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Design and development of portable smart traffic signaling system with cloud-artificial intelligence enablement

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ABSTRACT

With increasing traffic, apart from the major traffic junctions, there are few smaller junctions which witness heavy traffic only during a certain period of the day. For such cases, deploying of conventional traffic lights are not a viable option. A cost-effective internet of things (IoT) enabled portable smart traffic signaling system is designed using ESP32 dual core microcontroller, to assist traffic personnel working at small traffic junctions. It uses a foldable mechanical structure which can be carried easily. The system is designed to work with and without internet connectivity depending on its functionality and place of deployment. The system can be pre-programmed with default time value to work without human intervention. Using an android application, the user can manually control the traffic signal by analysing the traffic density. System gathers the traffic density information based on the operations performed by the traffic personnel and stores it in the cloud. In Smart mode, system computes the mean value and also runs K-means clustering algorithm on the dataset to generate optimized time values. Comparison of the data generated using manual and automatic modes infer the credibility of the system in generating optimized time values and reducing human effort.

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1. INTRODUCTION

The internet of things (IoT) is one of the most promising technologies. It helps to tackle the challenges faced due to traffic by creating a network of interconnected physical objects embedded with electronics, software, sensors, and network connectivity. Researchers have been exploring possible ways of reducing traffic congestion. Many methods have been proposed and implemented based on the technological advances in the field of IoT and microcontrollers. IoT device consists of an electronic chip which is capable of communicating through wireless mode, which include the technology of Bluetooth, wireless fidelity (Wi-Fi), and many other standards. These standards of communication have been incorporated with the chip [1]-[3] present on microcontroller in order to facilitate communication with different modules. The scope of IoT applications and the advantages of using ESP32 in order to get the desired results has been analyzed in [4]. Maier *et al*. [5] have created many applications that analyse the performance of ESP32 microcontroller and have documented ways of developing IoT with the help of ESP32 microcontroller.

ESP32 can be implemented as a web server in [6] which enable real time communication between different modules and devices. Certain topics have been incorporated in the project that deals with different protocols and the development and deployment of IoT applications [7]. IoT domain creates a vast scope in the field of cloud computing [8]. Smart traffic signalling system [9] plays a major role in the development of "Smart Cities". It paves way for smart city management and increases the ease of living. Bhairi *et al*. [10] have proposed an energy efficient smart street lighting system using low-cost microcontroller which is designed for energy conservation. Seme *et al*. [11] have given a complete overview of the work carried out in the field of photovoltaic tracking systems for the production of electrical energy. The work carried out in [12],[13] predict the density of the traffic based on image processing methodology. But these techniques require good quality images, and quality of images is weather dependent. Other researchers have used sophisticated algorithms to model the various states of the traffic such as fuzzy logic [14] and genetic algorithms [15]. Rithesh *et al*. [16] have discussed about an effective and efficient way of traffic signal light control to optimize the traffic signal duration across each lane. Bhagchandani and Augustine [17] talk about the ill effects of traffic jams and its impact on the vehicles designated for emergency purposes. Researchers talk about the economic and financial losses caused due to traffic jams and propose a smart system to tackle various congestion scenarios in [18]. Iyer *et al*. [19] have discussed about techniques used to obtain the optimized time values for the green signal using neural networks. Global positioning system (GPS) and data analytics-based solution is proposed in [20] for traffic management systems using route optimization planner based on real time traffic data analysis and considering various traffic situations. An adaptive and intelligent approach in design of traffic light signals is desirable and this paper [21] contributes in applying fuzzy logic to control traffic signal of single four-way intersection giving priority to the Emergency vehicle clearance. The classification of emergency vehicles in traffic surveillance cameras provides an early warning to ensure a rapid reaction in emergency events. Emergency vehicles are classified from the output of a closed-circuit television (CCTV) camera [22].

