An IoT-Based Water Management System for Smart Cities

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An IoT-Based Water Management System for Smart Cities

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Abstract Water conservation is one of the prime concerns in the current scenario where environmental conditions are deteriorating at an alarming rate. Smart cities, unlike the conventional system of living, are in the frontline of innovation in terms of both connectivity and technological advancement. The main idea is to use the available technology to make life easy with lesser harm to the environment. An Internet of Things (IoT) and data analytics (DA) based water management system will be a basic ground for implementation and future research on how data and IoT can be used to make this happen. This paper proposes an Internet of Things (IoT) and data analytics (DA) based water distribution cum management system that would help in optimal distribution of water based on user consumption at the plot holding level. The proposed system would not only save water misuse but also help in storing usage data for analysis and town planning at a macro-level.

Keywords Water management · Data analytics · Internet of Things · Smart city

1 Introduction

Smart cities combine technology and innovation in day-to-day living. The idea behind every smart city is that the application of IoT and intelligent techniques in regular everyday activities can increase the ease of living and efficiently perform these activities with less effort [1]. In a smart city, the basic idea of IoT is implemented which is "anything that can be automated will be automated". One very important task in a smart city or any city for that matter is water distribution and conservation. In traditional cities and housing communities, water is distributed manually with the use of traditional pipe and motor systems [2]. This being very inefficient in terms

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of availability and also conservative management of this valuable resource, planned and efficient water management is required. A water management system with the implementation of IoT and data analytics is expected to decrease water wastage and also be more efficient in terms of water availability and also from a conservation point of view [3]. This paper presents a plot holding level plan for smart water management. Applicable in upcoming smart cities [4], this IoT- and DA-based system uses user consumption behavior to optimize the water distribution. Using smart sensors, the proposed system also presents a plan to harvest rainwater at the plot level. The following sections of the paper will give detailed explanation on the basic terminologies used in this paper. It gives the specifications of the sensors and their usage. The next section will give the architecture of the water supply block. Following, it is the structure of the water tank and how its structure will help the rainwater harvesting mechanism and how the sensors are placed on the tank. The final part is the description of the water distribution of the water in the smart city and how it is optimized with the use of DA. In the end, the conclusions and future works summarize the paper and the methodologies proposed and present the possible research and advancement in the proposed methodology.

2 Existing Distribution Method

Urban water distribution methods, or the conventional method of water distribution which is being followed in cities all around the world, work but are inefficient and have a lot of opportunities for development. It has a one-way cycle, consisting of the reservoir/any water body, treatment plants, water storage, homes/consumers, finally to the waste management/treatment facility and send back to nature as groundwater or natural water (Fig. 1). This method of water distribution can have certain downfalls like inefficient water supply or unavailability of the resource at times due to unwanted

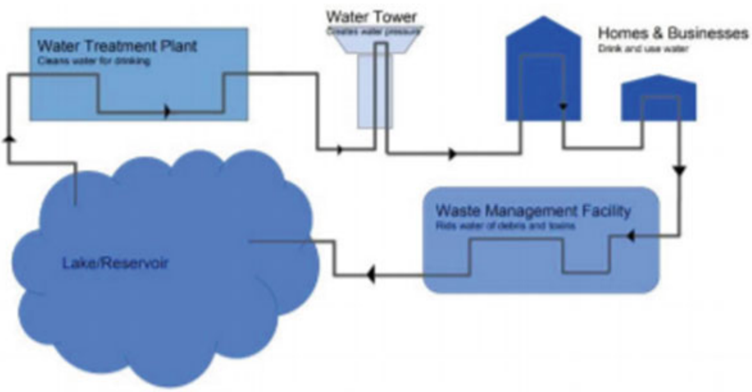

Fig. 1 Conventional water distribution architecture

usage or an architectural failure in the system. This paper has been targeted to overcome some of these basic failures that might occur in the conventional method of water distribution.

The aim of this paper is to optimize the distribution method, to achieve better, faster distribution and also better use of technology to conserve water, which is the need of the hour.

