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COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

An Embedded Fuzzy Logic Based Smart Street Lighting System

A dissertation submitted in partial fulfilment of the requirements for the award of Masters of Science degree in internet of things- Embedded Computing System

Submitted by:

GEOFREY TWESIGYE (Reg. No. 220014931)

November 2022

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Supervised by: Dr. NGENZI Alexander

Dr. Ndashimye Emmanuel

November 2022

DECLARATION

I declare that this thesis document contains my original work except in instances where specifically acknowledged and has not been submitted for the award of any degree in any institution of higher learning.

GEOFREY TWESIGYE

Reg. No. 220014931

Signature: ....

Date: ..../...../**2023**

BONAFIDE CERTIFICATE

This is to certify that research thesis entitled "An Embedded Fuzzy Logic Smart Street Lighting System" is a record of work originally done by Geofrey Twesigye of the registration number 220014931 as a partial fulfilment of the requirement for the award of masters of sciences in Internet of Things in the Academic year 2020/2021.

This work has been submitted under the guidance of Dr.NGENZI Alexander Yusuf and Dr. Ndashimye Emmanuel.

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To my family friends and fellow students, I also say big thanks for the support and believing in my abilities

ABSTRACT

Just like in any other city in the world street light takes play an essential role in Rwanda today with the government installing the same across the City. There is a move towards real-time street light system that can respond to the surrounding environment or actions providing a safe night time environment for all road users including foot-travelers. The Street light computerization system can reduce power consumption and maintenance costs and also supports to reduce crime activities up to certain limit. Such street light systems are mainly controlled on the basis of a combination of sensor technologies. However, most of the current systems in Kigali are based on thresholds which may lead to errors leading to increased costs and energy wastages. This thesis therefore, presents a prototype of Arduino based fuzzy logic controlled smart street lighting system so as to overcome the challenges. The study aims to implement fuzzy logic on Arduino as compared to existing solutions that depend on cloud based solutions which are a challenge implementing in Africa. The PIR sensor is used to detect motion and the surrounding environmental conditions using Light Dependent Resistors so the lighting is adjusted or switched on and off based on demand. In addition, the system will be able to monitor the working conditions of different lights and incase of any anomalies alert the concerned authorities via a GSM module. The results show that the implementation of a fuzzy inference system in Arduino did not effects its functionality an element that can be exploited to reduce on connectivity and energy costs. On implementation this system will lead to reduced costs, predictive maintenance and energy savings thus contribute towards the achievement of sustainable development goals.

Keywords: Internet of Things (IoT), fuzzy logic system, Smart Street light and Arduino

LIST OF ABBREVIATIONS

AC: Alternating Current

AI: Artificial Intelligence

FIS: Fuzzy Inference System

FL: Fuzzy Logic

IDE: Integrated Development Environment

IoT: Internet of Things

IT: Information Technology

LDR: Light Dependent Resistor

LED: Light Emitting Diode

LPWAN: Low Power Wireless Area Network

OT: Operations Technology

PIR: Passive infrared Sensor

SDGs: Sustainable Development Goals

WSN: Wireless Sensor Network

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The street lighting system is the one of the largest power/energy expenses for a city. A smart street light system can reduce the organization street lighting costs [1]. Nowadays lighting is seen likewise as a method of making a wonderful climate in the inside all in all and as a method for giving delightful conditions wherein to live and work [2]. Rwanda is a fast-growing in development country, characterized by development of people's livings, city and residential buildings, and construction of regional industrial areas. Kigali city and other districts are a focal point for many of these changes which make the increase of street lights in the cities. Energy/power saving has been identified as the major concern in designing any intelligent energy efficient lighting system [3].

Internet of Things is really playing a fundamental and significant role in our everyday life, after it's showing up. It shows remarkable changes over conventional framework/system and other traditional & general household equipment to make our life better [4]. IoT is basically a combination of Operational Technology (OT) and Information Technology (IT) which permits unstructured machine-created information to be investigated for experiences that will drive improvements [5]. So, IoT can be integrated in order to facilitate the street lighting systems [4], where different sensors are used to collect the information about smart street lighting placed in different location when it is fully energy efficient system, it informs the municipal cooperation to empty the container. Smart Street lighting control system enables to manage street lights more flexibly, save electricity/power, monitor the grid and cut maintenance costs at the same time. It consists of smart controllers and cloud-based software and simulation for the real-time management of street lights.

In order to analyze and decide on the data that will be collected by sensors, there must be a knowledgebase (database) storing the standard data about the needed lights parameters for street lights and by benchmarking the collected data with the standard ones, a decision must be taken, which make a need of a fuzzy-inference based model [6]. Fuzzy Logic (FL) is based on an approach of imitating human decision-making system by including all in-between alternatives of digital values YES and NO. The method of reasoning within fuzzy logic resembles that of human. This model is one of the most used algorithms for decision making systems of artificial intelligence [7]. Fuzzy logic, a branch of artificial intelligent (AI) systems, is a form of algebra employing a range of values from "false"(0) to “true" (1) that is used in making decisions with imprecise data. Fuzzy logic is a very powerful tool for dealing quickly and efficiently with imprecision and non-linearity issues, like light intensity level in a streets, requiring decision making [6].

To achieve a desired quality of light for a space, various lighting control systems have been investigated and described, including use of Computerized Addressable Light Interface (DALI), Programmable Logic Controllers (PLC), digital signal controllers (DSC), and Fuzzy Logic Controllers [8]. These and other existing solutions employ Fuzzy Logic to build a corresponding fuzzy inference system using cloud-based platforms for example Things Speak among others. In this thesis we explore the implementation of Fuzzy Logic on Arduino. Sensor nodes are designed to automatically light the smart street lighting basing on the fuzzy inference which will be experimentally implemented using a microcontroller board, sensors (Street lights, IR sensors, rain sensor, Relay, LDR,GSM/GPS/GPRS module and current sensors), and a AC power supply.

1.2 Motivation

In any giving city having reliable lights is an essential step towards happy citizens and at the same time away to enhance the security in the surrounding environs. Energy efficiency and sustainability are significant concerns in society today. A fuzzy logic controller, whose operation is based on expert’s knowledge and human reasoning, could be the best option for modeling an intelligent and energy efficient lighting system, which do not require fine accuracy in illumination levels. The knowledge gained from this research study would be beneficial to the universities and lighting industries. This thesis would form a basis for further studies on artificially intelligent systems energy saving and lighting control. This thesis would be used in improving the energy and comfort performance of modern smart street lights.

1.3 Problem Statement

There is on ongoing transformation of lighting industry due to the progress in smart street lighting, information technology, and the requirements for maintainable and energy-efficient solutions [9]. Requests on lighting frameworks/systems have changed significantly in later a long time. Whereas fair switching individual lights on and off utilized to be adequate, the new center is on dynamic lighting. There is a need to optimize the applications of the new generation of smart street lighting and intelligent systems, which in combination with advanced digital addressable sensors and controls, will fuel new lighting applications. Application of Artificial Intelligent (AI) software programs in control of smart street light sources are bound to become a way of life in the near future and lead to new lighting solutions [9], which are not possible with conventional lighting technology. It is necessary to optimize the utilization of natural light in both homes and workplaces as a strategy to save lighting-related energy costs, and at the same time improve the comfort of living and working in such places. To do this we need to monitor and adjust the amount of light intensity in the user places [10]. People also forget to switch on and off light on time or delay in doing so. It is, therefore, necessary to automate lighting intensity control in space. This study will seek a way to smart street light intensity and light control in space using fuzzy logic systems.