Low-power surface-mount-device, light-emitting-diode (SMD LED's) intensity and wavelength shift have been described in the paper [23]. The LED's optical parameters and spectrum were measured using a spectrometer. A 0.1855 W SMD LED is used in this work. The reliability of mid-power (0.5 W) and high power (1.0 W) SMD LED is investigated and evaluated in [24]. Utilized solar energy transformation [25] and extended battery life and charging efficiency of Li-ion battery, information providing system using LED traffic lights has been proposed in [26]. It is also used to communicate between optical receivers and LED traffic lights. Akanegawa *et al*. [27] have developed traffic information system that emphasizes visibility, light usage, and the movement toward LED traffic lights and evaluated the basic performance, such as sufficient signal to noise ratio (SNR) and the amount of receivable information. Liao *et al*. [28] have designed off-grid LED lighting system for traffic light using solar panel with 88% efficiency using maximum power point technology. A review of the literature is performed mainly for the field of solar photovoltaic tracking systems. Hamoodi *et al*. [29] have developed a hybrid e-bike using solar energy to recharge the batteries and using strong torque motor to drive the hybrid e-bike. With the assistance of a photovoltaic (PV) cell, the lead acid batteries are charged using solar energy. Solar cells convert the sun light directly into electricity by using PV effect. Electromagnetic radiation is converted into electrical energy by the PV effect, which is then used to produce electricity. Sodinapalli *et al*. [30] have designed an efficient resource utilization (ERU) model which exhibits reduced execution time, power consumption, and energy consumption for executing scientific workloads on heterogeneous cloud platform. Benkaddour *et al*. [31], authors present the study of a photovoltaic/thermal air collector that concentrates solar radiation using two mobile mirrors to enhance electrical and thermal energy. The model estimates the solar energy received by the hybrid collector during the day, to optimize the performance of the fixed collector, the values of the optimal daily tilt angles of the two mirrors are searched which enhances the quantity of incoming solar radiation on the collector.

A cost effective IoT enabled portable smart traffic signaling systems are need of the hour to assist traffic personnel working and operating at small traffic junctions, where conventional traffic signaling systems are not present. With increasing traffic, apart from the major traffic junctions, there are few smaller junctions which witness heavy traffic only during a certain period of the day. Normal traffic lights require heavy installation at 4 sides of the road and also requires huge investment and maintenance. Junctions which are smaller or narrow, do not have space for installing conventional traffic signals. With increasing traffic, traffic congestion at such small junctions needs to be addressed. During heavy rains, natural calamity or power breakdown, present traffic signals cease to function and the traffic junctions need to manned by traffic officials. This exposes traffic personnel to air and sound pollution. They have to continuously direct the traffic, using their arms. This causes health fatigues as traffic officials have to continuously use their arms, expose themselves to pollution and stand for long durations. Hence the portable traffic signal system is designed and the proposed solution is mentioned as:

- IoT based smart traffic signaling system whichsupports power management and portability.
- Controller system which controls LED arms, establishes communication network (Wi-Fi and internet) between other accessory devices.

- Deployment and development of efficient algorithms for portable traffic signaling system.
- Smart framework deployed at the ThingSpeak cloud for calculation of optimized time used in automatic signal mode.

The proposed portable device can be easily carried, helps the traffic personnel to install at the center of the traffic junction, lookslike a tripod-based mounting and can be operated remotely using mobile phone.

2. PROPOSED METHOD

The proposed design of the portable traffic signaling system is four faced. Sides are facing North, South, East and West directions. LED panels of red, yellow and green color are fitted on each side of the face. All the four panels are assembled in such a fashion that it forms a cuboidal shape, as shown in Figure 1. Microcontroller along with relays is fitted inside the cuboidal panel. The cuboidal box of traffic signal system is assembled and mounted on a foldable stand. The stand facilitates adjusting the height of the system in the range of 4-10 feet. Portable traffic signal system is a stand-alone working system with all the necessary controls and power modules in it, hence making it portable and is easily carriable. The entire control system is compactly designed such that it can easily fit into a small bag pack that is easily carriable.

The total system architecture is depicted in the Figure 2. It comprises of:

- The control system consists of Node MCU (ESP32), buck-converter, relay drivers, relays and all connectors.
- The system designed is powered by rechargeable 12.8 V LiFePO4 battery, which powers the led panels, microcontroller and relay drivers, designed to run for 8 hours once fully charged.
- Smart traffic signaling system demonstrates integration with ThingSpeak cloud and effective sharing of workload of running algorithms between edge device and cloud.
- Traffic lights are controlled remotely using an android application by sending data over Wi-Fi and remote operation of the portable system can be achieved up to a range 15-20 meters. User can toggle between different modes of operation based on the need and control the working of traffic signal.
- Based on the mode of operation and inputs received from the user, microcontroller generates signals which operates the LED panels. The LED panels are designed to be visible up to a close range of 10 meters.