3 Basic Terminology

This section presents in brief the terminologies and technologies used in this paper. This includes IoT, data science, the different sensors and its purpose.

3.1 Internet of Things (IoT)

The growth in computing power, miniaturization of components and higher bandwidth for faster communication has helped in the development of Internet technologies. What was initially envisaged as only a digital mailing system has now grown to be the World Wide Web. Taking full advantage of such technologies, an exciting new field has emerged which allows unprecedented control over devices spread over distant locations and enables data gathering for analysis and intelligent control. Termed as Internet of Things and better known as IoT, this is the systematic interrelation or interconnection of devices for different machines, objects or even humans each with a unique identifier and all interconnected with each other all through the Internet [5]. The main aim of Internet of Things is automation, human–computer interaction and data collection and analysis. Concepts like embedded systems, automation, wireless sensor networks and control systems, etc. contribute to Internet of Things.

IoT has found widespread applications in home automation, security systems, elder and child care, personal health care, telemedicine, transportation and traffic control, livestock tracking and farming management, wild life and defense to name a few. Applications are growing by the day and are limited only by imagination and sensor availability. One such application on water management is presented herein below.

3.2 Smart City

A smart city is an urban area where sensor-based Internet of Things is used to aid in management of resources and civil life. The sensors are used to collect data from various sources to be analyzed and used for better utilization of assets and services. This data may include citizen count, traffic data, electricity usage data, rainfall data, etc. which can later be used in analytical models to draw inferences to significantly change the quality of life for the citizens. “Smart city” or a “digital city” is the use of modernized techniques in communication, sensing, analysis and integration to run everyday living conditions [6].

Smart implementation of technology can give intelligent and prompt responses to different needs including but not limited to commute and traffic management, public safety, resource distribution and management and commercial trade and activities. In layman terms, a smart city is a way of living with and aided by technology and data. Unlike conventional cities, smart cities integrate technology with governance and that is what makes smart cities different. Automation is made from the smallest entities such as a simple traffic light to more complex infrastructure such as water supply, energy transfer, governance and emergency situation handling. A smart city is therefore portrayed as being better equipped to face growth-related changes through a simple transnational relationship of governance with citizenry and resource usage patterns.

3.3 Data Analytics (DA)

Increasing environmental awareness among people and the desire to work fast and effectively through the reduction of time spent on unproductive activities is forcing the realization on governments toward building smart cities. While one important aspect of this lies in connectivity through sensors, the other is data analytics.

Data analytics (DA) is the basic science of analyzing trends and features in data. As the name suggests, it deals with analyzing patterns in data to derive information on which decisions can be based. Data analytics is a sub-section of machine learning, as it uses several machine learning techniques to analyze the data including regression, classification techniques and also bagging and boosting techniques such as XGBoost and AdaBoost [6]. Use of analytical techniques in IoT and smart city-based applications can improve their performance [7]. Analysis of traffic patterns can help in deciding traffic flow regulation. Weather data analysis can help in street light control, which may additionally also depend on the traffic density saving power. Analysis of carbon emission data may help in devising means of reduction of emission. A host of such application can be found through intelligent sensor usage and data analytics. Data analytics in IoT is almost always clubbed with cloud techniques to improve data retrieval management so that the data is safely stored and accessible for use. The current paper proposes an IoT-based water management technique, which augmented with data analytics can be used in smart cities for effective water management and sustainable town planning.

