Autonomous Tracking of Portable Drinking Water System

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Abstract— Increased utilization of water and absence of seasonal rainfall leads to water scarcity. This necessitates the employment of proper scheduling in the existing portable drinking water distribution system. In this paper, an automated portable drinking water system is proposed for the regulation of the water flow and also for tracking the distribution of water from the filling point to the delivery point. The proposed system consists of two embedded modules: (i) to determine the capacity of water filled in the portable water truck at the filling point and (ii) to avoid water theft during dispatch at the water truck. The trip sheet was generated after the completion of registration of water requirement by the customer. It was then assigned to the water filled trucks. The opening of the water outlet valve in the truck could be made whenever the location in the trip sheet matched with its corresponding Global Positioning System values. Thus, water pilferage can be avoided through use of the proposed solution. The proposed system was implemented and validated in real time. The experimental results and performance characteristics were analyzed in terms of accuracy.

Keywords— *Water scarcity, Water theft, Scheduling and distribution, autonomous, Trip sheet and Global Positioning System.*

I. INTRODUCTION

Water is the most valuable and essential resource for the social and economic development of a country. The major issues in the developing countries are the availability of clean water, increasing demand for clean drinking water due to urbanization and industrialization in cities, cost management for water transmission, water storage, water treatment and water distribution [1]. Water scarcity occurs due to drastic climatic changes, water pollution, poor resource management and poor leakage detection system. Recent studies on piped water systems show 40% of the city water are wasted due to leakage in pipes and thefts through unauthorized connections [2]. Therefore water distribution network should be continuously monitored in order to avoid both leakage and thefts. The abbreviations and its expansions used in this paper is listed in the Table Ⅰ.

TABLE Ⅰ
List of abbreviations

ABBREVIATION	EXPANSION
Wi-Fi	Wireless Fidelity
IoT	Internet of Things
PC	Personal Computer
GPS	Global Positioning System
GSM	Global System for Mobile Communication
GIS	Geographic Information System technology
SoC	System on Chip
AWS	Amazon Web Service
ATPDWS	Autonomous Tracking of the Portable Drinking Water System
API	Application Program Interface
TCP/IP	Transmission Control Protocol/Internet Protocol
IPv4	Internet Protocol version 4
UDP	User Datagram Protocol
SSH	Secure Shell
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol over Secure Socket Layer
FTP	File Transfer Protocol
SFTP	Secure File Transfer Protocol
TDMA	Time Division Multiple Access
RISC	Reduced Instruction Set Computer
GPIO	General Purpose Input Output

The growing presence of Wi-Fi and Fourth Generation Long Term Evolution wireless Internet access technologies have enabled the establishment of smart connectivity among these networks. The evolution of Information and Communication technology allows the devices not only the obtaining of information from the environment (sensors) easily by interacting with the physical world, but making use of the existing Internet standards to provide services for data transfer, applications, communications and analytics. Incorporation of the IoT technology in the proposed work enables different water suppliers to create multiple business opportunities in a seamless manner. The proposed portable water distribution network with the help of the IoT technologies lays the foundation to the new field namely Water IoT (WIoT).

In the traditional water distribution system [3], measurement readings from the flow meter have to be taken manually. The existing system lacks automatic opening and closing of the water valve. Many technologies meeting this demand have been discussed in literatures, but provision of an effective solution for continuous monitoring and tracking system is not seen. The two major problems identified in the existing portable drinking water distribution system are: (i) Absence of a measuring module for the determination of the capacity of the water filled in the truck at the filling point and (ii) Unavailability of a tracking system for the portable water truck which paves way for the occurrence of theft. This research aims at the development of an autonomous system. It consists of two embedded modules - one for regulating the water flow measurement at the filling point and the other for continuous monitoring of the truck movement for regulating the water distribution, thereby preventing the water theft.

The organization of the paper is as follows: Section II elaborates the state of art related to the proposed work. Section III describes the proposed methodology. The results obtained are discussed in Section IV. Section V concludes with indication of the scope for future work.

II. LITERATURE SURVEY

This section presents the findings from literatures related to the proposed work. In [4], the authors have designed a non-contact flow rate measurement system using a hall probe sensor and rotameter. The developed system was implemented in real time and it measured the consumption locally. In order to support remote access, Personal Computer (PC)-based flow indicator has been designed. In this system, the measurement range depends upon the size of the float and the magnet.