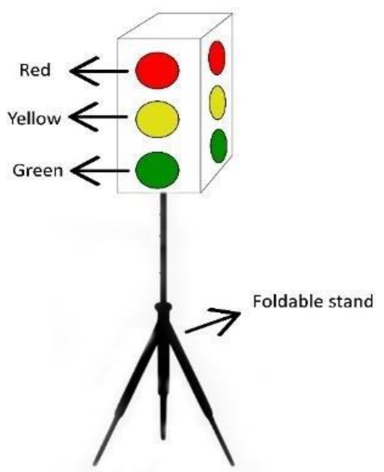

Figure 1. Proposed portable stand traffic light system

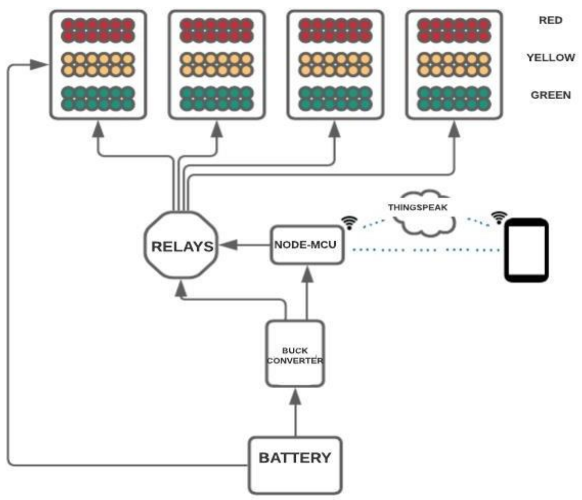

Figure 2. Block diagram of the proposed smart traffic light system

2.1. ESP32 microcontroller

ESP32 microcontroller is low powered with in-built facility of Wi-Fi and Bluetooth. These features make ESP32 a suitable candidate for the design and realization of IoT solutions. ESP32 microcontroller is the core of entire system as it receives data from android application, sends signal to relays to govern the functioning of traffic light. It also sends and receives data from ThingSpeak cloud. 12 general-purpose input/output (GPIO) pins have been used to generate digital signals which govern the functioning of traffic signal.

2.2. Data communication over Wi-Fi

Features provided by ESP32 for Wi-Fi connectivity are as shown in: i) ESP32 microcontroller can be connected to an existing Wi-Fi network. ii) It can also function as Web Server i.e.; it has the capability of setting up its own network which enables the other devices to connect to microcontroller.

ESP32 operates in three different modes: Station mode, soft access point (AP) mode, and both Station and Soft AP mode at the same time. When ESP32 is configured to function as Wi-Fi station, it has the capability of connecting to an access point (Wi-Fi router or mobile hotspot). A unique internet protocol (IP) address is assigned to ESP32 microcontroller which facilitates communication between the microcontroller and other devices that are part of the same network by referring to ESP32 microcontroller's unique IP address. Microcontroller acts as a station when it is connected to mobile phone (access point). So, data is transferred between phone (access point) and microcontroller (station) by using hypertext transfer protocol (HTTP) protocol and sending the signal with the help of IP address. Internet availability varies based on the geographical location of the user. Based the availability of internet, system utilizes it to send and receive data from cloud.

2.3. ThingSpeak as IoT cloud

ThingSpeak is a platform which allows the user to send, receive, visualize and analyse the data present in cloud. It provides the feature of sending data from any device and create a visualization of the data received from the device. In the proposed system, microcontroller records data and sends it to ThingSpeak cloud. Algorithms are run at ThingSpeak cloud to generate optimized time values. These values are retrieved by the microcontroller for operating in smart automatic mode. Data stored in the ThingSpeak cloud can be viewed by authorized users, helps in analyzing the traffic density at a particular traffic junction.

2.4. Android application

It provides the interface for the user to control the functioning of the traffic signaling system. The android app, gives the user an option to toggle between different modes of operation based on the traffic density and user's requirements. Based on the mode of operation, inputs are sent from android application to the microcontroller over Wi-Fi network. Microcontroller generates signals based on the inputs received and sends it to relay which operates the LED panels.