3.4 Sensors and Transmitters

The data for the analysis obtained from the water supply mechanism and the water reservoir and tanks present in the city is collected continuously using sensors and transmitted to the cloud [8]. This following section has the basic description of the technology used. This project uses the Arduino UNO is an open-source microcontroller to connect and coordinate the different sensors. Arduino UNO is an open-source microcontroller developed by the Arduino group [9]. This board has 14 I/O pins to connect different sensor and transmitter to collect the data and transmit the data to the cloud. It is programmed using the Arduino IDE and a simple USB cable. This board is powered by a 9volt power supply. Different sensors are used to measure the water conditions and levels for data collection [8]. The microcontroller, sensors and transmitters used are:

- Arduino UNO
- SRF-05 sensor (ultrasonic sensor)
- YF-S201 Hall effect sensor (Water flow sensor)
- LM393 chip-based sensor (Rain sensor)
- ESP-8266 Wi-Fi transmitter
- Stepper motor

1. RF-05 sensor (ultrasonic sensor): The SRF-05 ultrasonic sensor (Fig. 2) is a wide range distance sensor which uses the SONAR technology [10]. The SRF-05 sensor has a range of 4 m in total.
   It is used in the top of the water tank in this project to measure the amount of water present in the tank. Let x be the height measured from the top of the tank to the surface of water level and h, r be the height and radius respectively of the cylindrical tank. So, the volume of water in the tank can be calculated using the following formula.

$$\pi r^2(h - r) \tag{1}$$

2. YF-S201 Hall effect sensor: Accurate flow measurement is an essential step in terms of both qualitative and economic points of view. Flow meters have proven excellent devices for measuring water flow, and now it is very easy to build a water management system using the renowned water flow sensor YF-S201 [11]. This sensor sits in line with the waterline and contains a pinwheel sensor to measure how much water has moved through it. There is an integrated magnetic Hall effect sensor that outputs an electrical pulse with every revolution.
3. LM393 chip-based rain sensor: The LM393 chip-based rain sensor is a sensor used to sense whether there is rain or not. This sensor uses the principle of resistance. It is basically connected to the Arduino board to sense the presence of moisture on the rain board. If there is moisture, then a signal is sent back to the microcontroller.

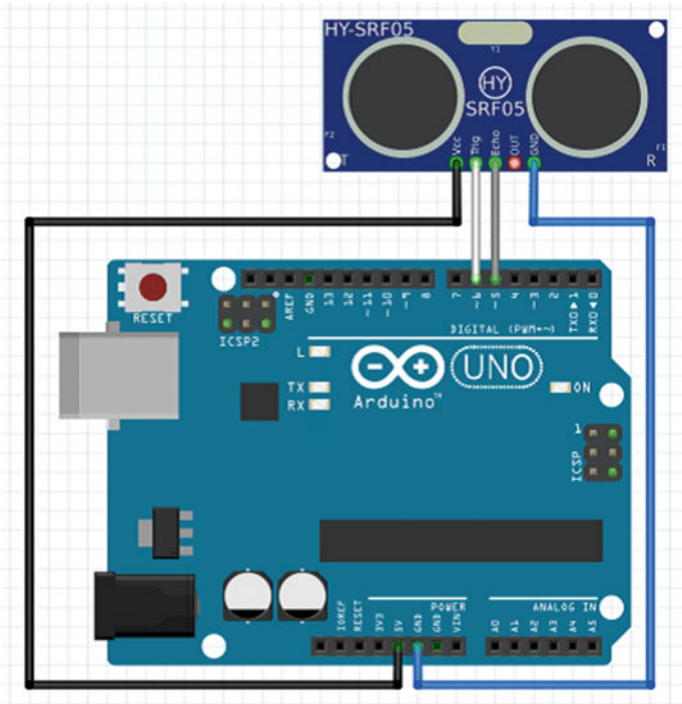

Fig. 2 SRF-05 ultrasonic sensor with Arduino UNO

4. ESP-82866 Wi-Fi transmitter: The ESP-8266 [12] (Fig. 3) Wi-Fi transmitter is the low-cost wireless microchip with a fully integrated TCP/IP stack ready for deployment with any microcontroller such as Arduino for experimental purposes.

