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Novel Smart Water Metering and Management System for Smart Cities

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***Abstract*—** This paper presents a novel smart water management system which provides facility for water level control, water consumption prediction and water usage analysis in a cost-effective manner. The proposed system uses a NodeMCU Wi-Fi module to achieve wireless communication. A HC-SR04 Ultrasonic Ranging Module is used to detect the water levels and automate the pump operation, in coordination with DS18B20 waterproof temperature sensor probes to detect anomalies in water inflow and close off the water supply on assertion of undesirable water characteristics. The data provided by the system is processed via optimized machine learning and neural network algorithms to provide critical analytics to users.

***Keywords*—** Water management, NodeMCU, HC-SR04, DS18B20, Firebase, Analytics, Data aggregation.

I. INTRODUCTION

Water is one of the most essential resources in the everyday world. Today's rapid urbanization has led to an upsurge in water consumption, which has led to a drastic depletion in the available water levels. This alarming overuse of water has brought about a need for effective water management. Water management is the management of water resources under set policies and regulations. The issues of water scarcity and water purity must be dealt with in an effective and quick manner. Furthermore, the process of water management should be user-centric, and the analytics provided should provide substantial information to the users.

This paper proposes a system which makes the use of ultrasonic ranging module and temperature sensors, to automate the operation of the pump to an overhead tank. The sensors automatically detect the water levels and activate the pump when the levels drop below a threshold. The system also detects if the water inflow has undesirable characteristics and stops the water inflow based on thresholds.

The details with regards to the water consumption and characteristics are recorded onto a Firebase hosted database. This data is used to generate datasets as well as present analytics to the user, which are developed using machine learning and neural network algorithms.

The datasets generated are used to draw up information on user intake levels at several households. Furthermore, the information is used to predict upsurges in water consumption, such as on festivals, and provide effective management solutions to ensure optimal supply to the households in such situations. The information is further used to draw up cost plans for the households with regards to their water intakes and provide effective suggestions to minimize costs. Households are also alerted on exceeding consumption limits, and critical management plans are brought into action to ensure resources are not wasted. The goal of the system is to provide a convenient and easy to use product which can help users monitor their water consumption levels and operate their pumps with the help of simple remote devices.

The rest of the paper is organized as follows, Section I contains the introduction of the system, Section II contains motivation for the development of the system, Section III contains the components used in the proposed system, Section IV contains the methodology involved in the calculation of depth of water in a water tank, Section V contains the flow of the instructions used, Section VI contains the machine learning concepts used for the prediction of the usage and Section VII concludes research work with future directions.

II. MOTIVATION

Currently existing systems lack the features of the proposed system as a single all in one package, starting from measuring the water present in the house to taking care of turning on the motor without human intervention as well as studying the usage pattern to make predictions and efficiently distribute to large metropolitan cities at the cheapest rate possible.

- Existing systems use long wires to connect the sensor (placed in 1st or 2nd floor) and motor (placed in Ground floor).
- In current systems there is no opportunity given to measure any other characteristic of water except for volume flow. [1]
- Data generated by the systems is just discarded. By monitoring the usage pattern, it is possible to predict the next usage statistics which will help in good city planning and water requirement analysis.

III. PROPOSED SYSTEM

To overcome the shortcomings of the current existing model, the following model proposes a smart Wi-Fi enabled water management system that uses a standalone Wi-Fi module NodeMCU as the microcontroller unit for the system.
Two very easy to use sensors are interfaced to the NodeMCU to monitor the level of water and its temperature continuously and these values are updated to the Cloud using the NodeMCU. The sensors used are: -

- HC-SR04 Ultrasonic Ranging Module
- DS18B20 Waterproof Temperature Sensing Module

