Real Time Adaptive Street Lighting System

Sahil Garg[1], Sahil Ahuja[2] and Sukhchandan Randhawa[3]

[1,2,3]Computer Science and Engineering Department,
Thapar Institute of Engineering and Technology, Patiala , India
sukhchandan@thapar.edu

Abstract. With the aim to optimize the cost and performance of hardware and software integration, this paper discusses and inculcates the outcomes of various experiments that were conducted with different hardware and software technologies available commercially. This Smart Street light is designed with an aim of both performance and cost optimization, and includes a built-in weather station, forest fire/ general fire notification and has the ability to continuously send data to the server for Analytics and Data Acquisition, as well as to the Mobile Application server. The data through the Mobile Application server can be fetched directly onto an app with good performance and the data being sent onto the Analytics and Data Acquisition server can be used for analysis and further research. Also,this project is sensitive to day and night and optimizes energy when there is no motion or when the ambient light is higher than a particular threshold determined experimentally.This paper opens the need for a better IoT based Street Light project with additional features and improved performance.

Keywords— Smart Street Lighting; Internet of Things; Gateway; Cloud Computing; Machine Learning; Field Devices ; Sensor Technology;

1 Introduction

The growth of Internet of Things (IoT) has brought about a revolution in our day to day lives. Cheaper and improved sensor technology has provided an impetus to this revolution of IoT. Each and everything can be connected to the internet and synchronized to interact, collaborate and contribute. IoT has been responsible for machine-human inter-dependency. The major advantages that IoT offers include improved efficiency, reduced interaction time and human effort. It also provides support to Artificial Intelligence and Data Mining due to the involvement of larger data-sets and the need for extracting useful information in order to improve efficiency to the application and add 'Smartness' to it. IoT has a great potential for Automation and Data research. The thing that we are considering in this paper is a Street Light. The main motivation of this research work is derived from the fact that lighting accounts for more than 15 percent of electricity consumption of the world. This also contributes about 1.6 billion tons of carbon emissions (per year) in the atmosphere. With the aim to cut-short the energy wastage through the conventional street lighting systems and realizing the growing demand of Automation, it is important to work in this area. For making the Street

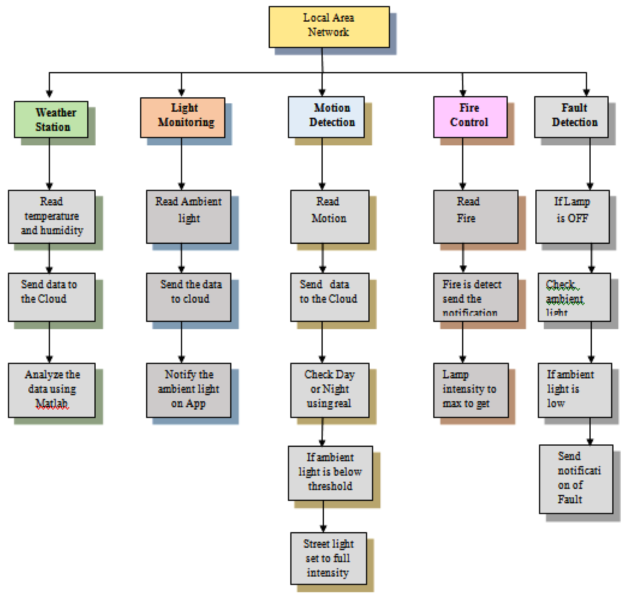

Fig. 1. Basic Features of a Smart Street Lighting System illustrating various modules involved in the system

Light smart, we need to define smartness. A 'Thing' is said to be 'Smart' if it is able to sense its immediate surroundings and perform actions that work towards a desired goal. If we fit the Smart Street Light to this definition, we can describe the system as composed to things called Street Lights equipped with sensors, illustrated in figure 1, to sense ambient light, motion, temperature, humidity, faults and moving objects, acquire data through the sensors, apply some pre-processing algorithms to compress data, and send it to the Cloud via an IoT gateway. From the Cloud which consists of a better Infrastructure and storage and Analytical capabilities, users can retrieve beneficial information including visibility in foggy days, ambient light, temperature and humidity in sunny days, traffic density, etc. and researchers can fetch useful data and analyze those data for further research that includes temperature and humidity characteristics of a particular location, season, etc.