In [5], the authors have developed an intelligent flow transmitter using a rotameter. In this work, the float movement of the rotameter was converted into an electrical signal controlled remotely. Back Propagation algorithm of the Artificial Neural Network was used for compensating the nonlinearity and inaccuracies in the Hall probe sensor caused as a result of temperatural changes. The developed work was seen as efficient and reliable. Further, the parameters affecting the performance could also be compensated using additional transducers.

In [6], the authors developed ATmega microcontroller based vehicle tracking system. The key objective of the system was to determine the missing status of the vehicle. The system contained a GPS sensor. The location of the vehicle was updated on the mobile with the help from a user navigation.

In [7], the authors have developed a novel approach to automate water consumption in a city water distribution system. The key objective of this work was to regulate the utilization of water. Using a water meter, the consumption of the customer was measured and transmitted wirelessly to the customer relations and billing management module present in the remote server. Billing was done on the basis of the utilization and communicated to the customer. Mobile app was developed to facilitate easy access to the applications. The developed work was validated in Real-time. The system could also be extended for piped natural-gas distribution systems in the city as well as for Energy-meter reading systems for domestic and industrial consumers.

In [8], the authors have developed a real-time tracking system. The core objective of the system was to localize the portable tracked unit and transmits its position to the tracking center. The portable tracked device could be attached to the vehicle, person or asset. The developed work was validated in real time. The proposed system could also be extended for piped natural- gas distribution systems in the city as well as for Energy-meter reading systems for domestic and industrial consumers.

In [9], the authors have designed and implemented a Vehicle monitoring system based on GPS, GSM and GIS. The main objective of the system was to design a monitoring center for the real-time positioning of the vehicle. The monitoring center received the message via GSM and made analysis of the position coordinates with the aid of GPS and GIS technologies and the information on the Google map was displayed. The developed system was validated in real- time. The number of vehicles monitored in the developed system was limited. This can be overridden through increase in the database system.

In [10], the authors have developed and implemented a vehicle tracking system for continuously tracking of the movement of the vehicle. The device to be tracked in real-time was embedded inside a vehicle. The data processing center having a database was designed to enable receipt of data, its storage and provision of remote control. Further, for easy access to the application, the mobile app is developed.

In [11], the authors have developed two types of water velocity measurement using contact and non-contact type sensors. In contact type, Hall Effect based water flow sensor is used as a sensing element which gives the corresponding pulse signal whenever water flows through it. In the non-contact type, the measurement system relies on video processing based optical flow technique. The developed system is accurate and reliable. The contact type is more accurate when compared to the non-contact type.

In [12], authors have designed and developed residential water metering system based on SoC. The objective of the system is to design an IoT based remote water metering. It uses a single-jet water meter to measure water consumption and Wi-Fi for high-speed data transfer upto 100 m coverage. To provide continuous monitoring, the water metering data is stored in the Ubidot cloud server in this developed work.

From the above survey, it is observed that implementation circuitry have been developed for piped water distribution network. The proposed research have developed a portable drinking water distribution system to deliver water from filling point to customer location where water pipeline distribution networks are not accessible. It uses YF-S201 Hall-effect flow sensor to measure the water flow. GPS is used to track water distribution truck from filling point to customer location and GSM for transmission of data to the control center. To enable continuous monitoring, flow rate and location coordinates data are stored in the AWS cloud and are displayed in the Google map using Google Sheets.

III. PROPOSED METHODOLOGY

A. Architecture

The architecture of the proposed ATPDWS is shown in Fig. 1. It consists of three layers:

