids (TDS). Real-time water quality monitoring has gained momentum in smart cities.

Fig. 1 presents an overview of IoT based water management system. It generally consists of a controller, sensors, and an application to display the data. Sensors are the devices connected to the controller that are used to record the values like pH value, turbidity, etc. Sensors collect the measurement value and transmit it to the controller. A controller is a small size computer with the capability to connect to network and execute programs. It can be programmed to receive value from sensors and transmit the values to the Internet for storing and analysis. An application is basically

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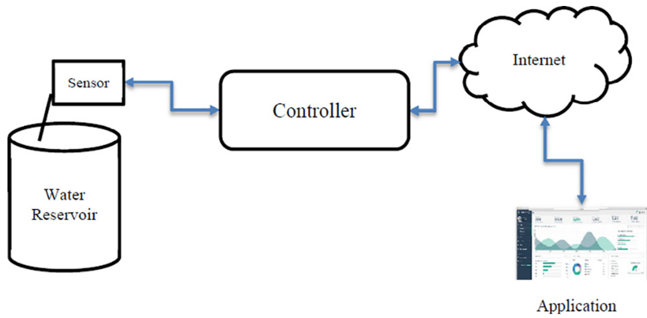

Fig. 1. Overview of a Water Management System.

a program hosted on the internet to receive value from the controller and display in user interface.

IoT based water management systems are low cost solutions that can be easily scaled. Low cost sensors allow easy measuring of water quality for presence for various contaminants. Availability of commonly used communication technologies allow deployment in existing system with little configuration. Use of IoT platforms provides easy access for remote monitoring and control.

1.1. Paper contributions

The following are the main contributions of this paper.

- We discussed the different components and technologies used for an IoT based water management system i.e. sensors, controllers, IoT platforms, etc.
- Analysis of different water management systems proposed in the literature along with different parameters used for measuring various properties of water. Parameter wise comparison of different techniques is done to show the relative importance of each technique.
- An IoT based architecture of a smart water management system which can be implemented in future is proposed. The essential attributes of an efficient and smart water management system are also framed.
- Machine learning is incorporated in the proposed system to increase the accuracy and efficiency of various predictions made by the system.

1.2. Paper organization

The rest of this paper is organized as follows. Section 2 discusses the sensors, communication technologies, controllers, and application platforms used in IoT based Water management system. Related work in the field of water management system using IoT is discussed in section 3. Section 4 presents the architecture of a proposed IoT system for water management. Conclusion and possible research areas are presented in section 5.

2. Architecture of IoT based systems

IoT based water monitoring system consists of a controller, sensors, and an application to display the data. Fig. 2 lists various components of an IoT based water monitoring system.

2.1. Water quality parameters

Measuring quality of drinking water is a complex task involving various parameters. While certain quality parameters can be easily measured, other require specialized hardware and expertise. Meride et al. [5] performed an assessment of water quality in Wondo genet campus, Ethiopia. The study analyzed turbidity, temperature, total dissolved solids, conductivity, pH, chloride, sulphate, magnesium, calcium, sodium, potassium, nitrate and bacterial contamination in the water and its effect on resident's health. The study concluded that all the parameters were well within the limit of WHO recommended guidelines. Commonly used parameters for water quality are as follows.

- *pH:* It is the measure of the acidic and basic property of a water-based solution. A higher pH value indicates the basic solution, whereas a lower pH value indicates an acidic solution. WHO [3] recommends an optimal pH value in the range of 6.5–9.5
- *Dissolved Oxygen (DO):* It is the measure of gaseous oxygen (O2) dissolved in the water. The amount of DO in water can tell the quality of water. Moving water, such as in river and stream, has high amount of DO while stagnant water has less amount of DO. Higher DO value makes the water taste better but leads to corrosion in pipes.
- *Turbidity:* It is the measure of the water clarity. It is a key test of the water quality. It is measured commonly in Formazin Turbidity Unit (FTU) and Nephelometric Turbidity Unit (NTU). As per the WHO guidelines [6], the value of turbidity in drinking water should be less than 5 NTU.
- *Conductivity:* It is the measure of the ability of water to conduct electricity thereby indicating what is dissolved in water. The value of conductivity should not exceed 400 μS/cm for drinking water.
- *Total Dissolved Solids (TDS):* It is the measure of the dissolved organic and inorganic materials in water. High TDS values indicate presence of large amount of minerals. Recommend value of TDS in drinking water is 500 mg/L. TDS value of water greater than 1000 mg/L is unsuitable for drinking.
- *Temperature:* It is another measure that have a significant effect on the water quality. WHO recommend temperature limit for drinking water is 30 °C. A comprehensive study on effect of temperature on water is presented in [7].
- *Salinity:* It is the measure of the salt dissolved in water. Higher salinity values have adverse effect on human body. Salinity value in drinking water should be less than 200 ppm.