2 Literature Survey

Many researchers have proposed a number of methodologies and ideas to reduce the energy wastage of the street lights and also highlighted the ways to make them smarter. Mullner et al.[1] has done an innovative literature review in the field of saving energy with the help of electro-technology as well as Information and Communication Technology (ICT) in Street Lights. Mahoor et al. [2] discussed about the state of smart street light which consists of monitoring and executive programming. Lavric et al.[3] found that the information exchange between lamp nodes and wireless sensor networks (WSN) can be a feasible since it is composed of three parts : Control center, Remote concentrator and Street lighting control terminals. Abhishek et al.[4] presented the idea of sending the information of center station by ZigBee wireless communication. Gupta et al.[5] proposed the solution for controlling the intensity of light with the help of dimmer using PWM and Firing angles. With the use of dimmer we can conserve 15 percent to 20 percent of the energy. Escolar et. al [6] reviewed the street light approach by using a simulator that combines wireless sensor network (WSN) and belief desire intention (BDI) agents to provide information . It tried to exploit our approach on more dynamic scenarios. Mohamed et al.[7] reviewed the state of smart street light system based on the innovation technology named as Vehicular Ad-Hoc Network (VANET). Smart Street Lighting system can be integrated with VANET to reduce the cost and use the rich service and communication feature of VANET. Pizzuti et al.[8] put forth an approach for adaptive street lighting control based on energy demand idea and showed that the conventional street lighting regulation system he tested showed that adaptive control provides on an average almost double energy saving. Badgaiyan et al.[9] reviewed on using ZigBee and wireless sensor network (WSN) – PIR (Proximity Infrared) sensor and found that this was using low power and was highly efficient from conventional street lighting system. There was an ease of maintenance and high communication rate among the devices in the system.

A Smart Street Lighting (SSL) system [1] is proposed for switching off the street lights based on the desired level of safety and location of pedestrians. The proposed system consisted of Zigbee enabled motes, a Base Station, a centralized SSL Server, server applications for system configurations and Web-Application for monitoring and controlling the lighting zones and lampposts and smartphones of pedestrians with GPS functionality.

A street lighting system based on ZigBee has also been proposed [2]. The monitoring of the connected sensors for fault detection, power adjustment and on/off control is done via Zigbee wireless technology. The proposed system gathers the parameters of street light via GPRS and Zigbee communication. It includes three main components: a terminal for street monitoring, concentrator and monitoring center. The concentrator acts as a repeater and works as a bridge between monitoring center and control terminals. Its main task is to forward command and data. The task of the control terminal is to fetch the data and make the required adjustments in the power.

An autonomous-distributed-controlled light system [10] was proposed in which lights get turned on before a pedestrian actual arrives at that location and then gets off after a pedestrian leaves a certain location. The proposed system comprised brightness sensor node, LED lamps, motion sensor and communication network based on short distance. There are access points which consist of the controller and the communication device. An Automatic Intensity Varying Smart Street Lighting System [4] is presented in which the initial step was to replace the existing lampposts by LED lights in order to reduce the energy dissipation as LED lights are more energy efficient. Secondly, Light Dependent Resistor (LDR) has been deployed in order to control the lights automatically without any human intervention. In order to control the luminosity of the lights, dimmers are installed. A novel street lighting system [5] is proposed which uses the renewable energy source i.e. solar energy. The luminosity of the street lights is controlled based on the intensity of sunlight which is sensed by LDR. In case of low intensity of solar energy, the resistance value of LDR is high and based on this value it is decided that whether the street lights should be on/off. In case of moderate value of resistance, the dimming function of lights is invoked. PIR sensor is also utilized to detect the motion of the pedestrian.A novel fuzzy logic based controller [11] is presented whose main objective is to minimize the wastage of power in street light systems. Solar energy is utilized in order to save electric power. A fuzzy rule base is designed which takes natural intensity and occurrence of vehicles as inputs based on the rule set defined by fuzzy logic.