2.5. Design of LED panels

The 12 V SMD LED based strips are used in designing of the panel due to its compactness and high luminescence as compared to the through hole type. The SMD LED strips are available in the market with 5050 SMD LED, which has higher luminescence compared to others. The LEDs are connected 3 in a series in each strip and every strip is connected in parallel. The strips are arranged in rows and columns and soldered as indicated in Figure 3 according to our requirement to cover the area of the designed LED panel. The panel design has 6 strips continuous in series and there are 11 subsequent such strips in parallel. The above procedure is continued for designing all the 12 panels with red, green, and yellow LED strips. Each LED panel will consume 3.5 W of power, resulting in total of 42 W of power consumed if all the led panels are lit.

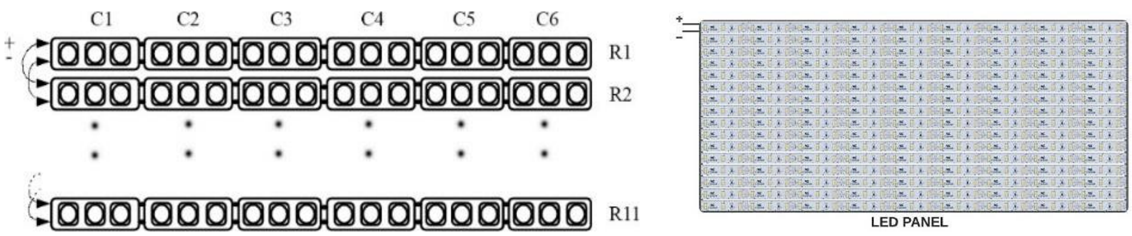

Figure 3. LED strip and panel design

2.6. Design of battery system

The custom battery powering the system should be compact and also carriable. The electrical system design includes designing of high energy density, and highly durable battery pack for powering the system. The battery is madeup of 12.8 V, 18000 mAh capacity. The cumulative arrangement of 12 individual 3.2 V, 6000 mAh LiFePO4 cells in four series and three parallel arrangement helps us in achieving the required power. The potential of 12.8 V is required to light the LED panels. Hence 4 individual cells are connected in series. According to the calculation, we require 18 mAh capacity of the battery pack to power up the portable traffic signal system, so to achieve the required capacity, it is designed to have three parallel and four series cells. The battery is also incorporated with battery management system (BMS) circuit and cell balancer to maintain the equal potential and power delivery to individual cells while charging. The charging may be achieved by using conventional 15 V, 2 A (30 Watt) charger or the 30 W solar charger which is accompanied with the system. The choosing of lithium ferro phosphate cell over lithium cobalt oxide (Li-ion), although comparatively having lesser energy density, is mainly due to its characteristic of higher charge cycles and immune to prolonged higher temperature operations.

3. METHOD

Working of the smart traffic signalling system is governed by ESP32 microcontroller with the help of three different modes. Each mode has a specific defined functionality. The flow of data between android application, microcontroller and cloud has been explained with the help of flow diagram in Figure 4.