2.2. Sensors

Various sensors are available in the market for measuring parameters like range, temperature, humidity, etc. in the Internet of Things ecosystem. Commonly used sensors for IoT based water management system include Ultrasonic sensor, temperature sensor and pH sensor.

- *Ultrasonic Sensor:* To measure the level of water in a tank/reservoir, an ultrasonic range sensor is used. An ultrasonic sensor is a distance measurement sensor which can be easily connected with different controller available in the market. This sensor is extensively used for real-time monitoring of water level in a water tank.
- *Temperature Sensor:* According to WHO guidelines [8], "Water temperature is an important element of control strategies against Legionella. Wherever possible, water temperatures should be kept outside the range of 25–50 °C and preferably outside the range of 20–50 °C to prevent the growth of the organism". To check the water quality, the temperature is an important factor. Various sensors are available in the market to measure temperature in the wider range (−50 °C to 125 °C).
- *pH Sensor:* To check the acidic and basic property of a water-based solution, a Ph sensor is used. A higher pH value indicates the basic solution, whereas a lower pH value indicates an acidic solution. WHO [9] recommends an optimal pH value in the

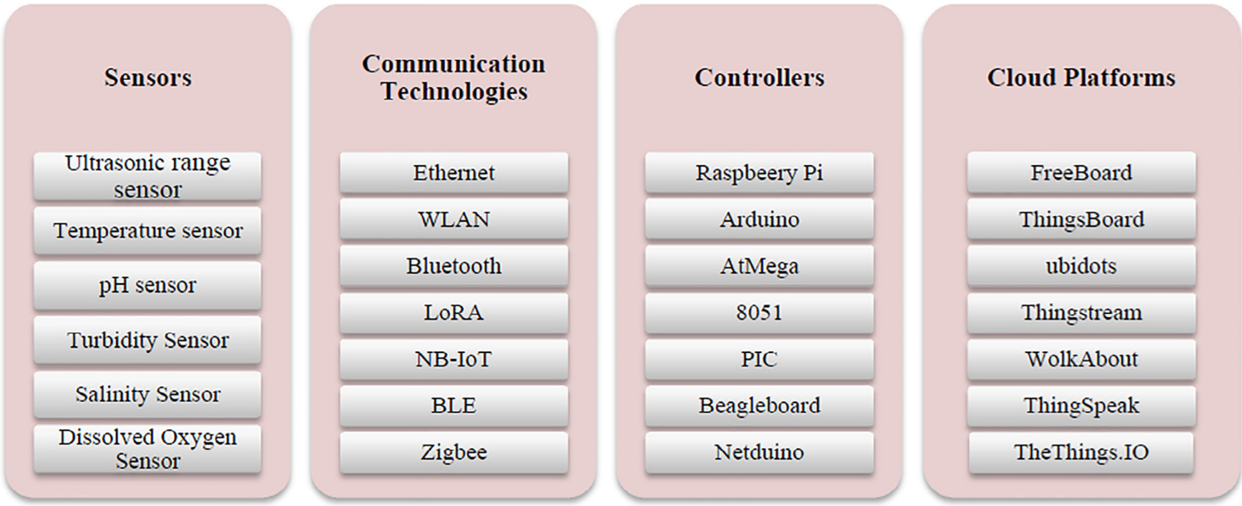

Fig. 2. Components of IoT based water management system.

range of 6.5–9.5. The report states that "exposure to extreme pH values results in irritation to the eyes, skin, and mucous membranes".