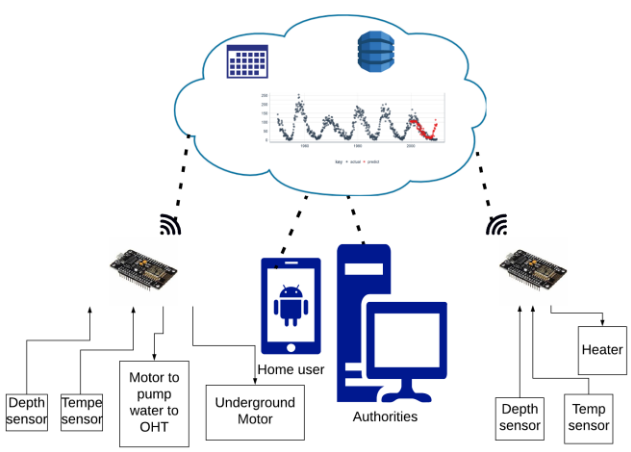

Figure 1. Architecture of the System

Architecture of the system is shown in Figure-1.The proposed system currently has two NodeMCU's, one for Sump and one more for the Overhead tank(OHT). NodeMCU of sump is connected to the depth sensor of sump, temperature sensor of sump, underground motor and overhead tank motor through a relay. The current design was employed according to the design of the house, as all motors will have control at ground level and only the pipes go till the tank. NodeMCU of OHT will have only depth and temperature sensors.

IV. METHODOLOGY

The HCSR04 ultrasonic sensor uses sonar to determine the distance to an object at an estimated range of 2cm-400 cm with an accuracy of ±0.5cm. The transmitter (trigger pin) sends a signal: a high-frequency sound which after finding a surface, gets reflected and the receiver (echo pin) is high for the time the signal takes to cover a to and fro movement from the nearest surface. The time calculated is then used to determine the distance of the surface from the sensor.
As mentioned above, when the signal finds the water surface, it is reflected and the receiver (echo pin) receives it. Working and architecture are depicted in Figure-2 and Figure-3. The time taken for the signal to travel to and fro is calculated by the NodeMCU using the equation

Duration = pulseIN (EchoPin, HIGH)

and the distance is measured by the formula

Distance (in cm) = Duration*0.034/2

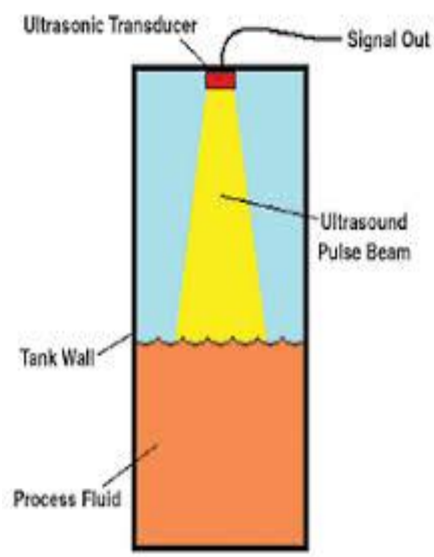

Figure 2. Working of Sensor

Figure 3. HC-SR04 Sensor

This value is stored in the real-time database of the project in firebase.

The DS18B20 is a 1-wire programmable Temperature sensor. It is widely used to measure temperature in waterproof environments. It can measure a wide range of temperature from -55°C to +125°C with a decent accuracy of ±0.5°C. Each sensor has a unique address and requires only one pin of the MCU. Sensor is shown in Figure -4.

Two extremely efficient libraries are used to measure the temperature within a matter of microseconds: 1) The One Wire Library and 2) Dallas Temperature library.

The sensor is activated by using the command

sensors.Begin ()

The temperature is then monitored continuously by using the commands

sensors.requestTemperatures ();

temp (in °C) = sensors.getTempCByIndex(0);

This value is also stored in the real-time database of the project in firebase.