This problem comes from the cities and rural areas around in Rwanda- Kigali city have raised serious concern due to their extensive destruction to material goods and human life. Recently we have a problem with the manual system in Rwanda where the lights are ON in the evening before the nightfall as mainly stated below;

- Manually switching ON/OFF of street light
- Not fully Energy Efficient systems
- Wired Switching
- No monitoring system
- Huge energy/power expenses
- More manpower

1.4 Objectives

The general objective of this research was to develop a Fuzzy logic driven Arduino based smart street lighting system from smart cities. The specific objectives were:

a) To investigate the existing techniques used in smart street lighting solutions.

b) To find out the parameters necessary for context aware street lighting.

c) To design a fuzzy-based smart street lighting solution using Arduino.

d) To prototype for a fuzzy logic-driven smart street light.

1.5 Research Questions

The thesis was guided by the following questions;

1. Which are the existing techniques used in smart street lighting solutions?
2. What are the parameters necessary for context aware street lighting?
3. Is it possible to use fuzzy logic on Arduino for a smart street lighting solution?
4. Which is the best being to prototype a fuzzy logic-driven smart street light?

1.6 Hypothesis

The hypothesis for this study is that the use of a fuzzy based smart street lighting system will reduce energy and system maintenance costs

1.7 Significance of the Study

This research will make a contribution to the existing knowledge base, many smart street lighting systems have been developed but to the best of our knowledge non implements fuzzy logic on Arduino, this study explored the implementation of a fuzzy logic system on an Arduino giving future researchers to a guide for other use cases. The design of the system will also be made available for use by Kigali city planning team.

For the government, cost spent on electricity/energy system and its reparation minimizes, there will be invention of new systems making ease the delivery of services in the country. In addition, the work of country management team will be made easy (most of the work will be done remotely). The citizens will also benefit from the automated lights systems and also ensuring that the street lights are always working will be an added benefit.

The system will also contribute in achievement of Sustainable Development Goals (SDGs): (i) Goal 7, Affordable and clean energy, the system will reduce energy wastages while at the same time lowering costs incurred; (ii) Goal 11, sustainable cities and communities because the system will enhance monitoring of street lights so the city services are not interfered with; and (iii) Goal 12, Responsible consumption and production, the implementation of the system will ensure responsible use of energy produced.

1.8 Scope of the Study

This research focuses on automatic control of street lights based on detection of movement and the surrounding environment. Any form of movement will be assumed to mean there is a need for a bright light while environment monitoring will only include the intensity of light detected to determine if its day or night. A demonstration of the prototype will be done in a lab setting only.

1.9 Organization of the Document

The rest of the document is organized as follows: Chapter 2 gives the breakdown of related work; Chapter 3 Methodology, presents the general introduction, descriptions of components and platform used; Chapter 4 Implementation, comprises experiment setup, circuit diagram of prototype, configuration of the prototype; Chapter 5 Results and discussion, and Chapter 6 concludes the document by presenting the recommendations drawn from this study.

CHAPTER 2: LITERATURE REVIEW

This section presents a review of related literature. This was conducted so as to put the study in the context of related studies. Studies and solutions for smart street lighting are first presented followed by an analysis of IoT lighting solutions based on fuzzy logic. In addition, the use of fuzzy logic on Arduino is presented and lastly a conclusion drawn.

2.1 Smart Street Lighting

There have been attempts to develop smart street light solutions using IoT. First review was a study in [11]. In this study the intensity of light is controlled by considering the movement of objects near the light. Photo electric sensors and light sensors are used. As soon as the sun sets and darkness begin the system automatically switches ON lights. When the sun rises the lights are automatically switched OFF. For the detection of human beings and light intensity in a given area, LDR and PIR sensors are used [11].

Also reviewed is a system for controlling and monitoring of street lighting with two zones namely a control zone and device zone. The components that make up the device zone of the system include microcomputer system based on Raspberry Pi, power supply system, energy meter, and sensor systems. The device zone is also made up off the output module which is mainly made up of several lamps and a telecommunication system. For the control zone, the components include a laptop for controlling the lighting of the street lights remotely, telecommunication system and power supply system [12].

In [13] a smart city street lighting system is presented. A lamp unit is the first module in the system. it consists of sensor which is used to identify the motion and brightness of the LED device, controller and communication device. If sensor detects the motion, light will be turned ON condition else, Light will be turned OFF condition. A Sensor unit that consists of the motion sensor, a controller and a communication device.

A project aimed at inventing an intelligent system which can make decisions for luminous control (ON/OFF/DIM) considering the light intensity was also reviewed. In this proposal the day and night mode can be identified by fixing a particular intensity value on LDR sensor and street light can be controlled by IR sensor. [14].

In [15] a smart lighting system is presented. The street lights collect all information via sensor and send it to the server by using wire/wireless network. The user can use the smart devices or PC to connect to the sever by using management system.

A Smart LED luminaire is presented in [6] It provides intelligent ON/OFF switching, dimming control via remote management and constant health monitoring status. The inputs and outputs of the wireless mesh devices are mapped using open protocols which allows easy integration with other systems [16].

A paper that discusses the design of an adaptive street lighting management and control system pilot was reviewed. The objective of this pilot project was to demonstrate that LED light fixtures provide energy savings over their HPS counterparts. In addition, as it is possible to monitor streetlights remotely, malfunctioned streetlights can be detected early, reducing maintenance costs [17].

In [18] a smart street lighting system based on NB-IoT was reviewed. In the study a smart architecture, including the perception and control layer, the street lighting system is a typical application of the smart transport layer, the platform layer and the application layer is presented.

An IOT enabled streetlight management system is presented in [19]. The project uses Light Emitting Diodes (LED) that do not consume an enormous amount of electricity to replace the power consuming traditional HID lamps. The proposed work has achieved a better performance compared to the existing system.

The major drawback of the systems reviewed in this section is that they are based on threshold values and some do not integrate the aspect of monitoring weather conditions and also have no capabilities of monitoring the state of the lights. In addition, some solutions have a control module that depends on humans to operate.

2.2 Fuzzy Logic in smart Lighting

In an attempt to develop a better solution smart street lighting solutions that apply the use of fuzzy logic were also reviewed. To begin with a study that discusses the optimization of using artificial intelligence with civil fuzzy logic methods to obtain a level of evenness that is in accordance with the standard, with input variables such as road width, pole height, lamp power and mounting distance between poles is presented in [20].

In [21] a proposed design was implemented and executed in a residential area, and the results were carried out at different scenarios and various seasons. The decision making module exploited the analysis factors obtained via lighting sensor, motion sensor, PIR sensor, etc. artificial neural network and fuzzy logic controller made an efficient decision making process for demand based utilization and to avoid the unnecessary utilization of street lights.

Also reviewed is a paper that focused on the energy saving by controlling the light intensity of street light according to the street condition which be measured by the sensor such as light dependent resistor (LDR), passive infrared sensor (PIR), and rain sensor module. In this project, the light intensity of street light is controlled using a functional controller known as the fuzzy logic controller [22].

A fuzzy-based control approach is proposed in [13] to control the street lighting systems depending on solar and wind renewable energy sources. The light intensity is controlled according to the battery level and the speed of the wind. Fuzzy Logic Control (FLC) is an efficient technique for solving complex problems with little mathematical equations [23]

In [14] a system for controlling the brightness of street lights by predicting pedestrian paths, identifying the position of pedestrians with motion sensing sensors and obtaining motion vectors based on past walking directions, then predicting pedestrian paths through the route prediction smart street lighting system is proposed. In addition, by using motion vector data, the pre-treatment process using linear interpolation method and the fuzzy system and neural network system were designed in parallel structure to increase efficiency and the rough set was used to correct errors. It is expected that the system proposed in this paper will be effective in securing the safety of pedestrians and reducing light pollution and energy by predicting the path of pedestrians in the detection of movement of pedestrians and in conjunction with smart street lightings [24].