2.3. Communication technologies

In order to meet the low power, memory intensive and resource constrained IoT devices, many low power communication technologies have been proposed to meet the various constraints of IoT devices and network. These technologies include Bluetooth Low Energy (BLE), Zigbee, Low Power Wi-Fi, Narrowband IoT (NB-IoT), Low Range (LoRA), etc. The comparative analysis of these communication technologies is presented in Table 1. In BLE, all peripheral devices are in sleep mode and are in wake mode whenever a packet is transferred from the central node. This helps in reducing the overall energy consumption of the network. On the other hand, Low Power Wi-Fi is based on IEEE 802.11ah standard and consumes lower power compared to normal Wi-Fi based communication while achieving higher transmission range. Zigbee operates on IEEE 802.15.4 standard and is used for low data rate short range communication applications such as in automation, industries, etc. LoRA and NB-IoT are Low Power Wide Area Network (LPWAN) based communication technologies. LoRA is the first low cost communication technology that has been adopted commercially. It provides long range communication with a low data rate of up to 50 kbps. On the other hand, NB-IoT has higher data rate but it consumes more lower compared to LoRA and cost per device is also relatively higher.

2.4. Controllers

Controllers for IoT based water management system can be broadly classified into microcontroller board type and minicomputer type. Arduino [10] is an example of microcontroller which runs one program again and again. These are relatively cheap as compared to minicomputer type controllers. Raspberry Pi [11] is an example of single-board pocket size minicomputer type controllers. These are full-fledged computing device with ability to run multiple programs. Raspberry Pi contains an onboard Wi-fi as well as Ethernet network interface to connect to Internet. Arduino board require external hardware to connect to Internet.

2.5. Application platforms

With the rapid increase in the use of IoT devices, a large number of IoT platforms also called as dashboards are now available. Some platforms also provide apps for controlling and monitoring IoT devices using mobile devices like Blynk [12]. FreeBoard [13], Ubidots [14], ThingSpeak, etc. are some of the commonly used IoT application platforms.

Radhakrishnan et al. [15] discussed the architecture, applications, and use of IoT devices in the water management system. The study analyzed six commercially available sensors namely Spectro: lyser, SmartCoast, Kapta 3000 AC4, Smart water (Libelium), Lab-on-chip and I: scan. The study also analyzed the energy harvesting techniques that can be used to generate energy for sensors. The study suggested that 6lowpan, LoRa and Zigbee are the best choices for communication in the water management system. The study also listed the applications of IoT based water managements system in smart irrigation, smart gardening and Aquaculture systems.

Olatinwo et al. [16] presented a detailed survey on the issues and challenges in enabling communication networks for applications in water quality monitoring. While traditional communication technologies have high power consumption and short communication range. New communication technologies are

Table 1
Comparison of existing low power communication technologies for IoT.

Parameter	BLE	Zigbee	Low Power Wi-Fi	NB-IoT	LoRA
Modulation Scheme	TDMA	CSMA-CA	CSMA-CA	BPSK/QPSK	CSS
Network Topology	Point-to-Point	Mesh	Star	Star	Star
Range	Up to 50 m	30–50 m	20–100 m	Up to 10 km	Up to 20 km
Data Rate (Max.)	24 Mbps	250 kbps	6 Gbps	200 kbps	50 kbps
Operating Frequency	2.4 GHz	915 MHz	5–60 GHz	800 MHz	868 MHz
Power Efficiency	High	Very High	Low	High	Very High
Cost Per Device	Low	High	High	High	Low
Application	Inter Device	Automation, Industries	Broadband Internet	Personal and Public	Industries

designed to achieve low power consumption with a higher communication range. The survey recommended that LPWAN variants and the IEEE 802.11ah are promising solutions to achieve low power consumption with a higher communication range.

3. Related work

The water management system can be broadly classified into two main categories namely water level monitoring systems and water quality monitoring systems. Water level monitoring systems are those systems that attempt to measure in real-time the water level of a water reservoir using sensors. The water quality monitoring system attempts to measure various water quality parameters like pH, conductivity, TDS, etc. value in the water by using different sensors. Fig. 3 presents the classification of various water Management systems.

3.1. Water level monitoring systems

In 2015, Verma et al. [17] presented a system for water level monitoring on the campus. The system used a low-cost ultrasonic sensor having the capacity to measure the distance of 10 m. The system used a sub-GHz communication network to communicate between tanks located at a large distance. The system consists of three main components namely gateway, end nodes and relay nodes. The gateway receives the data from other nodes and transmits it to the cloud server. The end nodes connected to the sensors periodically wakes up and sends recorded values to the gateway. Relay nodes are enhanced end nodes with the capability to relay values from other end nodes. The system achieved a range of 10 m with an accuracy within 1.5%.