Figure 4. Water proof DS18B20 temperature sensor

A small condition is then taken to determine whether the pump should be on/off. This value is of Boolean datatype.
This value is stored as a Boolean datatype in the real-time database of the project from where it is taken into another NodeMCU at the sump tank side which runs the pump, sending water to the overhead tank

The system makes use of the Google Firebase Cloud which makes use of the simplest read and write functions for the database from both NodeMCU and Mobile applications. The data in the cloud will be given in appropriate format for the user and government authorities to monitor the water consumption

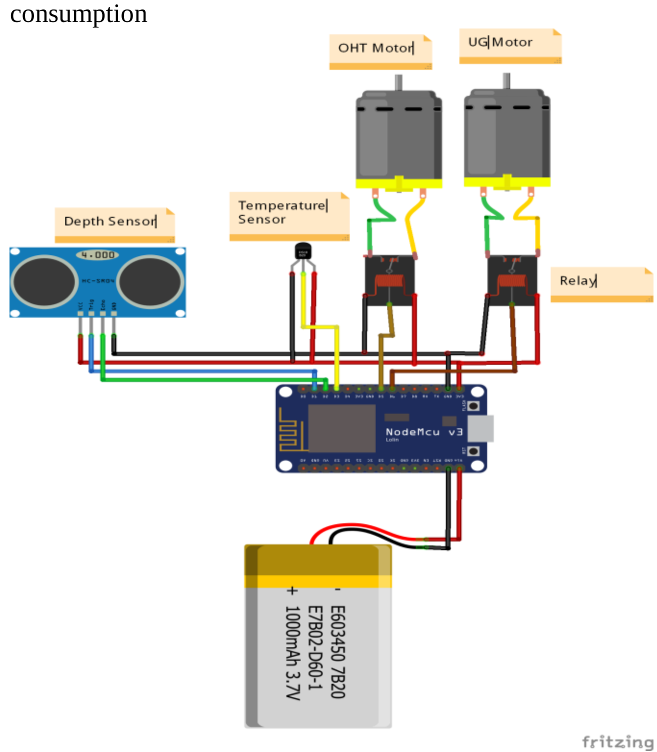

Figure 5. Circuit Diagram

The circuit diagram of micro- controller and sensors is shown in Figure 4. Circuit diagram of the OHT tank is similar with omission of the relays and motor. By using the Wi-Fi connectivity of the NodeMCU and powering by battery makes the system completely portable and wireless.

Table 1. Pin Diagram

Sensor	Sensor Pin	NodeMCU Pin
HC-SRO4	Trig	D1
HC-SRO4	Echo	D2
DS18B20	Data	D3
UG motor	Relay in	D4
OHT motor	Relay in	D5

V. IMPLEMENTATION

The working of OHT NodeMCU is simple as it does the job of monitoring and updating the Firebase only and does not involve any of the motor operations. Complete functioning of the Sump MCU is according to the flowchart depicted in Figure-6. The operation starts by reading temperature. Upon reading the temperature, if it is not in the range, then a signal to stop the OHT motor is posted and waited for the 5 minutes. If temperature is in the range, depth is read and if depth is lesser than low level OHT motor a turn ON signal is posted, and the water level is monitored constantly. And once the water level reaches the higher-level motor OFF signal is posted.