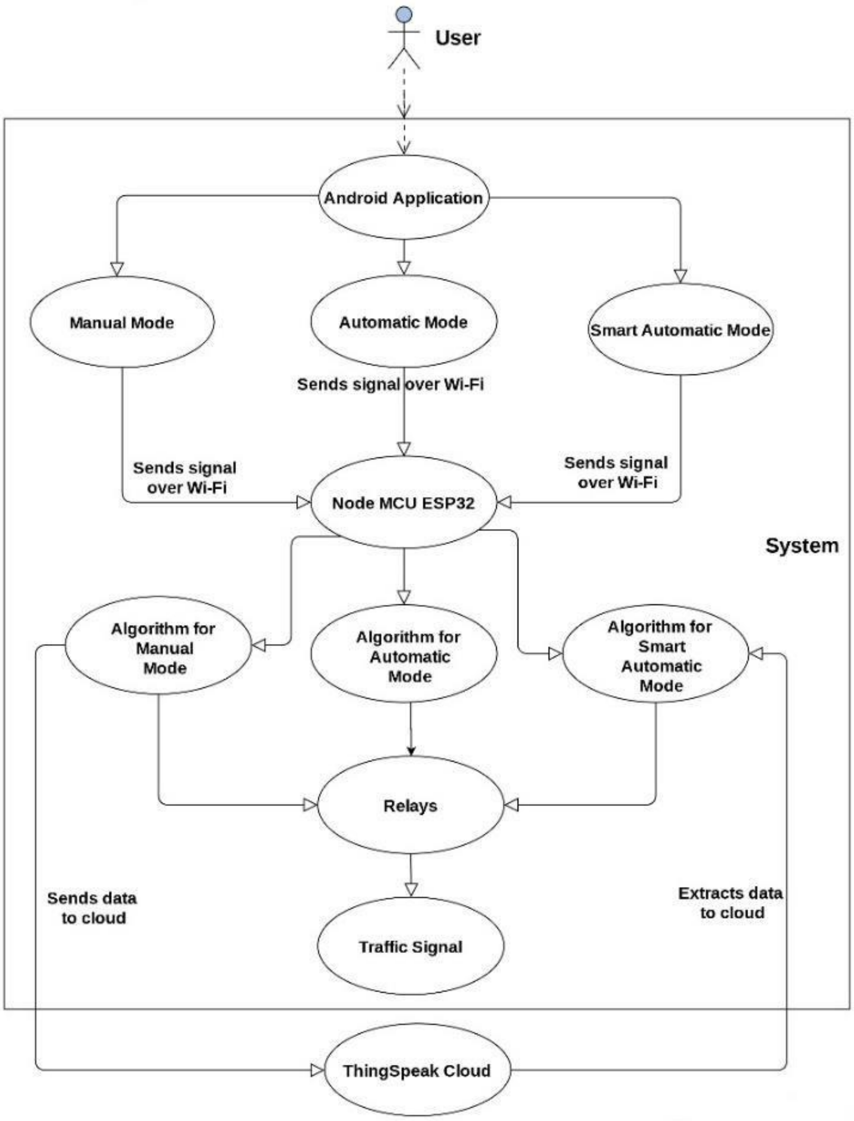

Figure 4. Use case diagram representing flow of data

3.1. Functioning, modes of operation of ESP32

The smart traffic signaling system is configured to work in station mode. Microcontroller is programmed to connect to the phone's hotspot (Wi-Fi router) of the user. Credentials for connecting to the device will be saved in the program that is run in the microcontroller. The access point is connected to the internet. Using the ESP32 board, the data from the cloud can be published to online platforms. The prerequisite for establishing connection between user's phone and microcontroller is that the user will have to turn on mobile phone's hotspot before powering the traffic signaling system. When mobile phone's hotspot is turned on, it sets up a network of its own. Once Wi-Fi hotspot is turned on, user can power the traffic signaling system and establish connection as it is pre-programed to connect to user's phone. Data transfer between microcontroller and mobile phone does not require internet connection. The microcontroller alone cannot drive the high-powered LED panels, hence a three-channel relay for each direction has been designed for this purpose. An optocoupler PCF817 for driving the 12 V electromechanical relay is used, which in turn drives the LED panels. The optocoupler has the characteristic of making the system optically connected and electrically insulated which is much needed as high-power connections and its faults may permanently damage the ESP32 microcontroller.

3.1.1. Manual mode of operation

In manual mode of operation, the user will be given access to four buttons representing panels of the traffic signal facing North, South, East and West direction. Depending on the traffic density in a particular direction, more time can be given to the required traffic lane. Pressing the 'On' button will turn on the green signal in that particular direction, and the remaining signals will turn Red. There is no time restriction for start and stop of green signal (in a particular direction) while operating in manual mode. The system is programmed to record the time for which green signal was operated in a particular direction. Entire day consisting of 24 hours in divided into four time zones namely Zone 1: 00:00 hrs to 05:59 hrs, Zone 2: 06:00 hrs to 11:59 hrs, Zone 3: 12:00 hrs to 17:59 hrs, Zone 4: 18:00 hrs to 23:59 hrs (All time zone values are represented in 24-hour format).