A hybrid street lighting system based on Vehicular Ad-Hoc Networks (VANET) [7] and traditional street lighting system is proposed. VANET provides various functionalities such as reporting the location, direction, speed of vehicles in real time scenario. Road-Side Units (RSUs) are deployed usually 300-400 m apart. The main task of these RSUs is to report the data to the light controllers to switch on and off a light. A reliable on-demand street lighting model [8] is proposed in which the concept of traffic flow rate forecasting model is utilized. There are number of methods based on 1-h prediction whose results are compared with the model based on ANN which reports the best results. As per the above discussed literature, it is clearly concluded that most of the ideas are based on motion detection of a person or a vehicle on a road.

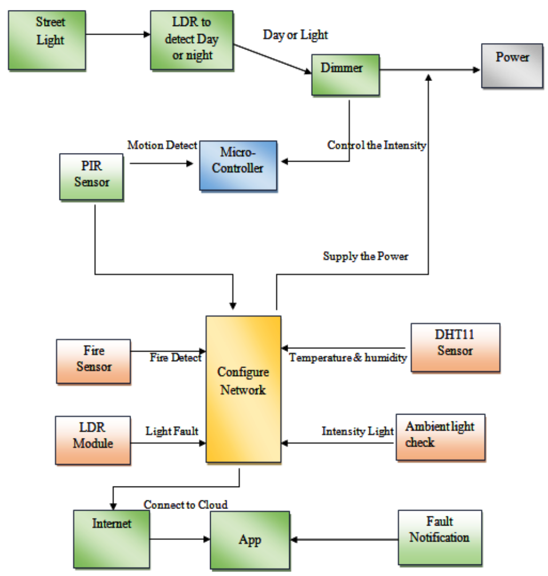

Fig. 2. Architecture of the Proposed Solution depicting various units in the Smart Street Light system

3 Proposed Methodology

Based on the previous works and current problems we defined the objectives of our work. The broad objectives of this Smart Street Light Project are as follows:

– Design and development of low cost and energy efficient Smart Lighting System.
– Deployment of multiple sensors for motion detection, ambient light detection, optical fog sensing, fault detection, fire detection etc.

- To control the intensity of light of deployed LED lights and their power consumption based on weather conditions, diurnal timings, traffic levels and motion detection.
- To record essential data and apply analytics to extract useful information which further sends a feedback to the main network improving its performance and adding ”Smartness”.

4 Components of Smart Street Lighting System

The Smart Street Light as illustrated in figure 2 had broadly four units : 1) Field devices which sense the environment and generate triggers and pulses and also actuate based on the pulse received from the microcontroller 2) IoT gateway which acted as a link between the microcontroller and the network 3) Cloud which stored all the data received from the IoT network and performed Analytics on that 4) End User which could fetch information from the cloud as well as control the field actuators via the Cloud services. The Field devices that we installed onto the Smart Street Light included a microwave based motion sensor, Light Dependent Resistor for Ambient Light recording, LDR for Fault detection, Flame sensor for fire detection , Digital Temperature and Humidity sensor to record temperature and humidity readings at a particular location making it a weather station as well. For surveillance and object recognition we have also added a camera that is continuously streaming video clip to the control center and also training the object recognition model using a CNN (Convolution Neural Network) model capable of feature extraction and thus record the frequency of various entities including vehicles and human beings. The entire Smart Street lighting

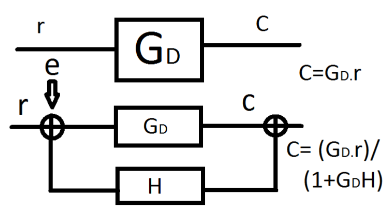

Fig. 3. Comparison between Open and Closed System with G_D as the Transfer Function and C and r as output and input respectively. H is the feedback element and E represent the error signal

system works using the concept of feedback in order to minimize error. Illustrated in figure 3, Let G_D denotes the transfer function of the measurement system. Let C and r denote the output and input signal respectively. Also, let H denote the feedback element in a closed loop system and e be the error or the interference introduces in the system. Consider an open loop system as shown in figure 3. We know that

$$C = G_D.r$$

Let the transfer function change from G_D to $G_D + \Delta G_D$ which changes C to $C + \Delta C$ therefore, in an open loop :

$$C + \Delta C = (G_D + \Delta G_D).r$$

Comparing LHS with RHS we get,

$$\Delta C = \Delta G_D.r$$

Now, consider the closed loop system with H as the feedback element and error introduced is e,

$$C = G_D.e \text{ , where } e = r - CH$$
$$C = G_D.(r - CH)$$
$$C = \frac{G_D.r}{(1+G_D H)}$$