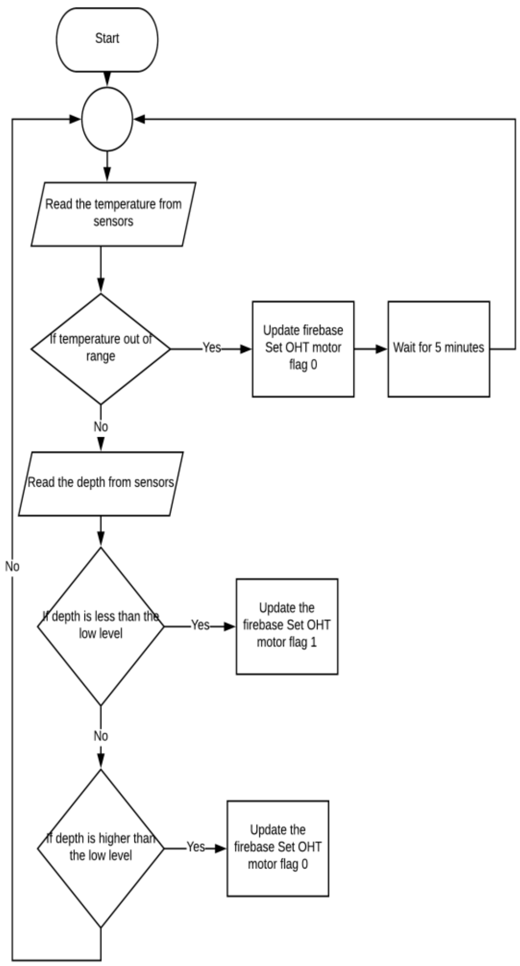

Figure 6. Flow chart of OHT NodeMCU operation

Functioning of the Sump NodeMCU is a bit more complicated as the action also involves Motor control for Sump and the OHT tank. The initial monitoring operation for sump is like OHT tank where instead of turning on the signal turn on; the relay of motor is turned on. And additional reading of the signal from the firebase for OHT motor is read and OHT motor is turned on according to the signal. Flowchart of the OHT NodeMCU is depicted in Figure-8.

Figure-7 displays the firebase table of one house.

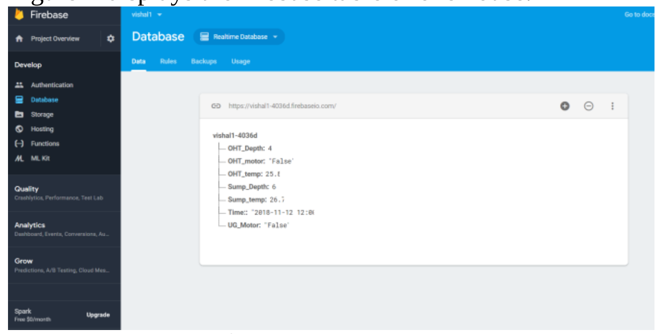

Figure 7. Firebase table of a single user.