Based on the present time value, system automatically sends the recorded time value to the cloud and stores it according to the timestamp that falls in suitable zone. The cloud is programmed to generate optimized time values for each direction zone-wise. Based on the availability of internet, recorded time value is sent and stored in the cloud. Separate channels for North, South, East, and West directions have been created in the ThingSpeak cloud. Each channel representing a particular direction has been further divided in to different fields (zones) to store the recorded time value based on timestamping. Controlling of signals facing North, South, East, and West directions does not require internet connection. If the system detects availability of internet connection on user's mobile phone, it would automatically utilize internet connection to send the recorded data to cloud. Lack of internet connectivity only restricts the process of sending data to cloud, it does not affect the process of controlling the signaling system. In the absence of internet connectivity, the recorded time value will be discarded from the system. Portable Traffic Signaling System gathers traffic density information based on the operations performed by the user while working in the manual mode. This constitutes the dataset for the algorithm that is run at the cloud (ThingSpeak). When operated in smart automatic mode, algorithms are run on this data set to build mathematical model and use this model to generate optimal time values.

3.1.2. Smart automatic mode of operation

In smart automatic mode, the system will function automatically by taking the optimized time generated by the algorithm run at ThingSpeak cloud. The system is programed to retrieve optimized time value based on the suitable time zone. When the system works in smart automatic mode, it would retrieve optimized time values from the cloud. Figure 5 depicts the implementation in generating the optimized time values and processing of data in cloud for a particular direction. In similar fashion, data is stored and processed for each direction (North, South, East, and West) separately. In manual mode of operation, the system is programmed to record the time for which green signal was operational in a particular direction. A MATLAB analysis code is automatically run at ThingSpeak cloud after every 24 hours time interval. Optimized values would be given as delay for operation of green signal in respective direction. Once the user turns on smart automatic mode, no further human intervention is required. Hence it eases the labour involved on traffic personnel. This mode requires internet connectivity as the system needs to retrieve values from ThingSpeak cloud. Smart automatic mode can also be implemented with the machine learning algorithms like K-means clustering for obtaining optimized time values. User can choose between the average based mathematical model and machine learning algorithm. We have defined the value of K=3 by considering the K-inertia graph as shown in the Figure 6. This enables the dataset to be divided three clusters as shown in Figure 7. These clusters would contain values which are similar in nature. Based on the cluster size, the cluster having maximum number of elements would be selected and average of all the values present in the cluster would be calculated. This value would be sent to the microcontroller while it is operated in smart automatic mode. Hence this machine learning algorithm helps us in obtaining optimized time value.

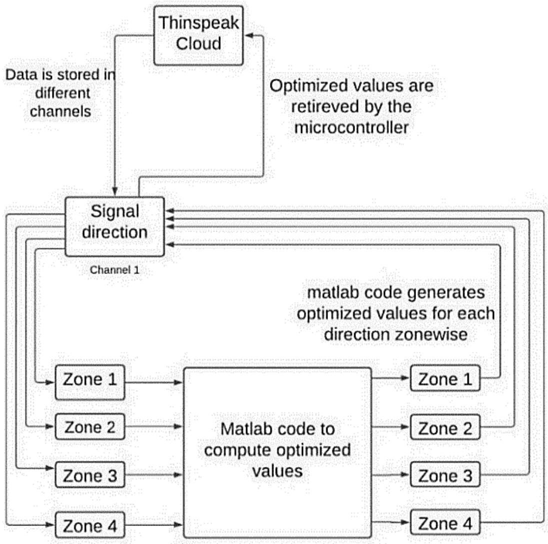

Figure 5. Process of storing data in cloud based on timestamping, computing optimized time values based on timestamping and sending it back to microcontroller