In [25] a working prototype of an IoT system which controls natural and artificial light balance in combination with a dynamic shading system was reviewed. The control system adopts a fuzzy logic solution which is able to ensure fast control without high computational effort.

The use of fuzzy logic is indeed an improvement on systems based on thresholds and manual control centers. However, the studies are mainly modeled through MATLAB fuzzy logic and simulations. Our study however explores the use of fuzzy logic on an embedded device a concept referred to as efuzzy.

CHAPTER 3: METHODOLOGY

This chapter presents the methods and materials used in the study. The first section resents the embedded system level design including a high-level architecture of the proposed smart street light monitoring system with different components for the solution. The fuzzy logic control design is also presented together with the device and simulation setups.

3.1 Embedded system level design

3.1.1 System Architecture

The system is made up of three main sections: sensing, computing, and data analysis and visualization. Sensors are used to detect different environmental parameters: The light dependent resistor (LDR) is used to detected the time of day by sensing light intensity, the Passive Infrared sensor (PIR) is used to detect movement around a given street light with the rain sensor being used to detect the weather conditions, the sensors are connected through to an Arduino microcontroller where the fuzzy logic engine is integrated to control the lights. After fuzzification and defuzzification the light will be actuated based on the outputs. In case of any notifications they will be sent via a GSM. Figure show the high level system architecture.

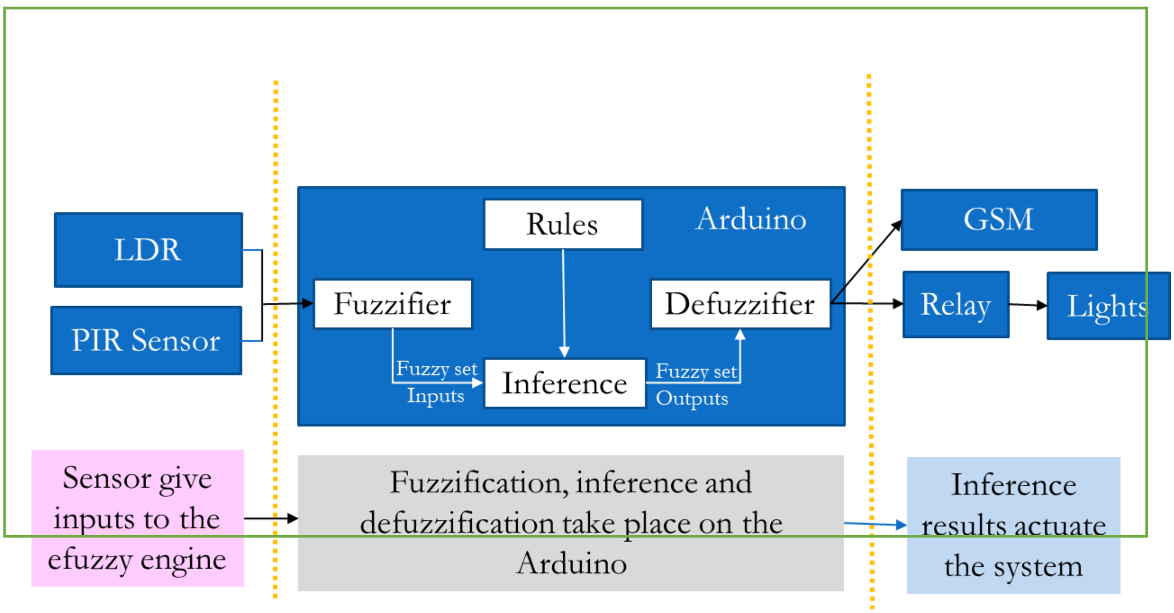

Figure 1: High level architecture of the smart street light system

3.1.2 Sensing Layer

The sensing unit consists of 4 sensors: The LDR, IR and rain sensors

A. *LDR*

A photoresistor or light dependent resistor [26] is an electronic component that is sensitive to light. When light falls upon it, then the resistance changes.

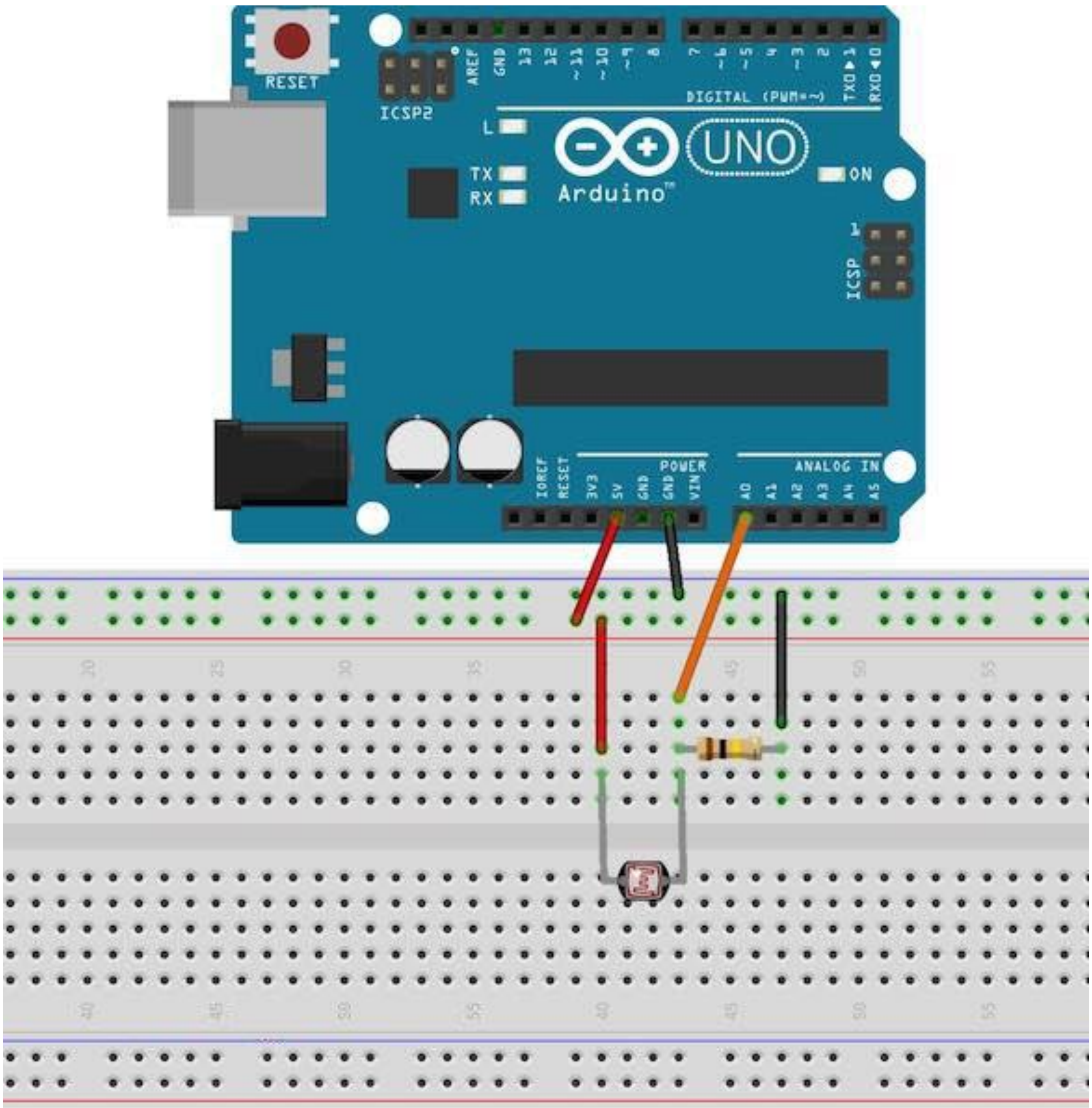

Figure 2: LDR connection diagram

B. PIR Sensor

PIRs [27] are basically made of a pyroelectric sensor which can detect levels of infrared radiation.