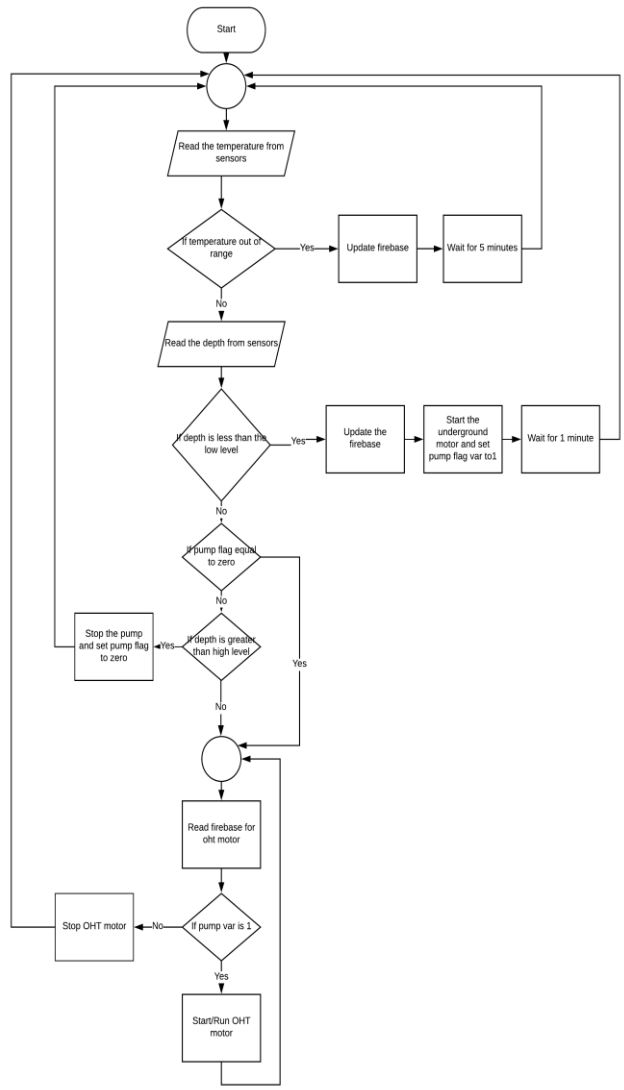

Figure 8. Flowchart for the Sump System

The hourly reception of the data for consumption will be done by monitoring the depth level at each hour with an exception of the motor ON duration.

Operating temperature range is fixed to be at 20^0C to 35^0C. The low level and high level are custom varied for each system installed. In general, low level for sump is chosen as 1.5 times the OHT's capacity such that at all time there will be water level of OHT capacity and for OHT the level is chosen as 20% of OHT's capacity

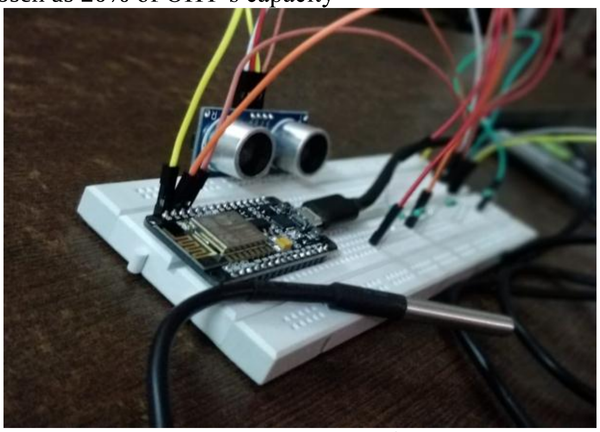

Figure 9. Hardware implementation of OHT hardware

VI. FINDING THE LEAKAGE AND PREDICTING THE USAGE PATTERN USING MACHINE LEARNING

The present-day smart meters provide mechanisms to detect leaks. This is achieved by occasional cloud-based monitoring of the meter readings and sending alerts to the subscribers through the mobile app whenever anomalies in water usage patterns are detected. In cases wherein a leak is correctly detected, the subscribers are then required respond to it by sending a request through the mobile app to temporarily close the water meter valve [4].

The major drawback associated with this policy is that continual cloud-based monitoring of the readings for every meter in the network is required. Furthermore, timely manual intervention is also needed to ensure that the wastage due to the leak is minimal.

Other drawbacks associated with the current smart water meter models is that a naïve strategy to predict the water bill of the subscriber is deployed, such as finding the average cost incurred per day and multiplying it by the number of days, the results of which are highly inaccurate and non-real-time, and therefore are not of much use to the customers.

By using an appropriate time series (for example 1-hour time intervals), enough samples were generated from the dataset for training and testing. The first step involved feature scaling the data to represent the data in accordance to the time series chosen. Each of the time series was associated with a leak label and the amount of water consumed. This followed with the analysis of the relationships between the adjacent time sequences by classifying the sequences using a support vector machine/multi-class classifier (depending upon data consistency, accuracy and feasibility of implementation) to generate different events or classes from the data. After analysis of multiple data streams, identification of the appropriate sequence of events which represent anomalies was done. The attributes of the leak event sequences or classes were then be used as a basis to train a rule-based decision tree. The proposed ML model was found to be capable of making decisions such as temporarily closing the water meter valve when such anomalous sequence of events is detected. The system also sends an alert to the subscriber through the mobile app wherein the subscriber is given an option to resume the suspended water connection.

The dataset was obtained, and one class support vector machine was used to separate the normal and the anomalous points. The advantage of using one class support vector machine is that data points having similar parameters are separated by hyperplane from anomalous observations.