In 2015, Robles et al. [18] presented a smart water management model using IoT. The model used "OPC UA (Object Linking and Embedding for Process Control Unified Architecture)" for control of processes. The model consists of three main modules namely water management module, common communication module, and Coordination subsystem interface. A deployment scenario at Aula Dei, an experimental station on Zaragoza was later described. The study concluded that the usage of IoT devices for water monitoring and governance has wider benefits.

In 2016, Perumal et al. [19] presented an IoT based system for real-time water level monitoring in a smart home. The system consists of sensor actuators, power sources and wireless connectivity. The measurement value is sent to the cloud server on the internet and displayed using a remote dashboard. An alert is also sent to the twitter handle. The system uses an ultrasonic range server and water sensor for measurement. An ATmega328P controller board was used for the proposed system. The system took 126 ms response time to finish a single cycle of sensor feed. The work recorded 500 readings during the experimentation. The implemented system was very basic in nature consisting of IoT devices using sensors for water level monitoring in a smart home.

In 2017, Malche et al. [20] presented an IoT based system for water level monitoring for the smart village. The main objective of the proposed system was to monitor the real-time water level from a distant location. The system consists of three layers namely physical layer, service layer and presentation layer. The physical layer consists of the WSN node which senses the level of water and the networking required to transmit the recorded values to the service layer. The service layer used the Carriots Platform as a Service (PAAS) for IoT devices for collecting and storing date from IoT devices. Freeboard [13] was used in the presentation layer to display the data. REST API was used to communicate between Carriots and Freeboard. The system used the Arduino Uno R3 board.

3.2. Water quality monitoring systems

In 2013, Wang et al. [21] established a system for an online water quality management system to monitor water in the river at Xinglin Bay, Xiamen, China. The system consists of three units namely water quality analyzer unit, information transmission unit and computer system unit. An online water quality analyzer was

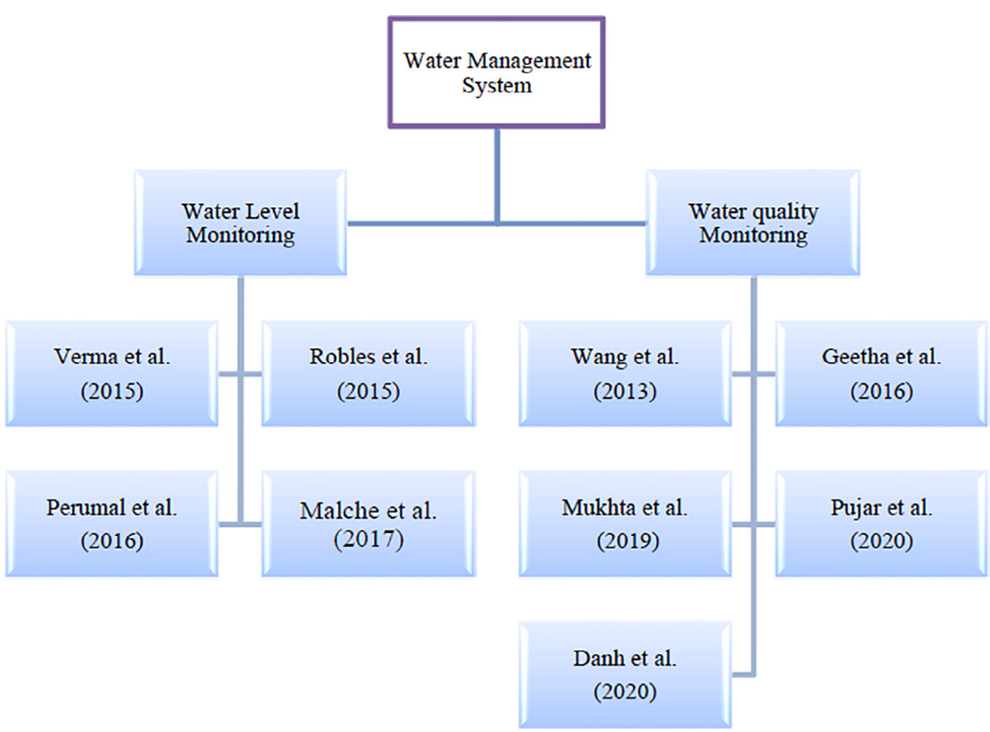

Fig. 3. Illustration of existing researches in water management systems.

used to monitor various quality parameters like pH, dissolved oxygen (DO), turbidity, conductivity, oxidation–reduction potential (ORP), chlorophyll, temperature, and salinity of the water in the river. The results exhibited that cycling river water was an efficient way to steady the river water quality. The process flow diagram for the river along with the cyclic purification is shown in Fig. 4.