Let the transfer function change from G_D to $G_D + \Delta G_D$ which changes C to $C + \Delta C$ therefore, in a closed loop :

$$C + \Delta C = \frac{(G_D+\Delta G_D).r}{1+(G_D+\Delta G_D).H}$$

$$\Delta C = \frac{\Delta G_D.r}{1+(G_D+\Delta G_D).H}$$

If $G_D >> \Delta G_D$ so,

$$\Delta C = \frac{\Delta G_D.r}{1+G_D.H}$$

It is clear that ΔC in closed loop is very less as compared to that in an open loop. This method of high gain feedback therefore reduces error in a measurement system with the help of feedback.The sensors are positioned in such a way so as to reduce error from internal temperature and heat generation, hindrance in path of light from ambience to the LDR, etc. All the field sensors are capable of working at a voltage of 3.3v DC or 5v DC which is supplied from the voltage regulators connected to the main DC power supply unit which is charged through Solar Panel of rated 24V output voltage as well as through the mains with 220v 50 Hz standard power supply. The AC Dimmer is a device that is designed to control the AC voltage, which can transfer current up to 220V (5A 10A) (TRIAC BTA16 for 600V/16A). Discharge lamps do not support dimming. Power part of dimmer is isolated from the control part, to exclude the possibility of high current disruption to a microcontroller. The logical level is tolerant to 5V and 3.3V, therefore it can be connected to the microcontroller with 5V and 3.3V level logic. Dimming can be achieved by Pulse Skip Modulation: Technique 1 : One or more cycles (sine wave signal) are transferred to the load while following one or several cycles are blocked. Technique 2 : Partial transference of each sine wave to the load. Technique 3 : Generation of modulated full sine signal of different frequency up to few hundred Hertz. This method requires specialized powerful AC generators with different modulation. Methods 1 and 2 are the easiest to execute with the help of a Dimmer and program code: in both cases, there is a need of circuit that detects the zero crossing and can control a TRIAC.Figure 4 shows the circuit diagram of a basic dimmer circuit where the symbols have their usual meaning. Alarm generation happens when the flame sensor that is based on YG1006 sensor which is a high speed and high sensitivity NPN silicon photo-transistor detects a fire source or other light source of wavelength in the range of 760nm-1100nm. Due to the black epoxy coated on the diode, it is sensitive to Infrared Radiation. When the sensor detects flame, the signal LED will light up and the digital pin goes low as designed by the manufacturer using an internal Data Acquisition circuit.Table 2 describes the specifications of the flame sensor used in the street lights. Generic procedure for Fault Detection :

Table 1. Table depicting the specifications of the dimmer used in the project

Parameter	**Details**
Power	up to 220V (5A 10A)
AC frequency	50/60 Hz
TRIAC	BTA16 — 600B
Isolation	Optocoupler
Logic level	3.3V/5V
Zero point	Logic level
Modulation (DIM/PSM)	logic level ON/OFF TRIAC
Signal current	Greater than 10mA
Environment	For indoor and outdoor use Operating temperatures: 20C to 80C Operating humidity: Dry environment only
ROHS3	Compliant

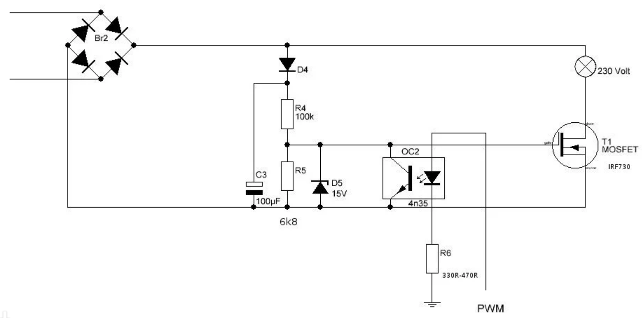

Fig. 4. Circuit Diagram of a general purpose dimmer used to vary the intensity of AC Street Light