If a subscriber wishes to set a budget for the month/week then he/she needs to be informed dynamically about whether his/her current rate of consumption will adhere to the budget requirements or not. Depending on this information the subscriber can then start regulating his consumption to comply with the budget threshold. The patterns of water consumption of a household depend upon the trends followed by its residents. To make accurate predictions of monthly/weekly expenditure it is important that the historical data of the customers are taken into consideration as well.

At a high level, some of the major identifiable patterns in the water consumption of many of the households can be grouped as low, stable, and mutable consumption patterns.
Low consumption: The water consumption is low or non-existent. This pattern generally occurs when the family is asleep, also called as a night flow.
Stable consumption: The family has a scheduled and predictable consumption. This pattern occurs in the morning while most family members are awake and there is active water usage, and in the evening before they go to sleep.
Mutable consumption: A trivial pattern that is occasionally seen. Generally, occurs during the remaining daylight hours when most family members are outside the house or in general when there is no active usage.

Based on this, the potential questions that can be taken into consideration before deciding to temporarily close the water meter valve are.
The type of consumption pattern under which the flow was measured indicated by time of measurement.
The time interval over which the flow was measured

Whether the readings were nearly constant over the interval of time or anomalous to any leak sequence detected previously.

Through analysis of data, several other rules can be formulated as well for highly accurate decision making. As this decision will be taken locally (i.e. at the level of the meter) cloud-based monitoring will no longer be necessary thus economizing cloud usage. This change in policy will also massively help in minimizing wastage as the closing of the valve will be prompt and automated.

To do this the first step is to enrich the dataset comprising of the historical data of the subscriber collected over the past 2-3 months with additional variables such as information regarding public holidays, weather data (temperature and precipitation), time of the day etc. This pre-processing of the data can be done in cloud. This is followed by the generation an independent multivariate non-linear regression equation (or using any other equivalent ml algorithm) for each subscriber and loading it into his/her water meter.

A set of time series models – including ARIMA, TBATS, NNETAR, ETS were used to fit the dataset. The model was tested on 30% dataset and trained on 70%. The best model out of them (ranked by RMSE) was taken as the model for that time series and the forecast was done based on that model. The advantage of this approach is that one model cannot always generalize the model well. For instance, ETS performs well on data with lot of outliers while ARIMA does well on larger dataset.

Supplemented with additional information on variables common to all subscribers such as weather data or public holiday info sent to the meters via cloud, each meter will be able to take a decision on whether the current rate of consumption will be able to comply with the budget threshold set by the subscriber or not. If it finds out that the customer will exceed his/her budget, then immediately an alert will be raised which will be sent to the subscriber's mobile app.

Using these predicted values, it is also possible to calculate and inform the user about the optimum amount of water that his/her family can use during the day which will ensure that they stay within the budget.

Soon, this predictive model can be used for several other applications as well such as accurately forecasting the water demand of an apartment complex and optimizing pumping and water distribution operations.

The model will be developed such that it can be updated with a new dataset on demand with the standard being once every 1-2 months, so that it is in sync with the latest patterns of usage. The new updates will be done in cloud and will be made downloadable on the smart water meter. For initialization (i.e. when a new meter is installed) a standard data set will be used. As time progresses the model will eventually be able to adapt to the user's patterns and make highly accurate predictions and raise alerts intelligently.

VII. CONCLUSION

The proposed model is implemented, and the data is being collected from the RVCE CSE dept overhead water tanks and the machine learning model is being applied on the obtained data. The system has reduced the workload of the staff who had to monitor the level of the tank and turn on the motor accordingly. Since there was no sump in the Department only motor relay was used in the sump system.