In 2016, Geetha et al. [22] presented a low-cost water quality monitoring system using in-built wireless communication. The system monitored pH, turbidity and conductivity parameters for water quality measurement. The system consisted of three main subsystems namely data collection subsystem, data transmission subsystem and data management subsystem. The system used TI CC3200, a single-chip controller with inbuilt Wi-Fi. Ubidots [14], a platform for IoT devices, was used for storing the data to the cloud for analysis. The system had an option to alert the user when a certain threshold value is reached.

In 2019, Mukta et al. [23] presented a system for continuous water quality monitoring using four parameters namely temperature, pH, electric conductivity, and turbidity properties. The system used the Arduino-Uno controller with four sensors. The front-end application was designed using a .NET framework which checks these values against WHO recommended values. The system then predicts whether the water is drinkable or not. Sixty water samples were collected from three sources of water namely natural, impure and potable water sources for the study. Four machine learning algorithms (logistic regression, SVM, Averaged Perceptron and Fast Forest) were used to train and test the model. Accuracy and F1 score were used to measure the performance of the algorithm. Fast Forest machine learning algorithm achieved the highest accuracy and F1 score.

In 2020, Pujar et al. [24] presented an IoT based system for real-time water quality monitoring. Water from Krishna river was monitored for water quality parameters such as pH, conductivity, dissolved oxygen, temperature, biochemical oxygen demand and total dissolved solids (TDS). Arduino Mega 2560 was used as the controller. The system used a one-way and two-way analysis of variance (ANOVA) for analysis of data collected. The results indicated that one-way ANOVA was the best suited for training the IoT system. The study also concluded that during different seasons of the year, different parameters influence the water quality.

In 2020, Danh et al. [25] developed and deployed E-Sensor AQUA system for monitoring water quality in Mekong Delta as shown in Fig. 5. The system analyzed Dissolved oxygen, pH, Temperature and Salinity parameter in the water. The system used ThingSpeak IoT platform to store onto the cloud server. Data from sensor nodes is pushed to the master control unit which updates the data to the cloud server every minute. The system can be accessed via apps for android as well as iOS devices to view the data.

3.3. Related systems

In addition to this, some other possible applications include:

- *Irrigation Systems:* García et al. in [26] presented a detailed survey on application of IoT devices for smart irrigation systems. The study presented a detailed analysis of soil monitoring, weather monitoring and sensor networks for irrigation systems. The study observed that Arduino boards are the most commonly used IoT nodes for irrigation systems. A comprehensive analysis of the frequency band and maximum data rate of different technologies used in IoT is presented. The study observed that Wi-Fi was the most commonly used communication technology. ThingSpeak [27] was observed to be the most preferred cloud platform and MySQL as the preferred database system.
- *Flood Control Systems:* Rani et al. in [28] presented an IoT system for flood monitoring using artificial intelligence. Historical weather data was analyzed to find variables that can be used to train the model. Linear regression, Support Vector Machine (SVM) and Artificial Neural Networks were used for training the model with last three months rainfall data to predict the rainfall in following month. The study observed that ANN model produced better results compared with other models.