i. IoT Device layer

ii. IoT Service layer

iii. IoT Platform layer

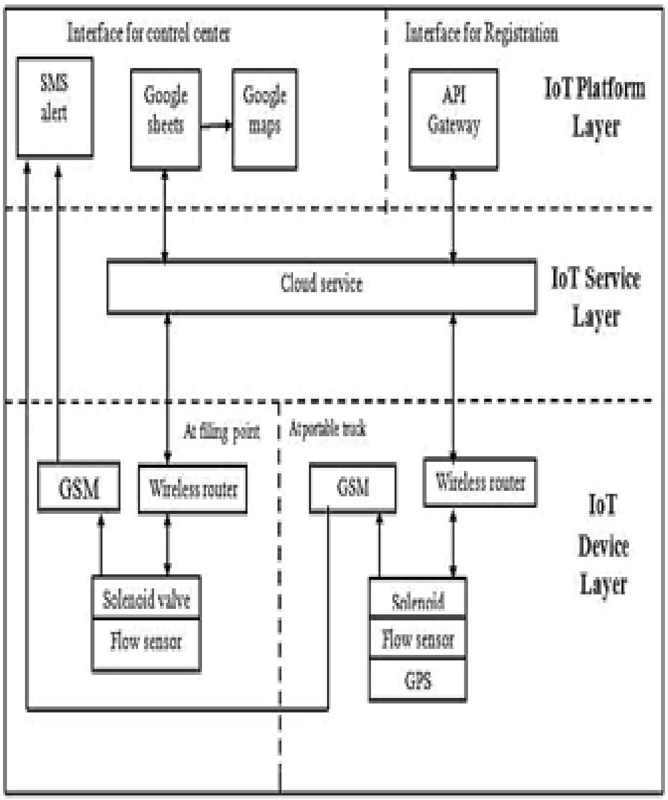


Fig. 1. Architecture of the proposed ATPDWS

1) *IoT Device Layer*: The IoT device layer handles the physical devices that are deployed in the filling point and the portable truck. The hardware utilized in the proposed work consists of ESP8266, water flow sensor, solenoid valve, GSM and GPS. Regulation of water flow was achieved by the water flow sensor and solenoid valve while GSM and GPS were used for tracking and alerting purposes.The GPS module was set up only in the portable truck in order to track the trajectory of the truck.

2) IoT Service Layer: The IoT service layer allowed cloud based data service and storage since the data handled in this proposed work was quite extensive. The data obtained from the IoT device layer was directed to the cloud through ESP8266. The data stored included the sensor data and the database relating to the customer and the trucks employed in the distribution. AWS [19] and Google sheets [20] were employed for cloud service in this framework. The data collected after each delivery was stored in the form of tables with parameters, namely, truck number, location coordinates and amount of water delivered at that particular location.

3) IoT Platform Layer: The IoT platform layer paved the pathway for the client and the server. A separate interface was made for the control center and registration processes. Customer registration and truck registration was done via API Gateways and stored in the cloud database. Generation of the trip sheets was performed and updation of the delivery details was visualized through the control center interface. Google maps helped in the real-time visualization of truck delivery.

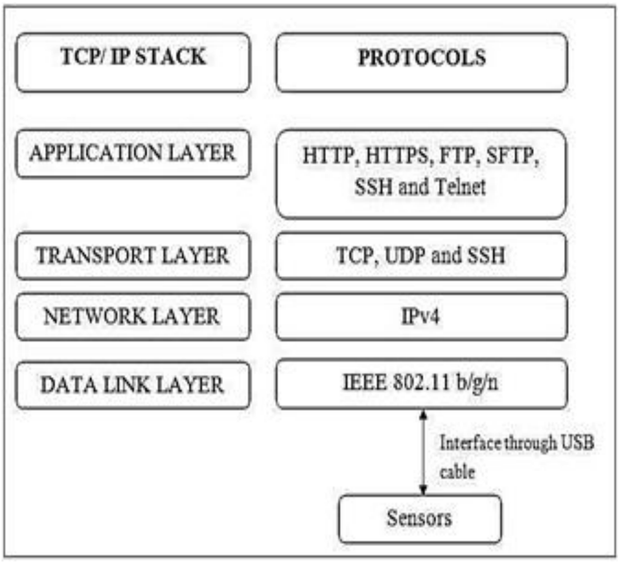


Fig.2. Protocol stack for the proposed ATPDWS.

B. Protocol stack

The IoT devices used in the proposed work were made to communicate with the cloud server using appropriate communication protocols as shown in Fig. 2.

The ESP8266 had a self-contained Wi-Fi SoC integrated with the TCP/IP stack that enabled access to a Wi-Fi network [21]. The data link layer formed the lowest layer and played an important role in establishing the communication channel. It handled all the physical connection made between sensors and ESP8266 module utilized in the proposed work. The ESP8266 acting as a wireless router used IEEE 802.11 standard for connecting the sensors to the local network segment. Once the physical connection was established, the network layer forwarded the data of the sensors over the internet. The ESP8266 module with TCP/IP stack is enabled with IP based connectivity. The IPv4 protocol used uniquely helped identification of the IoT devices with its network address. The transport layer ensured reliable data exchange between the networks. The proposed work incorporated TCP, UDP and SSH protocols in the transport layer. The application layer served as an interface between the sensors and desired web service in the cloud. The protocols mostly used included: HTTP, HTTPS, FTP, SFTP, SSH and Telnet. The Postman API development tool made extensive use of HTTP, WinSCP utilized FTP and SFTP, PuTTY utilized of SSH and Telnet protocols and data sent to the cloud incorporate HTTP and HTTPS protocols.