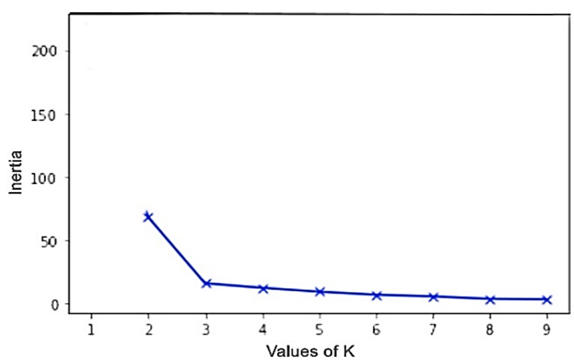

Figure 6. K-intertia graph for obtaining the value of K

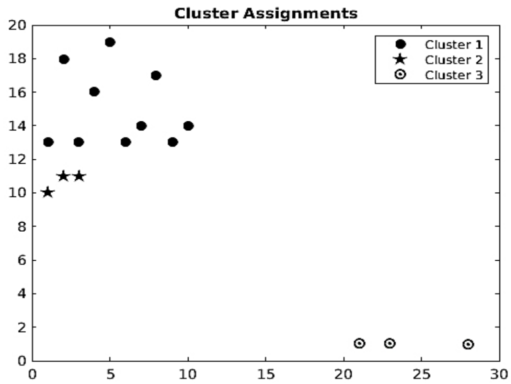

Figure 7. Clusters formed by K-means algorithm for a dataset of 15 minutes

3.1.3. Automatic mode of operation

The proposed automatic mode of operation gives few additional features over the existing conventional system. User can select a default time value and the same will be used as delay for operation of green signal in all direction. Here, the user will get the option of selecting different time delays based on the traffic density. Selected time delay will be used for all four sides of the traffic signal. Once the time value is set by the user, system will run continuously until it is turned off by the user. This mode of operation does not require internet connection.

4. RESULTS AND DISCUSSION

The snapshot of ThingSpeak cloud is as shown in Figure 8, it stores the data of time interval for which green signal was operational in a particular direction. ThingSpeak server refreshes after every 10 seconds. So, a gap of 10 seconds has to be maintained between two data entries. If the gap of 10 seconds is not maintained, user might end up losing the data. The optimized time values calculated by the algorithms is executed at the ThingSpeak cloud, is depicted in the form of a graph in Figure 9. Algorithm generates results with an error of ±0.5 seconds. The theoretical range of Wi-Fi network generated by mobile phone's hotspot is claimed to be in the range of 15-20 meters. When practically tested, the system successfully establishes connection between microcontroller and mobile phone (Wi-Fi hotspot) and successfully communicates data through wireless mode provided the range between the traffic signal and mobile phone is within 12-15 meters.