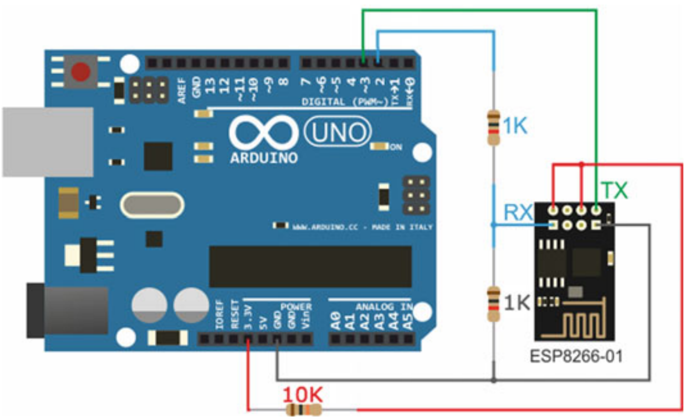

Fig. 3 ESP-8266 Wi-Fi transmitter connected to Arduino

The ESP8285 is an ESP8266 with 1 MiB of built-in flash, allowing for single-chip devices capable of connecting to Wi-Fi.

4 Blocks of Water Supply Architecture

This section gives a brief overview of the architecture of the smart city and how the basic blocks of the city are laid out for the water transmission.

4.1 Block Structure of Smart City

The water management system in the smart city is solely based on the fact that the city is divided into several blocks, and each block consists of several houses to which the water is supplied. The paper assumes this block structure to ease the explanation. The entire city is seen as a collection of blocks which are again recursively organized as sub-blocks. The recursion can go up to a suitable level as would be required for efficient and effective management. Individual houses would be the atomic constituents of such blocks. As shown in Fig. 4, initially the water is stored in the reservoir, from where the water for the smart city is obtained. From the reservoir, it is directly sent to the water treatment plant as it is treated to make it ready for use. Every outlet in the water supply architecture is monitored using motorized valve for ease of activation.

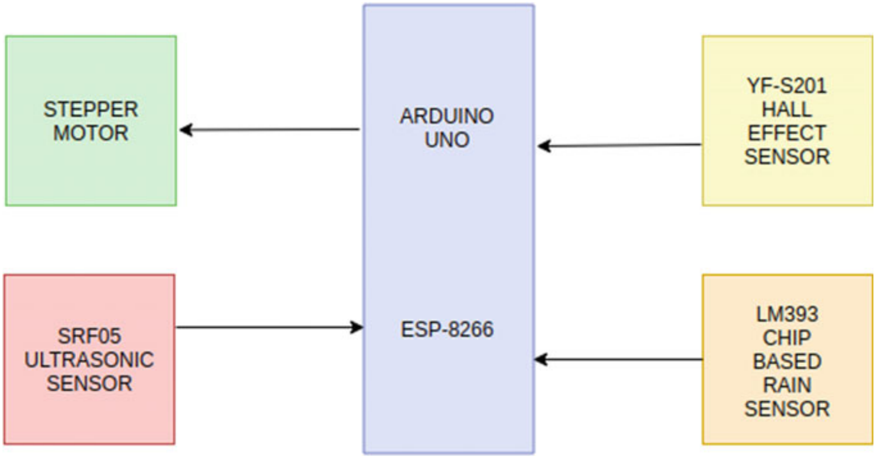

Fig. 4 Microcontroller setup

4.2 Server and Data Control Room

One of the main components of this architecture is the server and data control room where the data from every sensor in the block is collected and sent to the cloud and also a main hub for the maintenance of the valve and sensor mechanisms. The sent data is then used in the cloud to perform different extrapolation and feature modeling methods to find the water consumption and usage rate and predict the values for the future use.

4.3 Underwater Storage Facility

Water from the treatment plant is taken to the underwater storage facility [1]. This facility is present near every block of the city, and the water in this storage unit is used for immediate consumption on demand [11]. The water from this facility is sent to different blocks and houses using the sensors and the motor-controlled valve and smart water pumping systems.

4.4 Water Tanks and Pressure Control Systems

The water from the underwater facility is sent to every house in a block using pumps and sensors [5]. The specially designed water tanks are used to measure parameters like current water level and amount of water used to make the water supply more efficient [13], and conservation and management of the resource become easier. The structure and organization of the tank are explained in the further section.