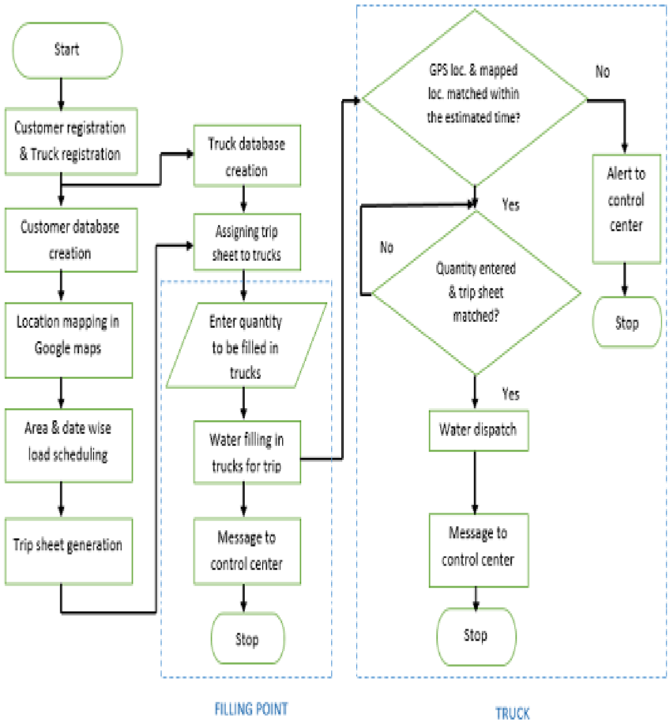


Fig. 3. Design flow of the proposed ATPDWS

C. Design flow

The design flow of the proposed work is shown in Fig. 3. The process started with customer and truck registration, with the simultaneous generation of the corresponding database. Based on the demand, generated trip sheets were assigned to the trucks. The water to be filled into the truck was based on the capacity of the truck. The dispatch of water from the truck depends on the customer requirement. After entering the water quantity at the filling point embedded module, the water flow was continuously monitored by a flow sensor and, when the desired quantity was filled, the solenoid valve closed the water valve automatically and the message was sent to the control center. After recording the water quantity at the portable truck embedded module, the values in the trip sheets were cross-checked with the quantity recorded. When the condition got matched, the location in the trip sheet and the trucks present location were cross-checked. Following this, the solenoid valve opened the water valve automatically, else an alert message was sent to the control center. The water flow was continuously monitored by a flow sensor and, when the desired quantity was filled, the solenoid valve closed the water valve automatically and forwarded the message to the control center.

D. Hardware setup

The test bed for the proposed system shown in Fig. 4. consists of a ESP8266 Microcontroller, a flow sensor, a solenoid valve, relay, a GSM module and a GPS module. Bubble top dispenser was used as the water storage tank in the proposed system.

1) Flow Sensor: The flow sensor was utilized for the determination of the flow rate of water flowing through the pipe [22]. It comprised of a rotor, a Hall Effect sensor and a magnet. When the water flowed through the inlet pipe, the rotor rotated and the magnet fixed at the center of the rotor rotates. The output pulse was high when the south pole of the magnet came in contact with the Hall Effect sensor. It was low when the north pole of the magnet came in contact with Hall Effect sensor. The speed of the rotor determined the output pulse. Pulses produced from the flow sensor were proportional to flow rate. Flow rate was determined by using Equation 2. The specification of the flow sensor is listed in Table II .