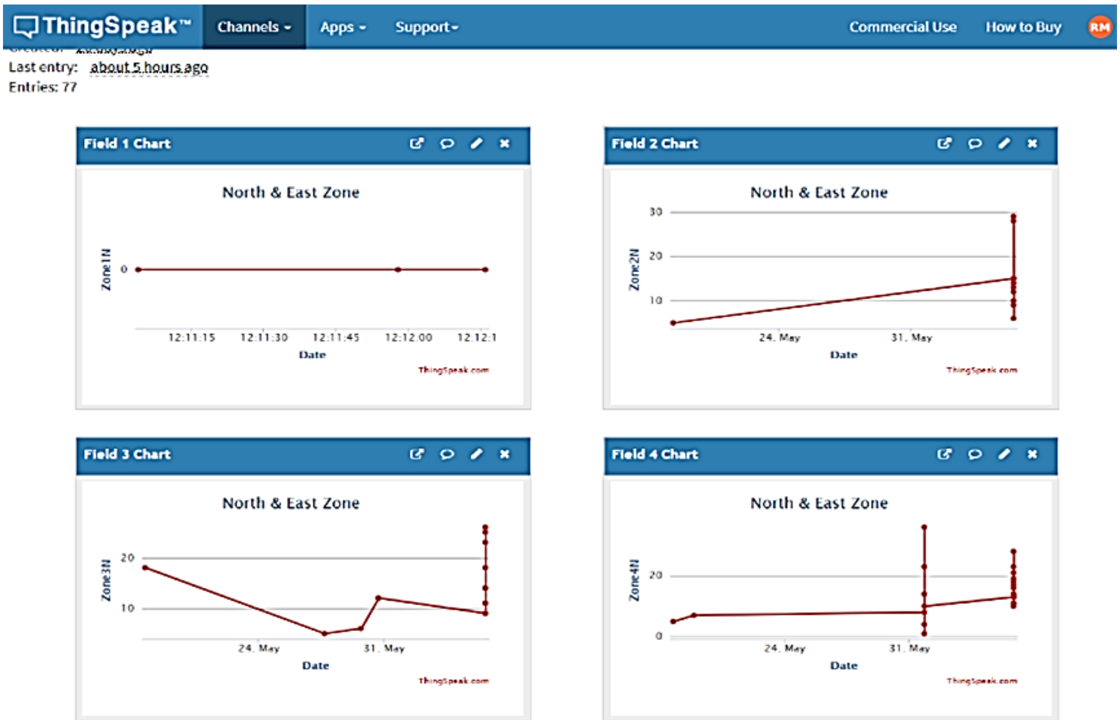

Figure 8. Snapshot of ThingSpeak cloud

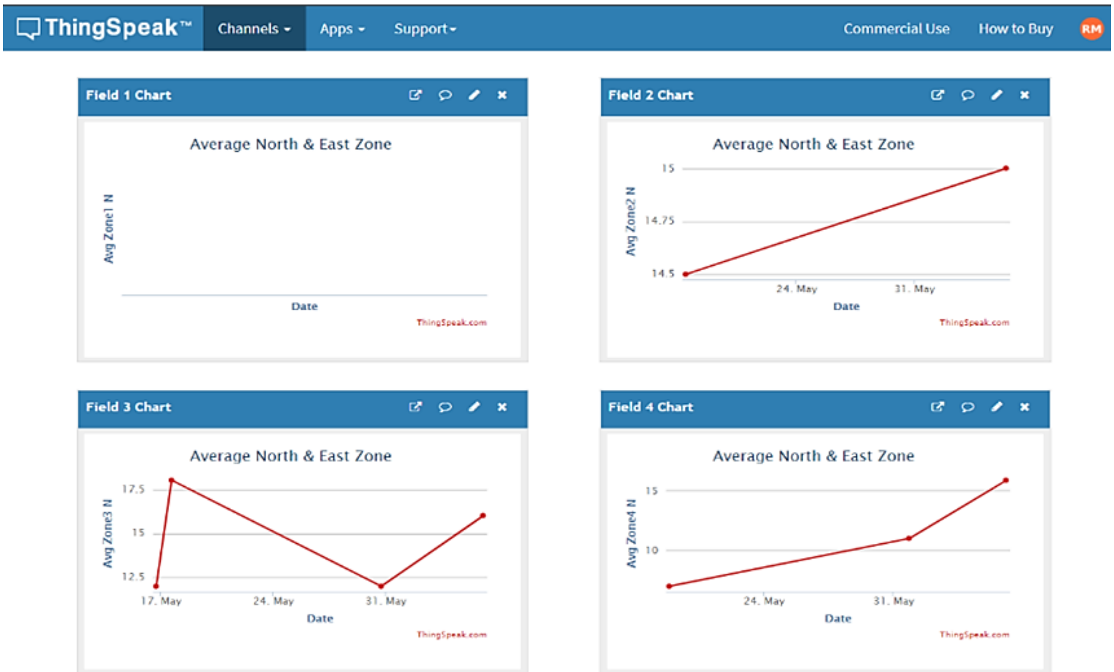

Figure 9. Snapshot of optimized values at ThingSpeak cloud

Data communication is not hampered by the presence of any obstruction between the source and destination. The application is equipped with a login mechanism. A user is required to enter correct credentials in order to operate/control the smart traffic signaling system. This enhances the security aspect of the system. Android application provides a feature for the admininstrator to view the login and logout time of the user. The power consumption of the system, as measured and documented, is around 23 W at any given point of time, after considering losses and heat dissipation.

5. CONCLUSION

A cost effective, IoT enabled portable traffic light system has been designed, assembled and tested. It is integrated with ThingSpeak cloud and effective sharing of workload of running algorithms between edge device and cloud. It is designed to work in three modes, manual mode, automatic mode and smart automatic mode. In manual mode, user operates manually using the mobile app with Wi-Fi connectivity, internet connectivity being optional. It gathers the traffic density information based on the operations performed by the traffic personnel and stores it in the cloud. This data constitutes the data set for the algorithm to be implemented at ThingSpeak cloud. Algorithms are run on this dataset to generate optimal time values, which are used when operated in smart automatic mode. Based on the output received from the algorithm, optimized time value is given as delay to the traffic signal. In automatic mode, the user gets the option of selecting different time delays based on the traffic density, same will be used as delay for operation of green signal in all directions. Once time delay is set, system works independently without any human interventions. The system efficitively demonstrates robustness and accuracy in wireless data communication, cloud computation and effective traffic management. It stands out as an autonomous system capable of functioning with minimal inputs from the user.

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