Table 2. Table depicting the features of the Flame sensor used in the Smart Street lights

Parameter	**Details**
Working Voltage	3.3V-5V
Detect Range	60 degrees
Output Type	Digital/Analog
On-Board IC	LM393 chip
Dimension	3.2cm X 1.4cm

- Set EXTLDR = External(isolated from lamp light) LDR reading
- Set INTLDR = Internal(Placed in Lamp box) LDR reading
- if EXTLDR is less than Dusk-light threshold and INTLDR is less than Dim-light threshold then Generate fault notification;
- otherwise Read EXTLDR and INTLDR;

Note : The value of Dusk-light threshold is generally taken as 50 on a scale of[0-1023] while the value of Dimlight threshold is taken as 900 on a scale of [0-1023]. The value of Dusk-light threshold is basically the value that the LDR senses at the time of dusk i.e. when we want our Street light to glow while the Dim-light threshold is the reading of the LDR when the street light is in Dim state i.e. when it sees no motion. A gateway is

Table 3. Table highlighting the various characteristic parameters of various device to device communication technologies

	Wi-Fi IEEE 802.11b	**Bluetooth IEEE 802.15.1**	**Zigbee IEEE 802.15.4**
Radio	Direct Sequence Spread Spectrum	Frequency Hopping Spread Spectrum	Direct Sequence Spread Spectrum
Data rate	11 Mbps	1 Mbps	250 kbps
Nodes per master	32	7	64,000
Slave enumeration latency	upto 3 s	upto 10 s	30 ms
Data type	video, audio, graphics, pictures, files	audio, graphics, pictures, files	small data packet
Range [m]	100	10	10-100
Extendibility	Roaming possible	No	Yes
Complexity	Complex	Very complex	Simple
Positioning technology	CoO, (tri)lateration, fingerprinting	CoO	(tri)lateration, fingerprinting

a device that on behalf of the local network interacts with other networks or the cloud. In our solution, the gateway is inbuilt in one of the street lights of a local network of street lights which we have labelled as 'Master Street Light' while other street lights that are left are termed as 'Slave Street Lights'. The master street light is the one that communicates with the slave street lights using the ZigBee Protocol which is power efficient for considerable ranges. There is a need for data pre-processing at the gateway since we have only one node that interacts with other networks on behalf of the entire local network. Data pre-processing at the gateway takes place in the following parts :

- Receiving of data from the Slave Street Lights which includes temperature, humidity, motion, ambient light intensity and fire/fault flags.
- Calculation of Mean of the temperature and Humidity values from the street lights in the small local area network and then send it to the thingspeak server and Blynk server.
- Motion/fire/fault flags are interrupt driven and it is generated by each individual street light with its Unique ID (UID). The notification, if generated is sent to the Blynk server with the UID and a mail is generated for fire/fault which is sent to the Admin with the UID of street light where the interrupt was generated.

The next important thing is the IoT gateway which links the local microcontroller network with the Cloud. The protocols used in the device to device communication is IEEE802.15.4 (Zigbee) for slave street lights and IEEE802.11 (Wi-Fi) for master street lights as shown in table 3. REST APIs are used to read/write data onto the Cloud server with the help of a unique authorization key which is valid for a particular channel. The data is sent to the server every 5 seconds from the gateway using a client and fetched information from the Cloud server if required if some logic permits. This timing is set to match the flow between sender and receiver and to reduce constant polling which affects the performance of the communication and accounts to the lag in actuation. The microcontroller used is ATMEGA328p of the Atmel series of microcontrollers and it has been interfaced with ESP8266 WiFi module to add WiFi connectivity to data transfer. The ATMEGA328p is a 8-bit high performance microcontroller which works optimally with cost and energy effectiveness as shown in table 4. Zigbee is a good alternative for Street Light to Street Light communication as it has a low cost, low power utilization, and appreciable performance.