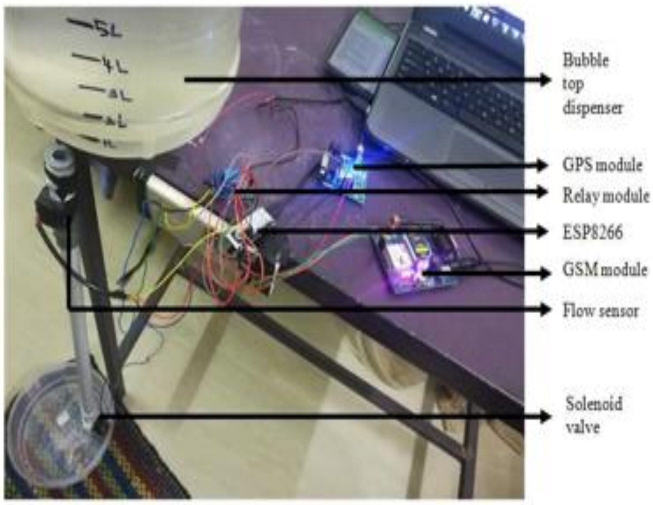


Fig .4 Real-time implementation of the proposed ATPDWS

In reference to the datasheet [13] provided for the flow sensor, 7.5 pulses per second are generated for 1 litre quantity of water. In this framework, the flow rate was determined by (1).

$$FR = \frac{P}{CF} \quad (1)$$

Where FR denotes flow rate of the water, P the pulse count and CF denotes the calibration factor which is equal to 7.5. The flow rate can be further simplified as (2).

$$FR = P \times 0.135 \quad (2)$$

TABLE II
Specifications of flow sensor

Model	YF–S201
Sensor type	Hall effect
Working voltage	5 V to 18 V
Max. current draw	15 mA @ 5 V
Output type	5 V TTL
Working flow rate	1 to 30 L/min
Working temperature	-25 to +80 ºC
Working humidity	35% to 80% RH
Accuracy	± 10%
Maximum water pressure	2.0 MPa
Output duty cycle	50% ± 10%
Pulses per litre	450
Durability	Minimum 300,000 cycles

2) *Solenoid valve:* It is an electromechanical valve comprising of a plunger, valve and spring. It was utilized for controlling the water flow. It is normally a closed valve in a closed position until its operating voltage of 12 Volts is applied.

3) *Relay:* The relay is an electromagnet used for providing isolation between microcontroller and solenoid valve. It is also useful in controlling an enormous amount of voltage from a small electrical signal. When the power is supplied to the relay, current starts flowing through the control coil. As a result, the electromagnet starts energizing and then the armature is attracted towards the coil, pulling up the moving contact together thus connecting with the normally closed contacts. So the circuit with the load (solenoid) is energized. This provides the ability for the switching ON and OFF of the relay to control the state of a solenoid.

4) *GSM:* Global System for Mobile Communication which operates at dual-band 900MHz/1800MHz consists of RS232 interface. The module uses TDMA technology and offers the data rate of 85.6 kbps for downlink and 42.8 kbps for uplink [23].

5) *GPS:* Global Positioning system that comprises of 24 to 32 satellites that transmits the radio signals help the GPS receiver to determine the location, time and velocity using the trilateration concept.

6) *ESP8266 Microcontroller:* This microcontroller consists of a 32-bit Tensilica RISC processor. It has 30 pins out of which 13 are GPIO pins and a serial port for programming and has an integrated 10 bit Analog to Digital Converter. The microcontroller has a self-contained SoC integrated unit with TCP/IP protocol stack. ESP8266 is designed for achievement of low power consumption with the power saving architecture operating at 3 different modes, namely, active, sleep and deep sleep. The cost-effectiveness and compactable design of this microcontroller which operates at the maximum clock speed of 160 MHz makes it suitable for IoT based applications.

IV. RESULTS AND DISCUSSION

In this section, the results obtained from the real-time implementation of the proposed ATPDWS are discussed. It includes database outputs, experimental outputs and analysis of the obtained results.

1) Database creation: Initially, customers are required to register in order to avail the service provider by the proposed system. Customer details such as the name, the mobile number and the address were obtained during registration and a unique User id is generated for each customer. Truck credentials such as the name of the driver, mobile number, truck capacity and truck number obtained during registration was used for this creation of the Truck database. Request from the customers for water was sent to the Control center through the process of Order registration. The unique User id generated for each customer was used during this registration. Details such as Customer User id, address, requested water quantity and the requested date are obtained during the Order registration. Registrations were done utilizing Postman API. Details of customer, truck and order of registration are stored in the related database. The database stored in the remote AWS server is accessed through PuTTY server.

From the Order database, data was segregated area wise and also date wise. So, the total water quantity required for a particular area was obtained on a daily basis. Based on this information, the trip sheet was generated for each area on a daily basis. The generated trip sheet was assigned to the relative trucks based on the capacity of the truck available. The trip sheet database stored in the remote AWS server could also be seen through the PuTTY terminal.