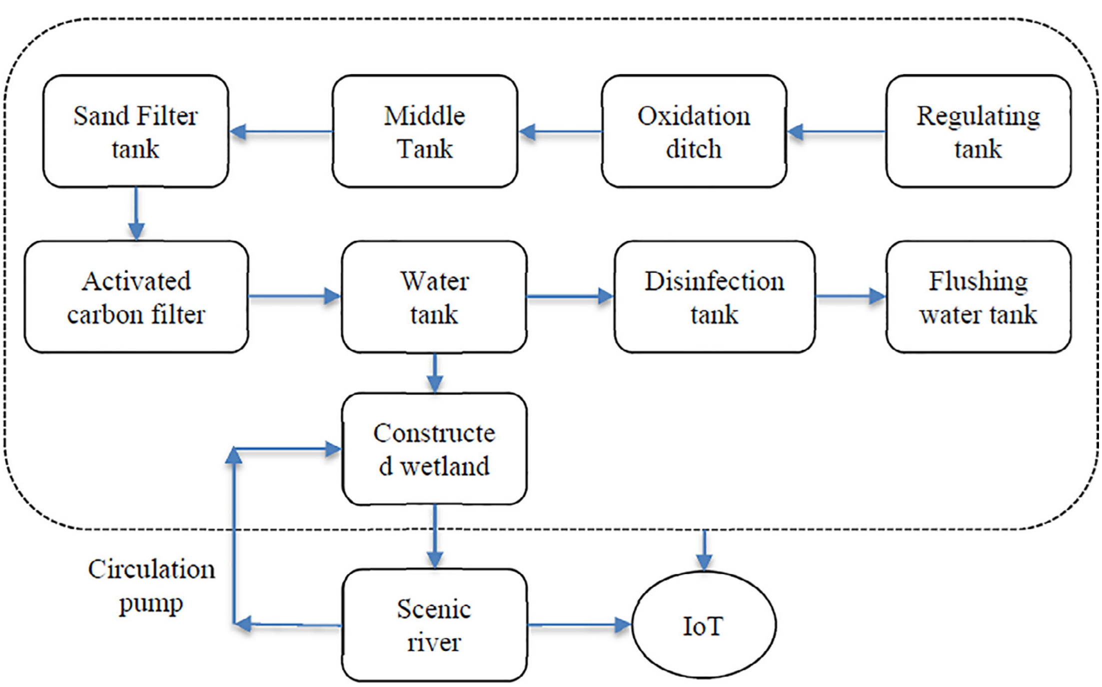

Fig. 4. Process flow diagram of the river.

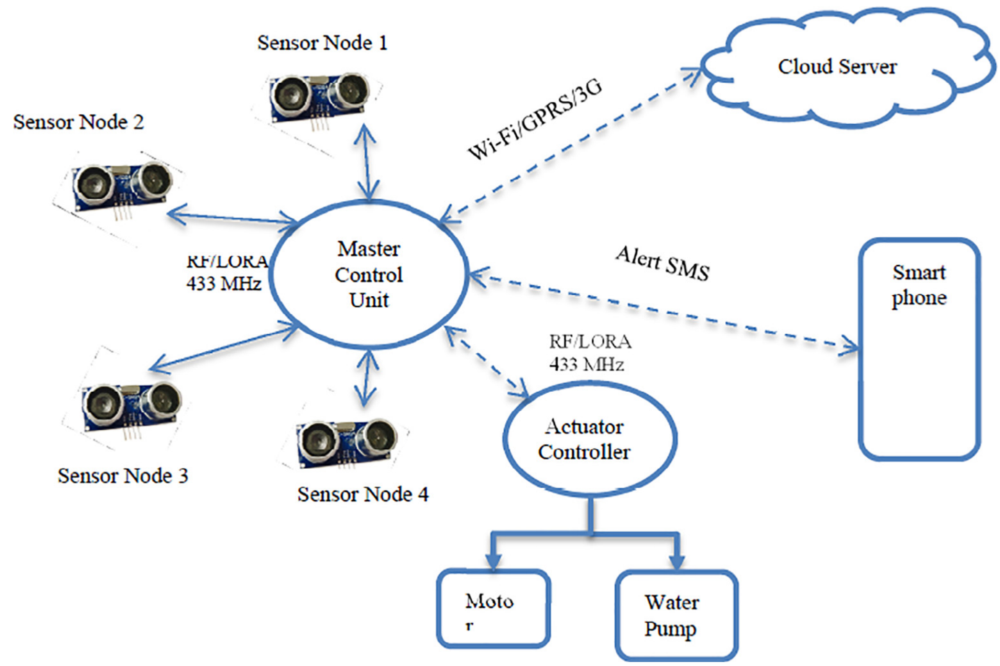

Fig. 5. Architecture of E-sensor AQUA system.

Table 2
Comparison of measurement parameters of various techniques.