Master Street Light is the main street light with some important tasks.Tasks of Master Street Light include:

- Uniquely identifying each street light (slave) in the network.
- Fetching data from these slave street lights and store them in the database. Since transmission of data by each lamp will consume more power so one master lamp is installed that is responsible for interacting with the external server and the cloud.
- Control the intensity of each street light in case of emergency.
- Communicate commands from the cloud and communicate it to the slave street light.
- On an abstract level it acts as a gateway to the local team of slave street lights.

Table 4. Specification of the Atmel Microcontroller that is used as a Programmable Logic Controller for the smart street light

Parameter	**Value**
Microcontroller	ATmega328p
Operating Voltage	5V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC current per I/O Pins	40mA
DC current for 3.3V Pin	50mA
Flash Memory	32KB
SRAM	2KB
EEPROM	1KB
Clock Speed	16MHz
ICSP Header	In System Programming, used when you want to bootload, you'll need an AVR-ISP

The data received from the sensors via an IoT gateway is sent to the cloud after pre-processing and compression to reduce un-necessary overheads. We have used two different clouds in order to reduce burden. One of the clouds is responsible for gathering data from the sensors and recording their data so that they can be further analyzed using Machine Learning and Analytics. We can fetch the spreadsheet of the data recorded with its timestamp and location parameters from the Cloud directly.We have installed MATLAB onto the cloud for analysis which is a great tool for analysis of data through different plotting techniques available in MATLAB. Referring figure 8, The other cloud server is responsible for handling requests from the users. The application which is running on a mobile continuously show real-time status of the sensors and the data that is being sent by them including ambient light, temperature and humidity ,as illustrated in figure 5, and generates an alarm if there is any fault or fire. There are libraries available which enable the required information to be fetched or sent from mobile application server to Cloud server with the help of APIs.

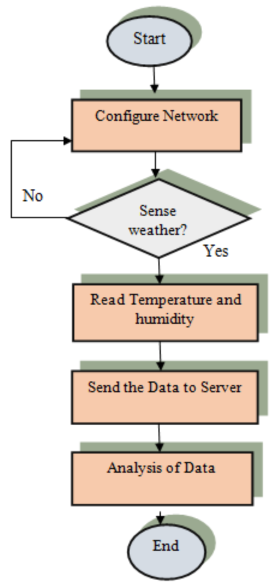

Fig. 5. Flowchart depicting the flow of temperature and humidity data from sensor to the cloud

5 Idea of Fuzzy Logic

Wireless Sensor Networks have limited processing capability and limited battery power. Due to large collection of input data, it is difficult to manage the data along with different domains. Hence energy efficient data aggregation technique is required for efficient data collection. Data aggregation is the method in which data coming from different sensors is combined and provides useful aggregated information. Keeping in view the above issue, a novel energy efficient fuzzy logic based data aggregation technique is proposed. The proposed technique collects, analyzes, classifies and aggregates the data of different domains automatically which is reported by various sensors. Further, fuzzy logic technique is applied as it has capability to deal with dynamic situations and to model the conditions which are inherently imprecisely defined. Proposed data aggregation technique aggregates the incoming data in an effective manner by reducing energy consumption based on different fuzzy rules designed in knowledge base, which further improves network lifetime.

5.1 Results

For Automation of Street Light based on the ambient light intensity, we found that climatic conditions play a major role. Also, the latitude and the location decide the angle of incidence of sunlight therefore the installation of Light Dependent Resistors should be done accordingly. Only locations lying along one line of latitude on the surface of the Earth can receive sunlight at a 90 degree angle on a given day. All other places receive sunlight at lesser intensities. Regardless of latitude or time of year, the