2) Experimental Results: Before water was dispatched from the truck, water quantity and location coordinates recorded from the truck are sent to the Control center to enable cross-checking with the Trip sheet data. The matched condition of the sent data with the Trip sheet could be the observed in the serial monitor output as shown in Fig. 5.

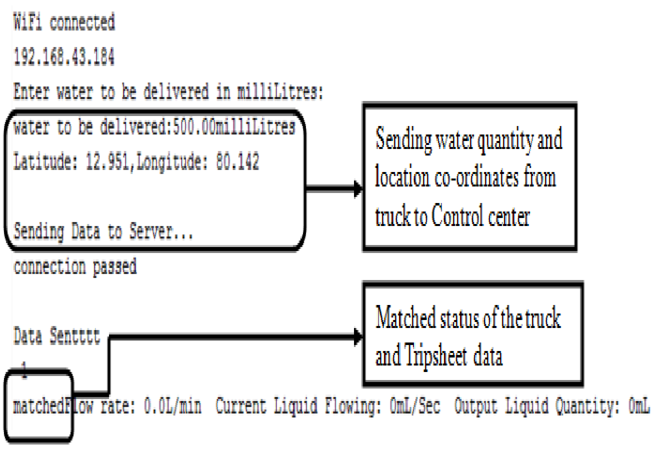


Fig. 5. Matched condition of location and water quantity

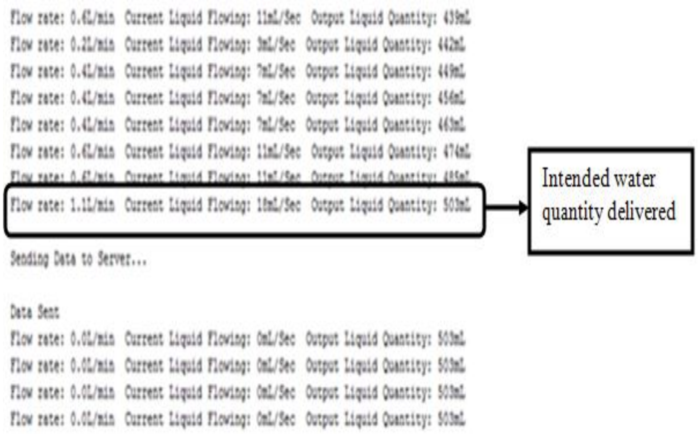
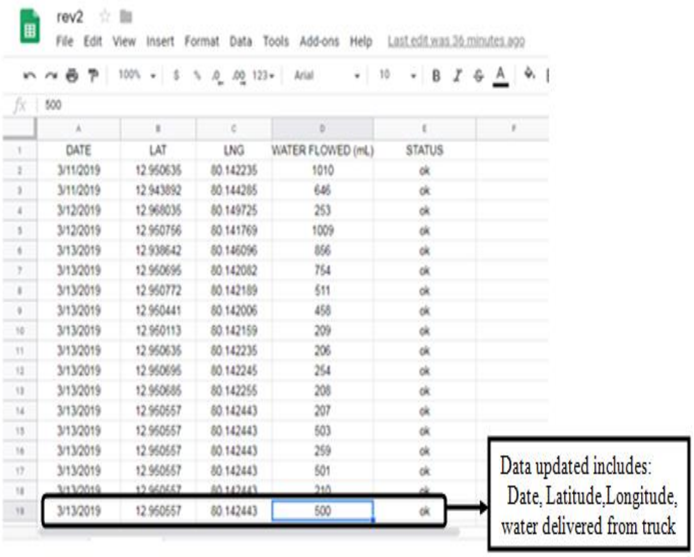


Fig. 6. Status of water flow

When the flow sensor came in contact with the flowing water, it measured the water flowing through the pipe. When the measured water flow reached the intended water quantity, the solenoid valve closed automatically and was viewed in the serial monitor output of the Arduino IDE as shown in Fig. 6.

The corresponding data is sent to the control center for the purpose of monitoring the truck. Google sheets were used for this purpose. The updated data in Google sheets is seen in Fig. 7.The same data is sent to the mobile number of the Control center for the purpose of information backup which is viewed in Fig. 8.

Based on the data obtained from the Google sheet, the movement of the truck could be tracked with the help of Google Maps. Truck delivery details such as water delivery date and water delivered at each location were observed from the Google Maps as shown in Fig. 9.