Parameter	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]
Water level	√	√	√	√	χ	χ	χ	χ	χ
pH	χ	χ	χ	χ	√	√	√	√	√
Dissolved Oxygen (DO)	χ	χ	χ	χ	√	χ	χ	√	√
Turbidity	χ	χ	χ	χ	√	√	√	χ	χ
Conductivity	χ	χ	χ	χ	√	√	√	√	χ
Oxidation-Reduction Potential	χ	χ	χ	χ	√	χ	χ	χ	χ
Total Dissolved Solids (TDS)	χ	χ	χ	χ	χ	χ	χ	√	χ
Chlorophyll	χ	χ	χ	χ	√	χ	χ	χ	χ
Temperature	χ	χ	χ	χ	√	χ	√	√	√
Salinity	χ	χ	χ	χ	√	χ	χ	χ	√

3.4. Comparison

Table 2 presents the parameter wise comparison of the various techniques discussed. Water level monitoring techniques analyzed the water level in the tank/reservoir. Water quality monitoring techniques analyzed various water quality parameters like pH value, TDS, DO, etc. The quality parameter pH value was analyzed by all water quality monitoring techniques. Temperature, conductivity and turbidity are other commonly used quality parameters for water quality monitoring.

4. Proposed IoT based smart water management system

In this section, we propose an architecture for a smart water management system keeping in mind the key analysis of various techniques discussed earlier. The proposed system is an IoT based real-time smart water management system that will record water level as well as water quality parameters as shown in Fig. 6. The proposed system consisting of programs written in popular programming languages like python will be running in the controller e.g. Raspberry Pi. The controller will be connected to sensors for quality and level measurements like the HC-SR04 ultrasonic range sensor to gauge the water level, pH sensor for detecting the pH level of the water, etc. For real-time monitoring, it is important to integrate IoT platforms like Blynk [12] within the controller. These platforms allow us to control IoT devices like Raspberry Pi over the Internet. The real-time water level can be displayed on the mobile app using this integration.

For the analysis of the water level and other quality parameters, it is important to store these values in a secure location on the Internet. The proposed system should be able to update the current values in real-time to google sheets using Google Sheets API [29]. Google sheets API is a light weight application programming interface for reading and writing data to google sheets from low computing devices like raspberry Pi. All read and write requests require API key as and as such is a secure method for updating data values and protected against replay attacks. The recorded values can be split into training and test data for developing machine learning model. The alerts and predictions thus produced can be sent to the stakeholders for necessary action.

4.1. Essential attributes

After careful analysis of the related work in this area, we propose the following essential attributes which are necessary for an efficient smart water management system:

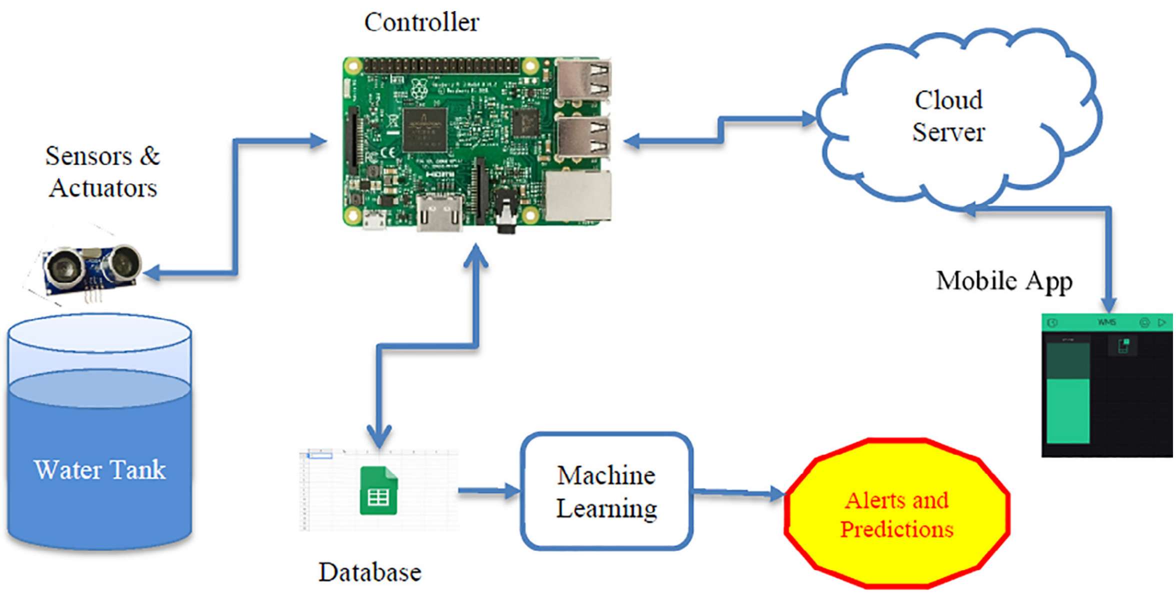

Fig. 6. Architecture of proposed system.