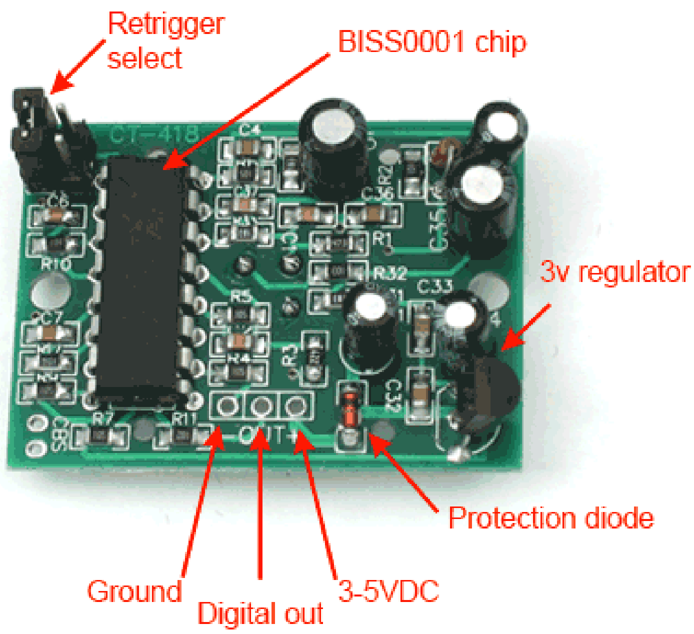

Figure 3: PIR sensor

When the PIR sensor detects a movement, the output will be HIGH, otherwise, it will be LOW.

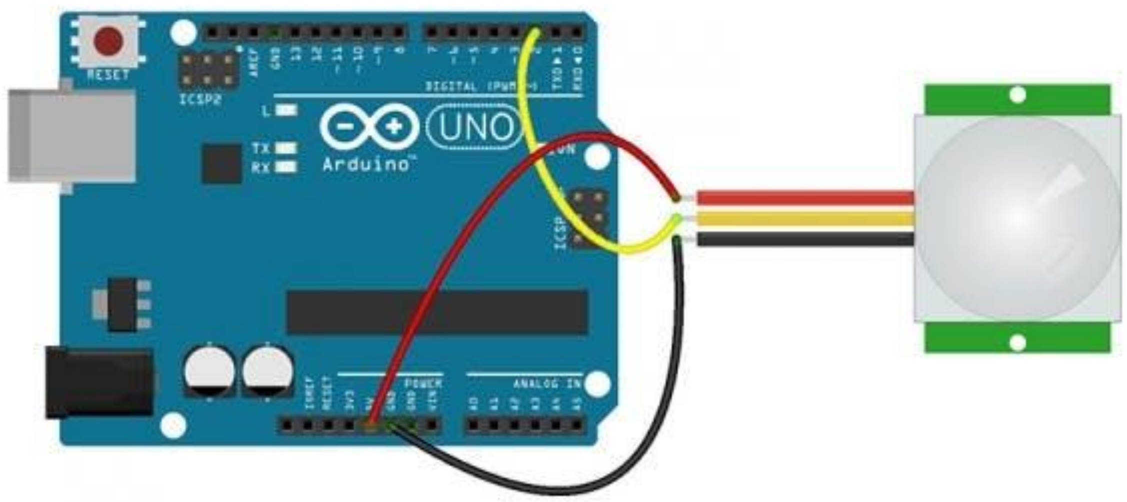

Figure 4: PIR Sensor Connection to Arduino

3.1.3 Processing Layer

A. Arduino Uno

Arduino Uno is a microcontroller board based on the ATmega328P.

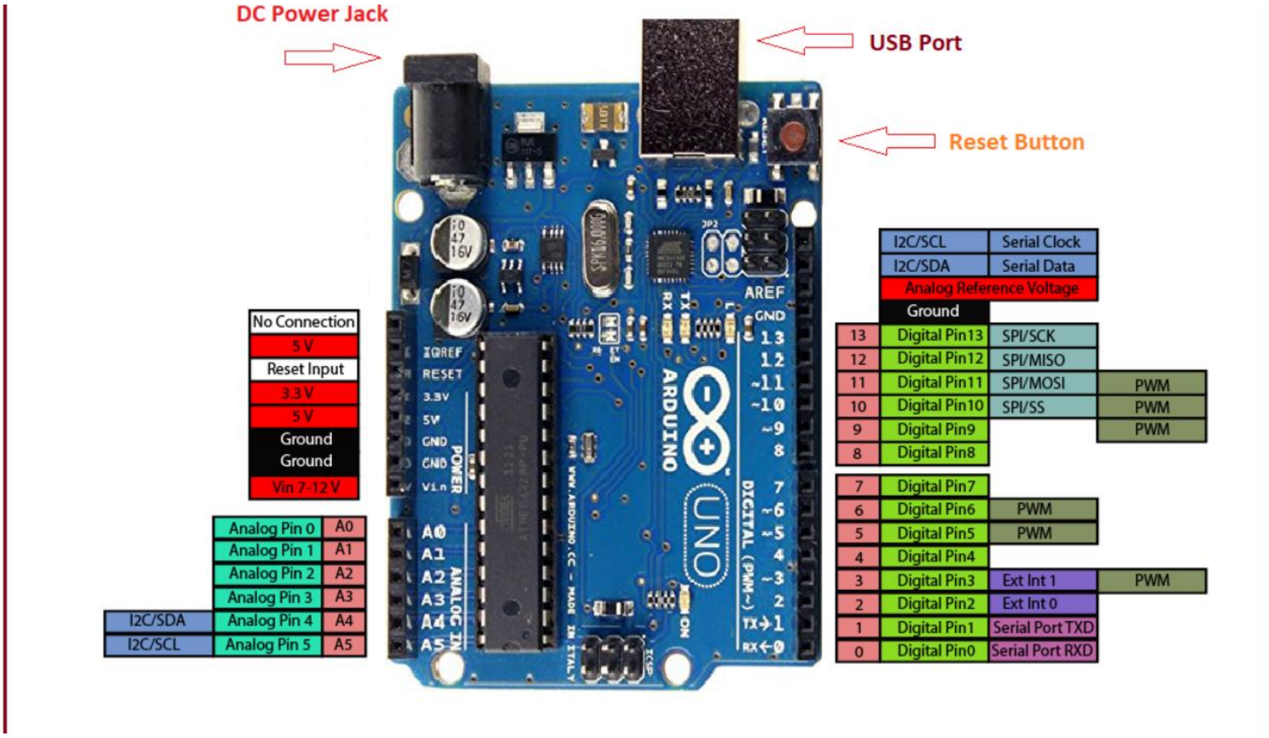

Figure 5: Arduino uno

3.2 Fuzzy Logic

This research deployed an embedded Fuzzy logic system controller (FLS). FLS is chosen because its algorithm works in the environment of uncertainties, dealing with uncertainty coming from linguistic concepts without a clear boundary, it is not easy to have a single measure of the electricity consumed by each load in a time, and it is not easy to conclude that the street lights is totally free. It is not easy to conclude that any machine or appliance is not consuming electricity when it is always connected to the power source, hence deploying Fuzzy Logic will help in minimization of committing errors probability.