DATE	LAT	LNG	WATER FLOWED (mL)	STATUS
3/11/2019	12.950635	80.142235	1010	ok
3/11/2019	12.943892	80.144285	646	ok
3/12/2019	12.968035	80.149725	253	ok
3/12/2019	12.950756	80.141769	1009	ok
3/13/2019	12.938642	80.146096	856	ok
3/13/2019	12.950695	80.142082	754	ok
3/13/2019	12.950772	80.142189	511	ok
3/13/2019	12.950441	80.142006	458	ok
3/13/2019	12.950113	80.142159	209	ok
3/13/2019	12.950635	80.142235	206	ok
3/13/2019	12.950695	80.142245	254	ok
3/13/2019	12.950685	80.142255	208	ok
3/13/2019	12.950557	80.142443	207	ok
3/13/2019	12.950557	80.142443	503	ok
3/13/2019	12.950557	80.142443	259	ok
3/13/2019	12.950557	80.142443	501	ok
3/13/2019	12.950557	80.142443	210	ok
3/13/2019	12.950557	80.142443	500	ok

Fig. 7. Update in Google Sheets

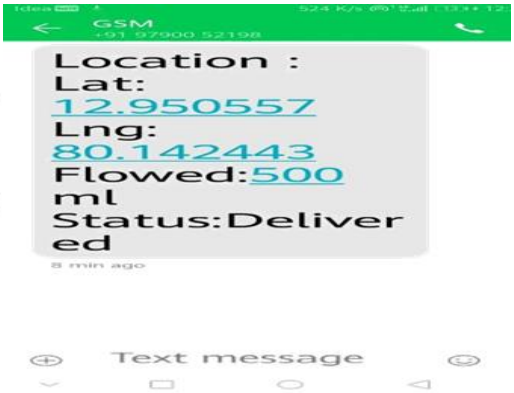


Fig.8. Message received by the control center.

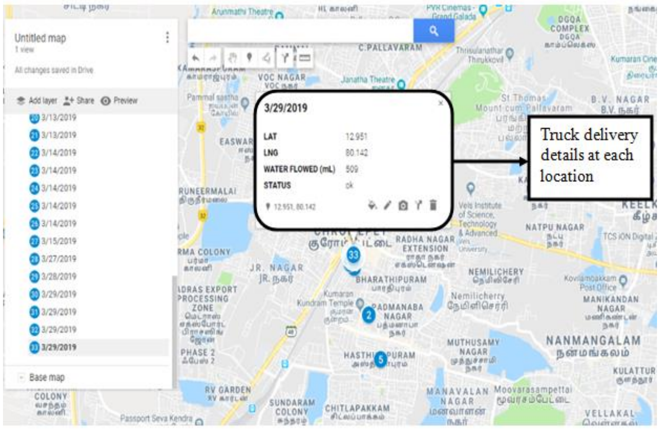


Fig. 9. Tracking of the truck using Google Maps

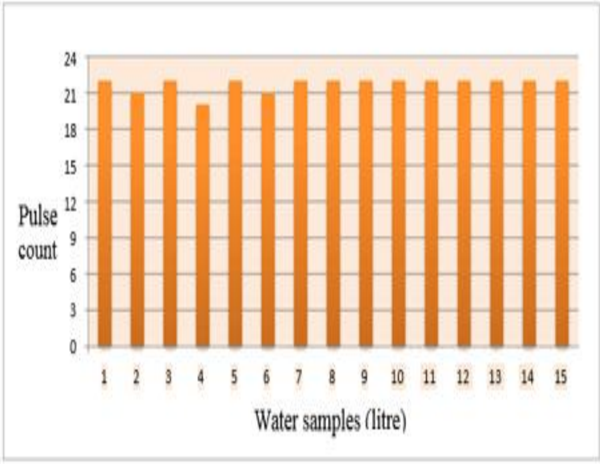


Fig.10. Pulse count per litre

TABLE Ⅲ
CALIBRATION OF FLOW SENSOR

Calibration factor	Experimental flow rate (L/min)	True flowrate (L/min)
7.5	2.93	2.73
7	3.11	2.73
6.5	3.32	2.73
5.5	4.1	2.73
4.5	4.8	2.73

3) Performance Analysis: The flow sensor was calibrated to find the pulse generated for one litre. Fifteen samples each of one litre were used for the calibration. The sensor was calibrated repeatedly and a pulse count of 22 was found to be constant after the learning phase of the sensor. The first six water samples constituted the learning phase as shown in Fig.10.