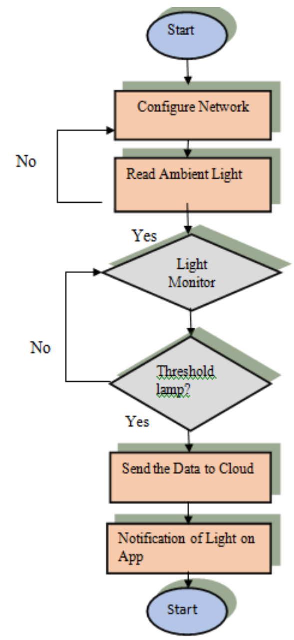

Fig. 6. Flowchart depicting the logic involved in fault detection of Smart Street Light and flow of control

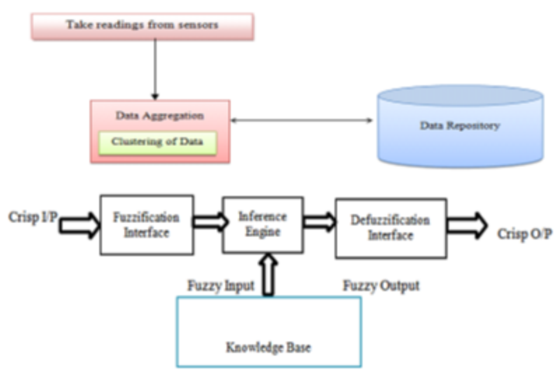

Fig. 7. Process of Data Aggregation used in Fuzzy

sun's angle reaches closest to 90 degrees and is therefore at its most intense at the midpoint of the day : noon.Therefore, we have to create a logic based on this variation so we decided to fetch the time of operation and location of a street light in addition to the actual LDR readings sent by the Street Light. Based on the actual calibrated LDR data, we adjusted the lamp wattage and lamp voltage with the help of a dimming

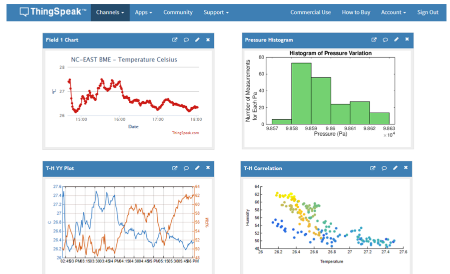

Fig. 8. Glimpse of the User Interface of MATLAB's Thingspeak platform showing plots of data collected

module and a instruction set executed by a microcontroller. The fault of the street light can be detected if the LDR at the street light shows a low reading when it is supposed to be ON. The real time clock attached to the server lets the microcontroller know when the lamp needs to be in ON state and to detect whether it is ON or Off can be found out by the LDR attached to it and a trigger is generated of failure or fault as illustrated in figure 6. With reference to the works of Mahoor et al. [2], we

Table 5. Table depicting the variation of voltage with changes in the intensity of light

Luminous flux [lm]	**Lamp wattage [W]**	**Lamp voltage (AC) [V]**
5000	50	220
3600	44	200
2520	37	180
1714	30	160
1114	24	140

Table 6. Table depicting the parameters used in Fuzzy

Parameter	**Value**
Network Coverage / m^2	200 X 200 m^2
Number of sensors	50 300
Initial energy / J	0.5
Data packet size / Bit	500
Control packet size / Bit	12
A	2.5
Maximum transmission range / m	30

have conducted experiments in order to obtain data with the aim of building A smart street lighting control system for optimization of energy consumption and lamp life. The table 5 highlights the variation of voltage, wattage and intensity of light during the day thereby reducing power loss and increasing efficiency. Figure 9 is a pictorial representation of the data in table 5 and it was observed that The electrical cost was reduced by 20 percent and the Lamp Life was enhanced by 100 percent for a time span of 12 hours. With the observations made it was recorded that the flow of vehicles as well as human traffic is at its apex during 6PM to 10PM time frame so, our operational strategy of street light was such that the intensity and luminous flux will be at its peak during these hours. Past, 10PM with the usage of AC Dimmer module the voltage takes downward leap to 160V up till 12AM after that the light operates on 140V till it get completely dimmed out with the dawn . The path with minimum () is