The sample of data collected is exported to excel sheet and a part of the data is as shown in Figure-10

Date	Time	Quantity	Holiday
3-Jan	1	0	0
3-Jan	2	0	0
3-Jan	3	0	0
3-Jan	4	0	0
3-Jan	5	0	0
3-Jan	6	0	0
3-Jan	7	0	0
3-Jan	8	125	0
3-Jan	9	65	0
3-Jan	10	45	0
3-Jan	11	200	0
3-Jan	12	85	0
3-Jan	13	215	0
3-Jan	14	70	0
3-Jan	15	35	0
3-Jan	16	75	0
3-Jan	17	65	0
3-Jan	18	30	0
3-Jan	19	0	0
3-Jan	20	0	0
3-Jan	21	0	0
3-Jan	22	0	0
3-Jan	23	0	0
3-Jan	24	0	0

Figure 10. Data Collected

With the data obtained from the system a graph of the usage pattern is plotted. It is observed that the usage is higher during the breaks and is nil during the holidays. With the above data a prediction for the next two weeks is obtained which also follows the pattern. The program executed is shown in Figure-11. The data predicted is shown in Figure-12. The predicted result as a graph is shown in Figure-13.

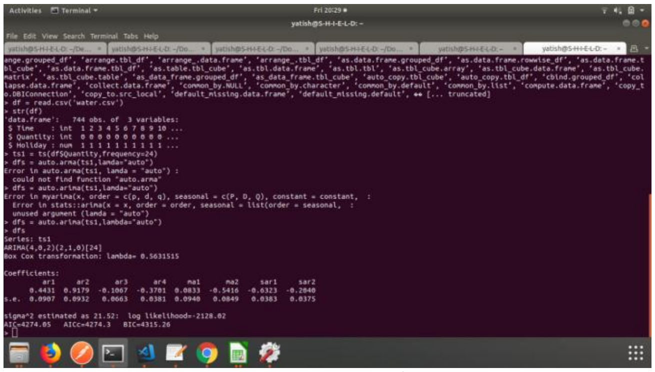

Figure 11. Execution of model

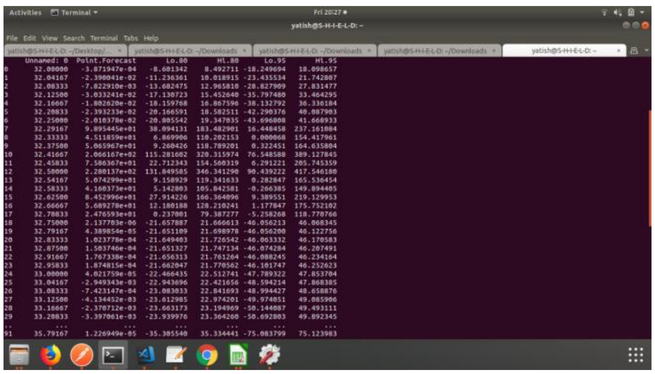

Figure 12. Prediction of consumption

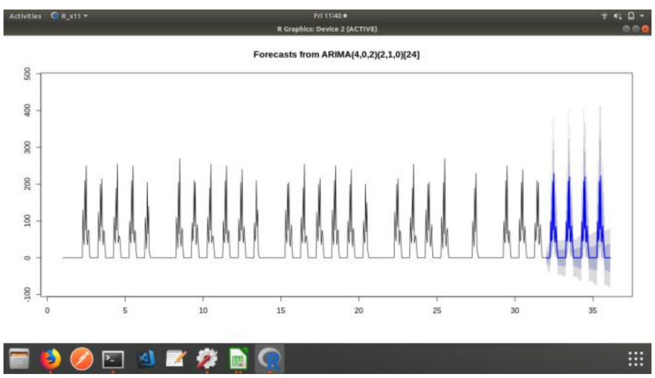

Figure 13. Prediction of consumption as depicted in graph

By summing up the results for each day the data for the daily and monthly consumption can be obtained.

For obtaining the result of the leakage a bigger data set is needed as model should recognize the pattern. And by human checking it was found that no leaks were there in the department paving it impossible to obtain the leak detection data.

VIII. ACKNOWLEDGEMENT

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