5 Structure of the Water Tank

The water tank present in every house is of a specific structure. Firstly, the water tank is fully customized to suit our requirements of the smart city [14]. It mainly takes care of three functions:

1. Senses the shortage of water to release water into the tank.
2. Records the amount of water used by the person/house on a daily basis.
3. Uses a rainwater harvesting method to smartly open the valve to capture falling rainwater.

5.1 *Build of the Water Tank*

As mentioned above, the water is stored and supplied to each house through a smart water tank fitted on top of each house [6]. The smart water tank has several features as mentioned below.

5.1.1 Microcontroller Setup

The water tank is fitted with the Arduino UNO microcontroller, and it is powered with a battery which is recharged with a solar panel. The board is kept in a waterproof container to keep it from moisture which might cause short-circuiting. This microcontroller will control all the sensors connected in and around the tank. The UNO is connected with an ESP-8266 Wi-Fi transmitter which is used to connect with the nearest access point which in turn is connected to the server room to transmit data [9].

The basic architecture is mentioned in Fig. 5. The second sensor is the SRF-05 ultrasonic sensor. This sensor is used to measure the amount of water in the tank. The sensor is fitted, face down inside the tank. The sensor emits ultra-sonic waves and sends it in the tank. The waves are reflected back to the sensor, and it senses the height h meters. Assuming that the radius of the base of the cylindrical tank is r meters, the volume of water in the tank volume would be:

$$\text{vol} = \pi r^2 h \tag{2}$$

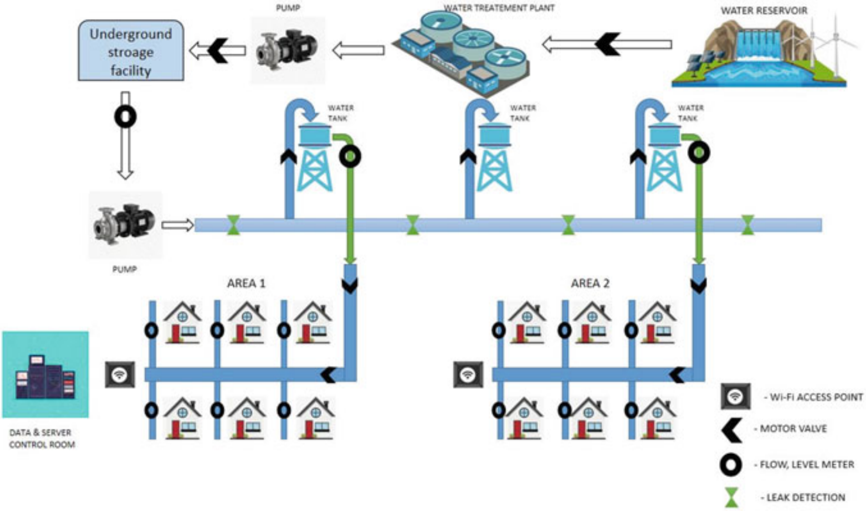

Fig. 5 Smart city water distribution architecture

This measure would help find the amount of water in the tank. If the measured amount is lesser than the minimum threshold, the automated motorized valve opens filling the tank with water. This also helps in supplying the house with the required amount of water. If the tank is having enough water for the home's usage, the valve is kept closed until required later. The amount of water used by the house (data) is collected using the YF-S201 Hall effect sensor. The tank has the outlet into the house on its base. The Hall effect sensor is placed on the outlet. The amount of water used up from the tank is calculated using Eq. (2), using the flow rate, average velocity of the water and the cross-sectional area of the pipe. This gives the essential data to analyze the data to identify and find out the rate of usage of water with the historic data.