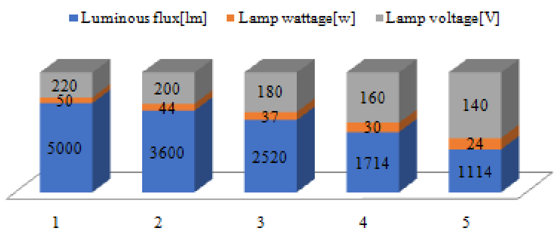

Fig. 9. Bar plot showing the the variation of voltage with changes in the intensity of light and lamp wattage

decided by fuzzy member functions and data is transmitted. Referring figure 10, The evaluation of FLDA is done through MATLAB and FuzzyJ Toolkit used for Java to implement the necessary fuzzy logic functionality.Figure 7 is a block diagram depicting the process whereas table 6 describes the simulation parameters used in this experiment work. i.e. denotes the energy dissipated in the transmission of message from source to destination. Based on the experiments the flowchart for control flow can be summarized in figures with impetus to motion detection, fire detection as in figure 11, detection of ambient light, detection of fault and temperature and humidity detection. With these experiments and the logic proposed, we have successfully collaborated all the essential features of a Smart Street Light and provided a generalized model that would help in future research endeavours.

6 Analysis of cost and energy consumption

This project is an amalgamation of all the positive results of researchers in the literature survey. The requirements of this project includes a street lamp that are already existent i.e. we need not re-install street lights since our peripherals that we will attach are compatible will both DC and AC systems with just a minor difference for variation of brightness. In addition, we will require a Raspberry Pi or a NodeMCU board that can connect to the network using Wi-Fi which is already available in smart cities these days. We will then install a Master Street Light that can send the data to the server which cuts down the cost of gateways and also decreases power consumption by these devices. Our novelty lies in the fact that we make out street lights dim when there is no pedestrian or traffic around thereby cutting down energy consumption. As depicted in Figure 9, the luminous intensity of the lamp is proportional to the energy consumption,

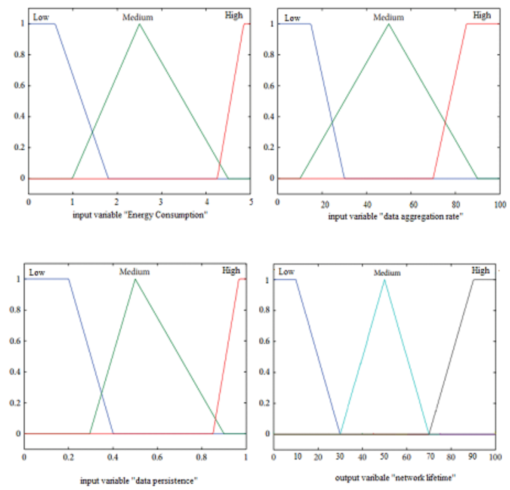

Fig. 10. Fuzzy subsets of fuzzy inputs and fuzzy output

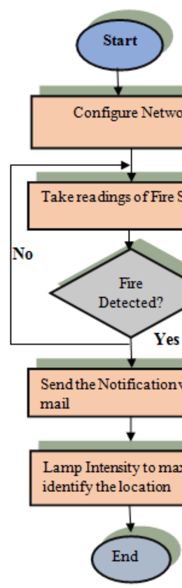

Fig. 11. Flowchart expressing the procedure involved in detection of fire and various steps involved in it

we are enabling the lights of the street light at dusk and disabling them at dawn by defining a threshold as mentioned earlier and when the are enabled we are further cutting down energy consuming by not running them at full intensity by running them in a dim mode. We some traffic is there they run at their full intensity thereby not hindering with the normal working.

7 Conclusion

From the discussion done in this paper, the characteristics of a smart street light have been defined in detail. A Smart Street should be energy efficient, able to sense the environment and act in an appropriate manner based on a certain set of instructions. It should also have the ability to send data efficiently with cost effectiveness to a standard server which is available all the time. Motion detection, ambient light and fire detection adds to its integral features and are essential to be smart in present scenarios. With all the methodology operated and results achieved a significant optimized model of smart street lamp light is presented and it was observed that model provides a vital energy saving model and corresponding to the results achieved, the model provides sufficient energy saving. The weather station further will integrate the data of forecast with the cloud storage and accordingly will give the inputs to smart street light.

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