The calibration factor range calculated for the flow sensor was between 4.5 and 7.5 considering the flow rate range of the flow sensor. The above-mentioned calibration factors were used for calibrating the flow rate of the flow sensor as shown in Table Ⅲ which shows the accuracy of the calibration factor of 7.5 as more compared to other calibration factors. The calibration factor of 7.5 was arrived at considering the flow rate as 1 L/min.

Analysis of measured flow rate to that of the true flow rate is shown in Fig. 11. The error is comparatively small at the lower flow rates around 1.7 L/min than at higher flow rates around 3 L/min due to the determination of calibration factor as 7.5 from the flow rate of 1 L/min.

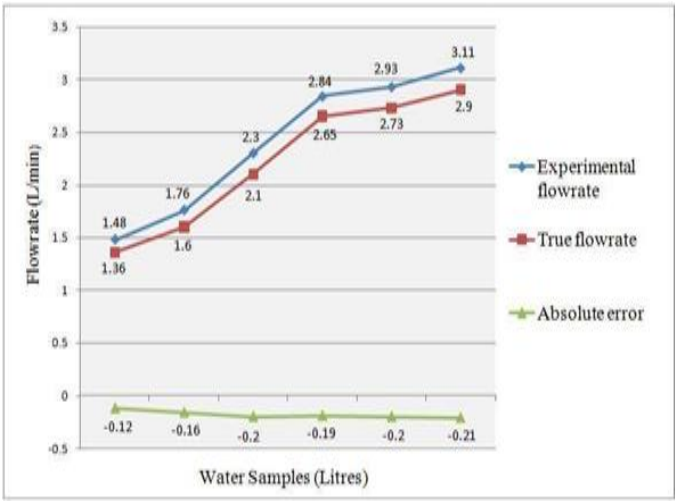


Fig. 11. Comparison of observed readings and error determination

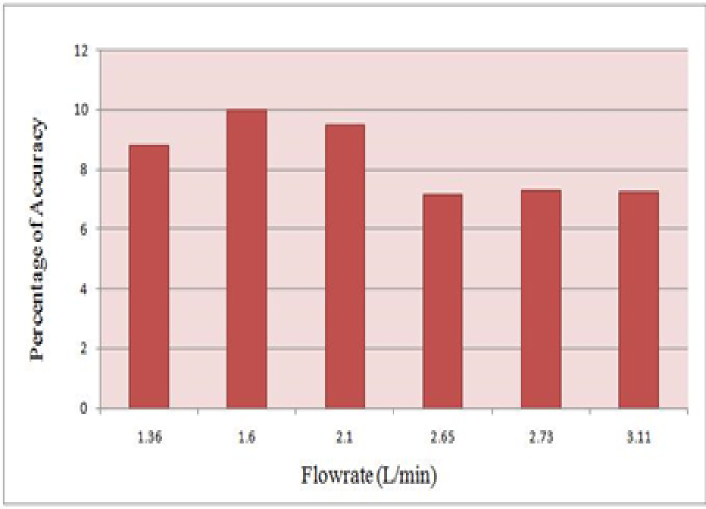


Fig. 12. Percentage of Accuracy vs. Flow rate (L/min)

Accuracy at different flow rates of the flow sensor was determined. The flow sensor datasheet [13], shows accuracy given by ± 10% of true value. Accuracy represented as the percentage of true value follows an increasing pattern of error from its minimum range to maximum range of operation which implies a decreasing pattern of accuracy along the operating range as shown in the Fig.12.

V. CONCLUSION AND FUTURE ENHANCEMENT

A design and the development of the real-time ATPDWS which makes use of IoT technology has been formulated. The design of the proposed system is simple and cost effective as it uses free cloud services and a low-cost hardware. The real-time implementation of the proposed autonomous system reveals the possibility of regulation of the flow measuremen and the prevention of water pilferage through continuous monitoring of the portable truck. The developed autonomous system can be used for the Chennai City Portable Water Distribution Network and it can be implemented at many other smart cities for regulating the water flow and continuous tracking of the portable truck.

Customized mobile application for the customers and the truck drivers, optimal route planning for the portable trucks to avoid the traffic jam, customized payment gateway for users, statistical analyzing tool for providing information relating to the actual demand of the water at the specific location, number of water bodies in the current location could be taken for future enhancement.

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