Fuzzy Logic [6] shows a number of advantages over other algorithms: more simplicity and flexibility, ability to manage troubles with non-precise data (with uncertainties), cheap for development, ability to cover huge area of operating conditions, work in conditions needing human reasoning, more precision and it is able to be used for the SSL system.

Inputs to the fuzzy model of this research are the street lighting substrate parameters collected from sensors typically, PIR sensor, and the LDR. The main parts of our efuzzy model are sensors inputs, street lighting knowledgebase, fuzzification, fuzzy rule base, membership function, fuzzy inference engine, defuzzification, and sensors outputs parts. The efuzzy logic controller comprises of four principal components:

- Fuzzification Interface: - Uses membership functions to convert inputs suitable linguistic values
- Inference Engine: - Does a simulation of the human decision making process. A number of knowledge control rules are used to infer the fuzzy control.
- Defuzzification interface: - Converts an inferred fuzzy controller output into non-fuzzy (crisp) control action signal.
- Fuzzy Rule Base Energy/power Management Controller: train an artificial fuzzy inference system employed to use the data from sensor nodes to recognize appliances' status and activities.

CHAPTER 4: CONFIGURATION AND DEPLOYMENT

4.1 Simulation of the solution

The system working of the system was simulated on proteus design suit. Different components were connected as shown in the figure 5. The main components of the simulation design include an Arduino UNO, PIR sensor, Relay, GSM module and a bulb and an LED. Different conditions were simulated so as to demonstrate the working of the embedded system.

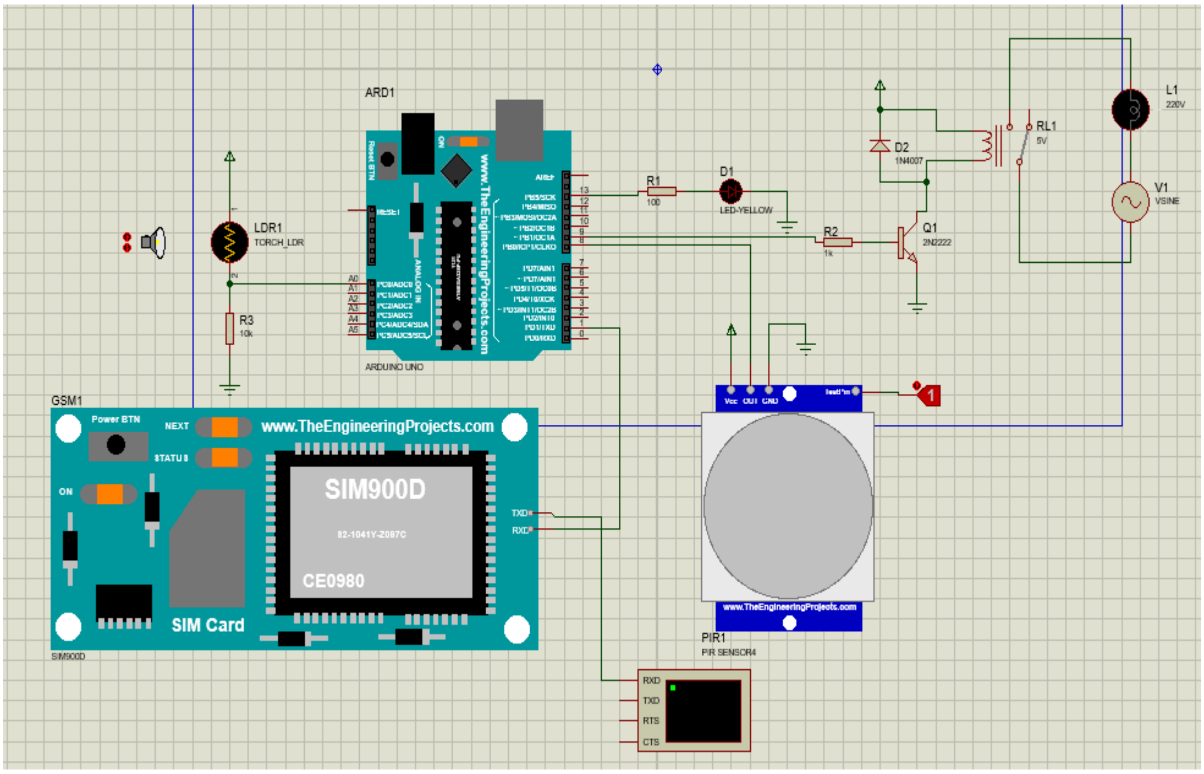

Figure 6: Prototype simulation set up

4.2 Fuzzy logic design

The fuzzy logic prediction model was designed and developed first in the MATLAB fuzzy logic tool box using logic rules implemented in a fuzzy inference system (FIS) and later converted into embedded fuzzy logic inference system. Two inputs were used for fuzzification in the design with one output expected after defuzzification.

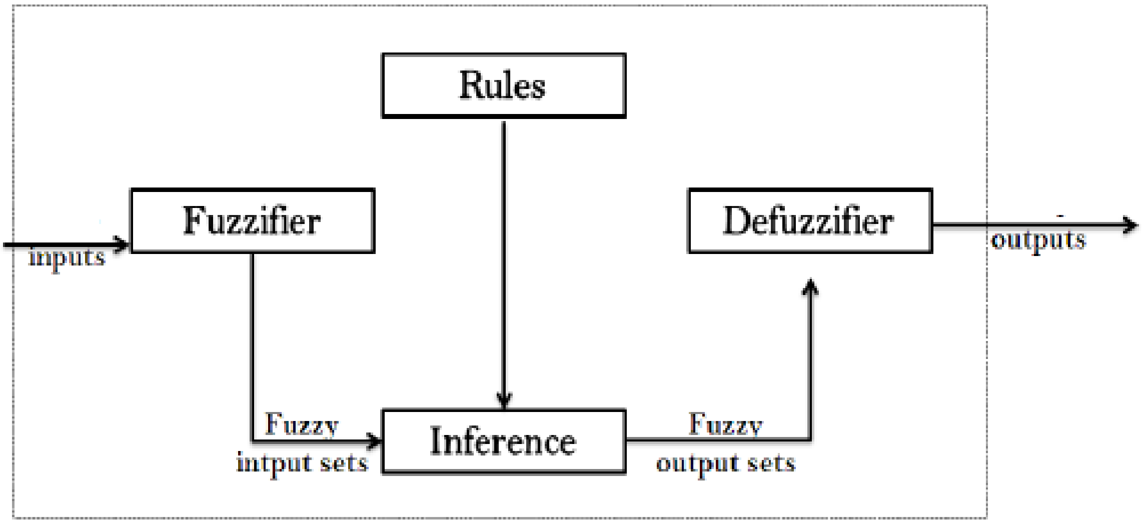

Figure 7: Fuzzy system block diagram

*A. **FIS Design***

The Mamdani method of the fuzzy inference engine was used. This method operates in four main systematic steps; The first step involves the Fuzzification of the inputs, this is followed by evaluation of the rules, there after the rule outputs are aggregated and lastly defuzzification is done and outputs given.

So as to get more accurate results the variables were tuned appropriately during the model design. The two inputs to the FIS were the LDR sensor readings and the PIR sensor readings with the output being the Voltage output which determines the status and brightness of the street lights. For both the inputs Gaussian and trapezoidal membership functions were used with the triangular membership function being used for the outputs. Figure 7 show the inputs and outputs for the FIS.