- *Low cost:* The total cost of the system should not be very high. The high cost is a deterrence to large scale deployment especially in smart campus or smart city.
- *Low energy consumption:* Keeping in view the increasing energy demand and effect on the environment due to high energy demand, it is important that the system should consume low energy. Renewable energy sources like solar power can be used to reduce energy costs.
- *Easy to deploy and maintain:* The system should be easy to deploy and maintain. It should support remote software maintenance and reset feature.
- *Water level and quality parameters:* For a complete water management system, it is essential that apart from water level other quality parameters be analyzed and stored. Additional sensors lead to extra energy consumption and added cost.
- *Real-time monitoring:* A smart water management system should support real-time water monitoring. Real-time monitoring can be useful in detecting water overflows and leaks. Real-time monitoring requires an active network connection and high energy consumption. In addition to this, cloud computing can be utilized for real-time decision-making process.
- *Security:* Securing IoT devices and messages is a challenging task especially when these devices are deployed in different physical locations. Vulnerability at operating systems can be exploited by hackers to steal sensitive information. These devices are prime target for bot infection as they are always connected to the Internet. Many malwares like Mirai [30], Hajime [31] infect IoT devices in their network to launch DDoS attacks.

4.2. Machine learning based prediction and security

Machine learning and deep learning has completely revolutionized the way we analyze and predict. Machine learning can be used in a water management system to predict water usage in a smart home/campus during different hours of the days/seasons. Similarly, the water requirement of various buildings on campus can be predicted by analyzing past data. Likewise, the effect of different events like a rainy season on the water quality can be analyzed and predicted.

Machine learning can also be used to check water portability by analyzing various quality parameters. Some efforts [32,33] have been made to use machine learning for checking water portability in the recent years with decent accuracy. Use of machine learning in checking water portability is expected to grow in the coming years.

Detecting attack and anomalies in IoT sensors using machine learning is another challenge. Hasan et al. [34] developed a model to predict attacks and anomalies in IoT sensors using five machine learning algorithms i.e. "Logistic Regression (LR), Support Vector Machine (SVM), Decision Tree (DT), Random Forest (RF), and Artificial Neural Network (ANN)". The work analyzed seven types of attacks i.e. "Denial of Service (DoS), data type probing, malicious control, malicious operation, scan, spying, and wrong setup". Synthetic IoT dataset from DS2OS traffic traces [35] was used to validate the results. The study concluded that RF classifier achieved the highest accuracy in detection attacks.

Xiao et al. [36] identified IoT attack models consisting of DoS attackers, jamming, spoofing, man in the middle attack, software attacks and privacy leakage. Various machine learning security techniques used against these attacks were discussed. Random forest and k-NN was used in [37] to detect malware. Neural networks was used in [38] to detect DoS attacks.

5. Conclusion and future directions

A water management system is the need of the hour for smart cities and campuses. The use of IoT devices for the water management system is becoming increasingly prominent. The availability of low-cost sensors connected to IoT devices has fixed the challenges of measuring water quality. In this paper, various components of IoT based water management systems were presented along with the in-depth survey of all existing smart water management systems. Various measurement parameters such as water level, pH level, turbidity, salinity, etc. were also identified and a comparison of all existing systems based on these parameters has also been presented. Also, a list of various essential attributes of smart water management systems have been framed. However, challenges of low energy consumption for real-time measurement are still there. Hence an architecture of a smart water management system based on IoT and Machine learning has also been proposed as future scope which addresses all these essential attributes and also uses machine learning based predictions which can increase the efficiency of the smart management system. In addition to this, factor of coverage of IoT for evaluation of uncertainty of measurement can also be incorporated in future works. Likewise improving the accuracy of predictions for water management system in irrigation and flood control is a challenge. Measuring economic water scarcity (EWS) particularly in agriculture sector using IoT devices can be further explored.

CRediT authorship contribution statement

Manmeet Singh: Conceptualization, Methodology, Investigation, Writing - original draft, Funding acquisition. **Suhaib Ahmed:** Conceptualization, Investigation, Supervision, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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