5.1.2 Rainwater Collection

The water tank is designed in a way not only to make the water distribution efficient but also to collect rainwater during a shower in order to maximize the water conservation. To facilitate this, a funnel-like structure is placed on top of the tank's opening with a door like structure which can be flipped and a water filter on its base. The door of the funnel is connected to a stepper motor. This stepper motor is used to force open and close the opening of the funnel. This is placed as keeping the funnel always open might lead to evaporation of the water from the tank. The top of the tank is fitted with the LM393 chip-based rain sensor connected to the Arduino board. When there is rain, the sensor senses it and sends a signal to Arduino. Once it receives the signal from the sensor, it sends a signal to the stepper motor to open the door of the funnel to capture the oncoming rainwater and passes through the filter into the tank for storage. This in turn increases the water ready for use in the tank. Once the rain subsides, and the rain sensor dries out, the Arduino sends another signal to the stepper motor to close the door of the funnel.

6 Water Distribution

The water distribution is also fully monitored and controlled with the help of sensors and fully connected valve systems. The water from the reservoir is sent to the treatment plant from which it reaches the underwater storage. From the underwater storage, the water is sent to each block in a specific manner. All the monitoring from when the valve opens, to how much water is sent, everything is controlled from the server and data control center. The underwater storage facility sends the required amount of water to separate distribution tanks in each block.

From the analysis of the data received and the predicted amounts of water, the water is sent through pipelines with motorized valves to each house. The water sent to each house depends on two things:

1. The signal from the sensors of the tank.
2. The requirement calculated from the data.

6.1 Signal from the Sensors

As mentioned in section IV, the water tank placed on top of every house is fitted with different sensors. These sensors keep sending the data to the control center. This data is used to determine when the water should be supplied and when not. When signals are received from the sensor that the water level is low, the motorized valve at the outlet of the pipe is opened and water is sent in. In case the sensor shows that enough water is present in the tank adequate for the consumption of the household (obtained from the historic data collected), then the water is not sent to the house. This helps to divert that water to another area or block where it is actually required. Following this method will reduce the wastage or unwanted supply of water to the houses in the city.

6.2 Supply on Demand

The water supply to the houses as mentioned above also depends on another factor, i.e., supply on demand. This means that the water is supplied only to an extent which the household requires. This requirement is calculated by the analysis of the historic data [15]. Extrapolating from usage patterns already recorded YF-S201 Hall effect sensor, future requirement can be predicted. This would allow regulated water supply in exact quantity as required by a household and prevent wastage. In case of excess requirement, special requests can be arranged for individual household delivery. The obtained value and the actual value are kept and later the error is used to tune the model better. Storage of such information and excess supply needed by individual households would help in tuning the predictive models for better analysis including error margins in prediction. The same information can also be utilized for taxing individuals for excess use beyond set limits. This application of data analysis differentiates this method of supply from the regular distribution methods. Regular tuning of the model can keep the prediction in range and can help optimize the distribution better. Even seasonal variations in usage patterns can be tracked and included in the model. Administrative decisions taken at times of water scarcity caused by lack of rain can also be handled through such models.

7 Conclusion and Future Works

The water distribution can be optimized, and the water can be conserved better by the application of the above method in a real-life scenario. The proposed methodology can be improved with the application of better sensors and industry grade materials which would make it efficient. Motorized valves can be replaced with a better alternative and the Arduino with the ESP-8266 upgraded with a NodeMCU or even better ones. This can make the working faster and better. Improvements in the analytics can be done by using advanced ML algorithms with neural networks or similar techniques for a better outcome.

In the current paper, as already mentioned, simplifying assumptions have been made about the layout and plan of the city where it can be implemented. This has been done purely for ease of identification of the individual households, as analysis of the data gathered plays a pivotal role in the proposed model. It becomes essential therefore to pinpoint every holding and regulate the supply accordingly. The scalability of the proposed model in its current form is limited only by the organization of the cities household. The same may however be implemented on any scale, small or big, provided a proper distinction can be made between individual houses to enable the analysis to be based on that identity.

Another novelty of the proposed model is its flexibility. The same model can be used for farmland water management, wherein the identification of every household would be replaced by individual farm plots. The analytics can be appropriately tuned without major changes.

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