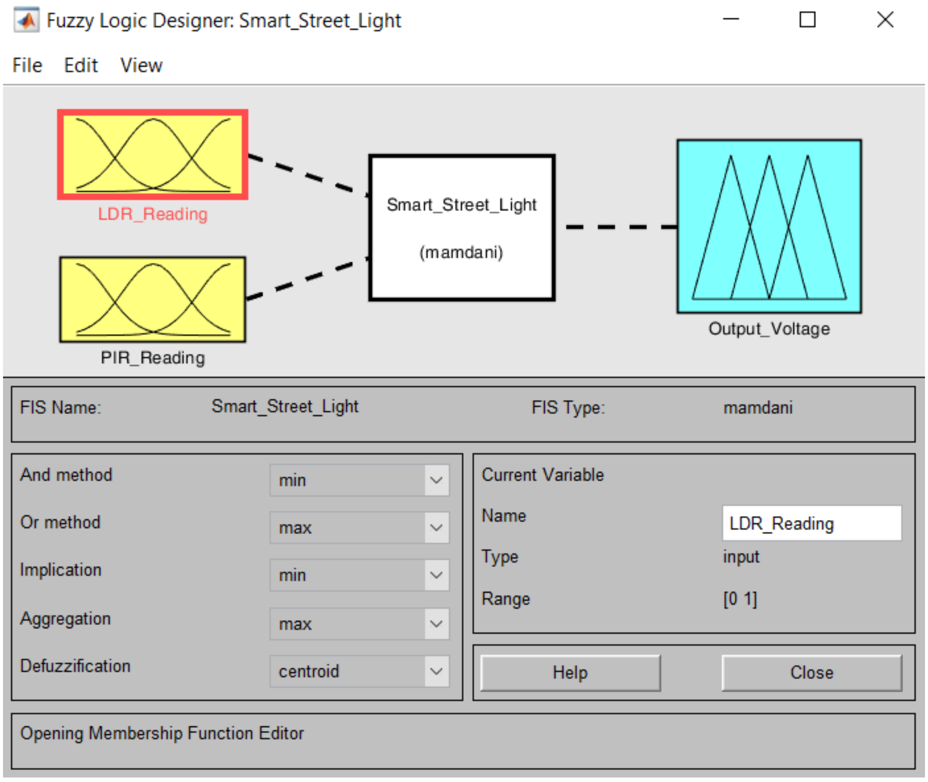

Figure 8: FIS inputs and Outputs

The snapshot of Arduino code below shows the declaration of inputs and output of the FIS;

```
// Number of inputs to the fuzzy inference system
const int fis_gcI = 2;
// Number of outputs to the fuzzy inference system
const int fis_gcO = 1;
// Number of rules to the fuzzy inference system
const int fis_gcR = 14;

FIS_TYPE g_fisInput[fis_gcI];
FIS_TYPE g_fisOutput[fis_gcO];
```

Figure 9: declaration of inputs and output of the FIS

B. ***Membership Functions****:*

The membership functions were each designed based on the expected measuring ranges for the inputs and the voltage output ranges. Different types of membership functions were used for the inputs and outputs.

For the LDR reading the Gaussian membership function was used, while for the PIR reading a trapezoidal membership function was used with the triangular membership function being used for the output voltage. Figure 8 presents the design of the membership functions. The LDR reading had three membership functions (Dark, almost dark and light), the PIR reading had two membership functions (No Motion and Motion detected) and the Voltage output had 3 membership functions (OFF, DIM, ON)

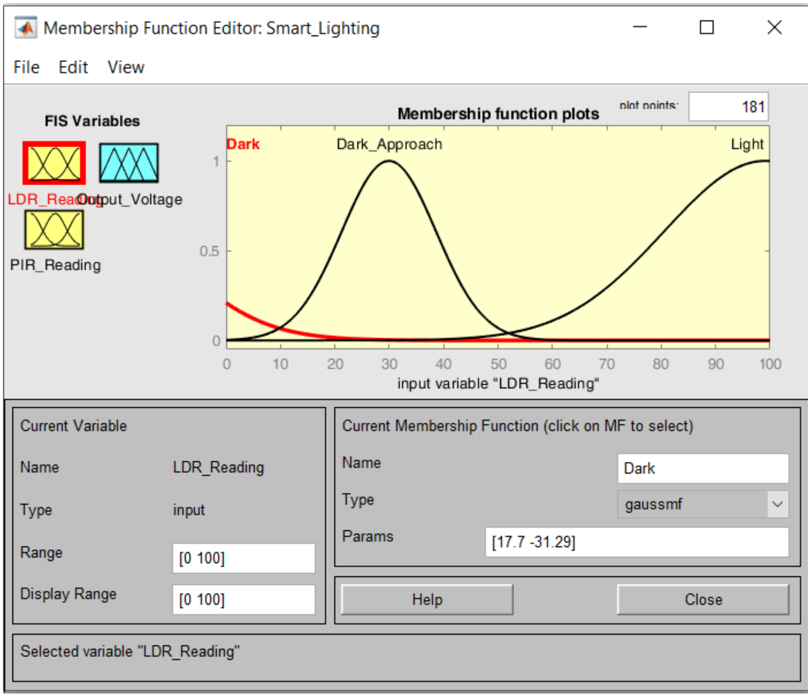

Figure 10: LDR_Reading Membership Functions

The Arduino codes for creating on the membership functions is shown below

```
//***********************************************************************
// Support functions for Fuzzy Inference System
//***********************************************************************
// Gaussian Member Function
FIS_TYPE fis_gaussmf(FIS_TYPE x, FIS_TYPE* p)
{
    FIS_TYPE s = p[0], c = p[1];
    FIS_TYPE t = (x - c) / s;
    return exp(-(t * t) / 2);
}

// Triangular Member Function
FIS_TYPE fis_trimf(FIS_TYPE x, FIS_TYPE* p)
{
    FIS_TYPE a = p[0], b = p[1], c = p[2];
    FIS_TYPE t1 = (x - a) / (b - a);
    FIS_TYPE t2 = (c - x) / (c - b);
    if ((a == b) && (b == c)) return (FIS_TYPE) (x == a);
    if (a == b) return (FIS_TYPE) (t2*(b <= x)*(x <= c));
    if (b == c) return (FIS_TYPE) (t1*(a <= x)*(x <= b));
    t1 = min(t1, t2);
    return (FIS_TYPE) max(t1, 0);
```

Figure 11: membership functions

*C. **Fuzzy Rules***

A total of 14 rules were created. This rules defined the inputs and the expected outputs under each rules. Sample of the codes for Arduino is shown below

```
//***********************************************************************
// Data dependent support functions for Fuzzy Inference System
//***********************************************************************
FIS_TYPE fis_MF_out(FIS_TYPE** fuzzyRuleSet, FIS_TYPE x, int o)
{
    FIS_TYPE mfOut;
    int r;

    for (r = 0; r < fis_gcR; ++r)
    {
        int index = fis_gRO[r][o];
        if (index > 0)
        {
            index = index - 1;
            mfOut = (fis_gMF[fis_gMFO[o][index]])(x, fis_gMFOCoeff[o][index]);
        }
        else if (index < 0)
        {
            index = -index - 1;
            mfOut = 1 - (fis_gMF[fis_gMFO[o][index]])(x, fis_gMFOCoeff[o][index]);
        }
        else
        {
            mfOut = 0;
        }

        fuzzyRuleSet[0][r] = fis_min(mfOut, fuzzyRuleSet[1][r]);
    }
    return fis_array_operation(fuzzyRuleSet[0], fis_gcR, fis_max);
}
```

Figure 12: Sample of the codes for Arduino

*D. **Conversion to Embedded fuzzy***

After the design and creation of the rules. The code was analyzed and converted to an Arduino code the was tested on proteus simulations and on an Arduino device.

4.3 System Prototype

Different hardware components of the solution were connected in a lab setting so as to test the functionality of the system. Figure 10 show the system prototype image.

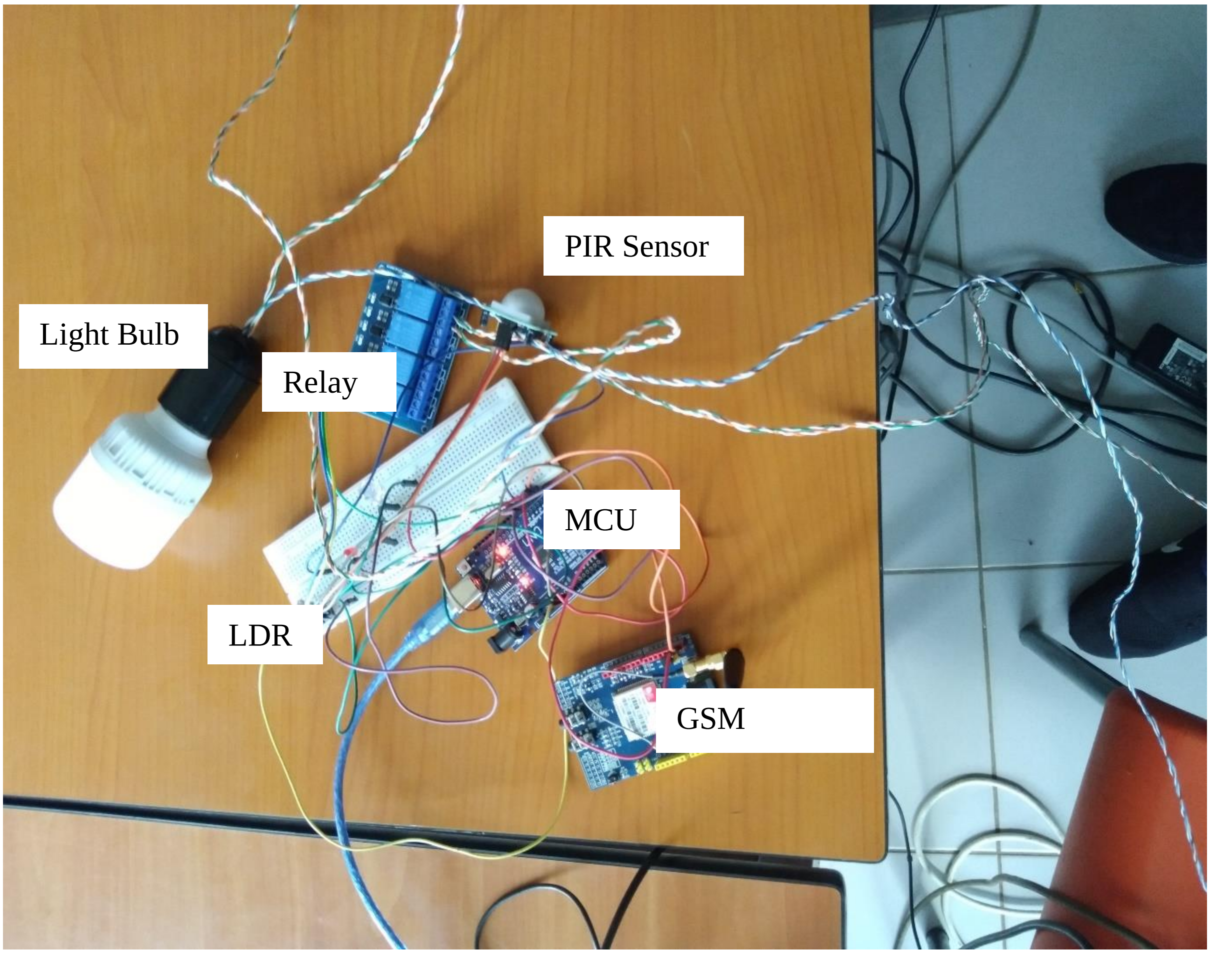

Figure 13: System Prototype

The LDR and the PIR sensors form the main sensing unit. The LDR monitors light intensity while the PIR sensor is able to detect motion. The readings from these sensors form inputs to the FIS in which different rules are applied based on the readings from the sensors. The result of the fuzzification process gives an output if the voltage that is supplied to the relay which in turn actuates the bulb in controlling the street lights. The LDR is also used to determine in the bulb is on or not and incase an anomaly is detected. An sms is sent via the GSM module to the users an immediate action.

CHAPTER 5: RESULTS AND DISCUSSION

In this section the results for the solution are presented, the results from the FIS are first given and discussed, this is followed by the simulation results and there after the results from the prototype. A discussion on the objectives and an analysis of the system performance are also presented.

5.1 FIS Results

The surface viewer shows in figure 11 gives a plot of the results under different conditions. When there is no motion is detected and there is too much light especially during the day the output voltage is 0 indicating the lights will be OFF. As it becomes darker the lighting moves from off to DIM and become brightest when completely dart and there are motions that have been detected.

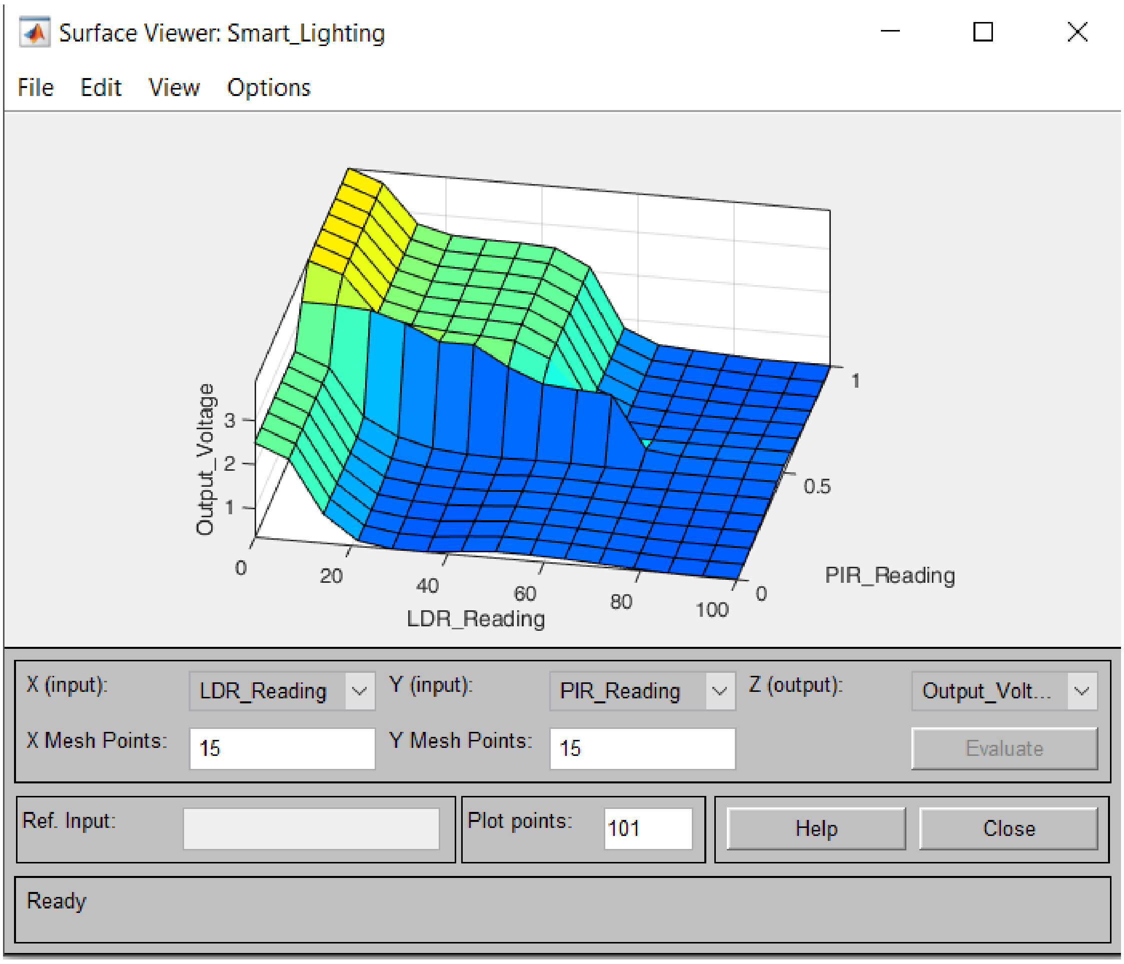

Figure 14: Surface viewer showing the results

5.3 Comparison of FIS results in different platforms

After the design of the FIS it was tested in MATLAB, simulated on proteus and also tested on an Arduino UNO. A comparison was done and I was found out that the results of the output did not change in all the tested platforms. This proves that the use of an embedded fuzzy logic system does not affect the working of a FIS. Figures 12, 13 and 14 give the results from different platforms while using the same inputs.

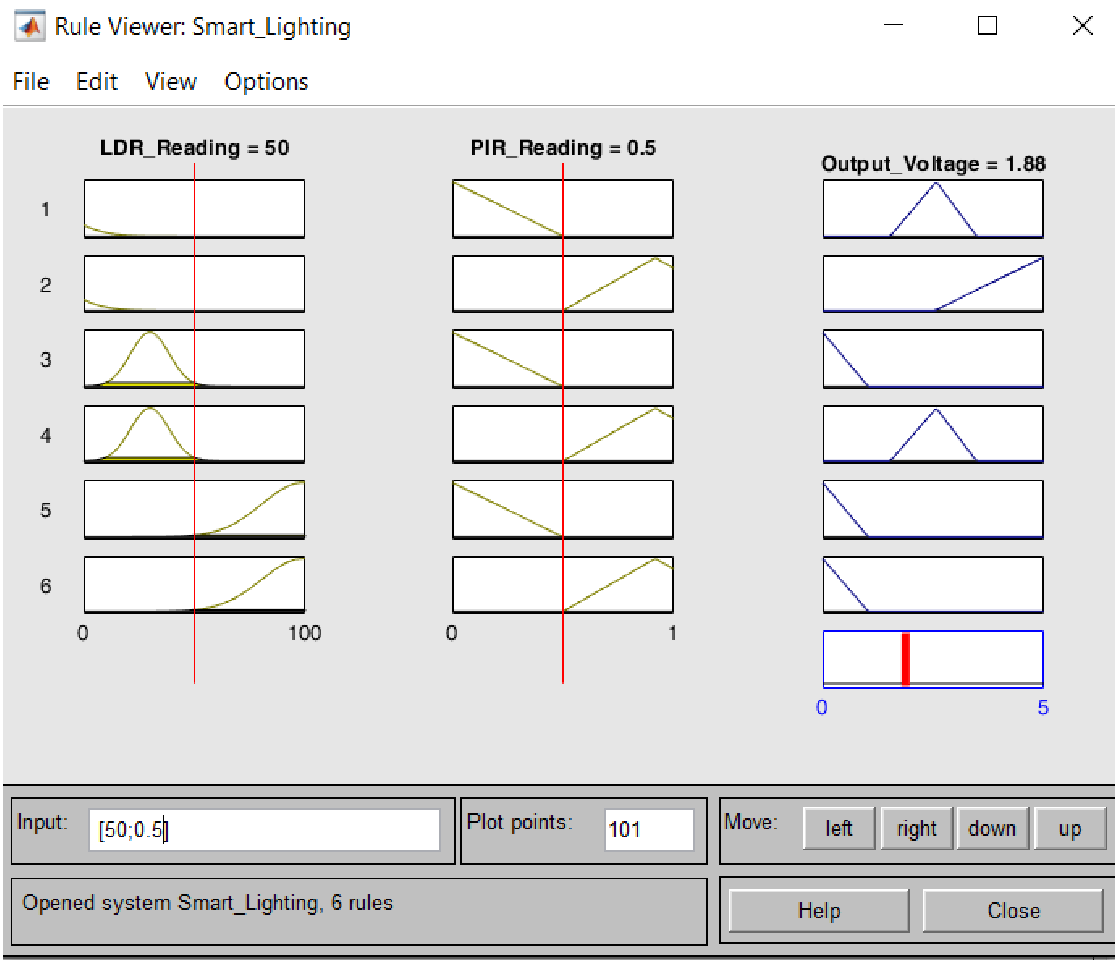

Figure 15: FIS Results on the cloud platform

The converted FIS code for Arduino was compiled and an HEX generated for testing and implementation on proteus design suit. The same input values supplied on matlab rule viewer were also supplied as sensor reading in the Arduino forming the Arduino FIS inputs. The diffuzzication results were the same in both platforms and on Arduino Uno.

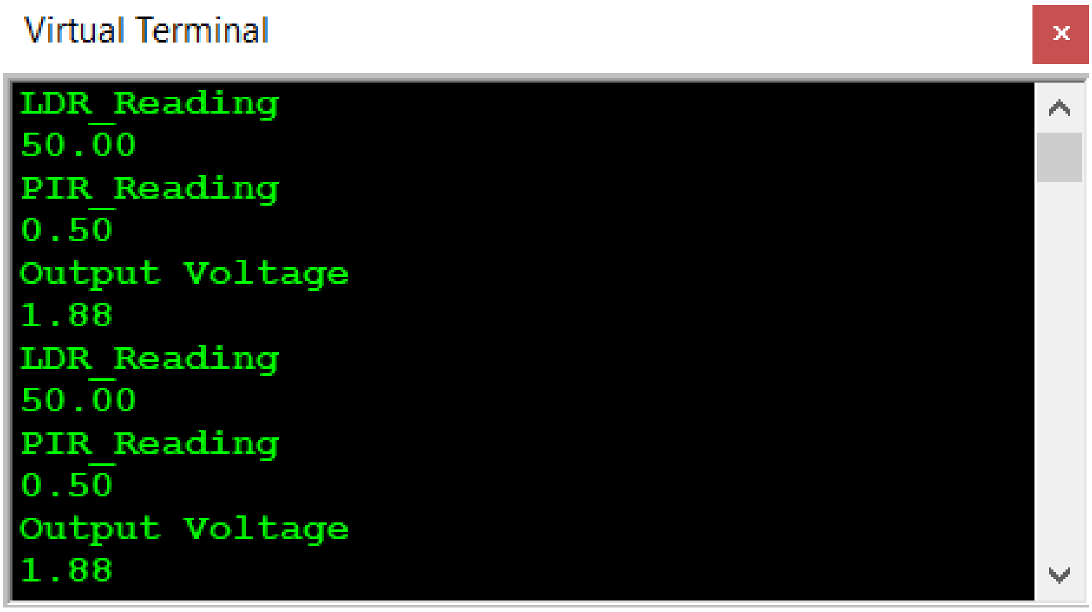

Figure 16: FIS Results from proteus simulation

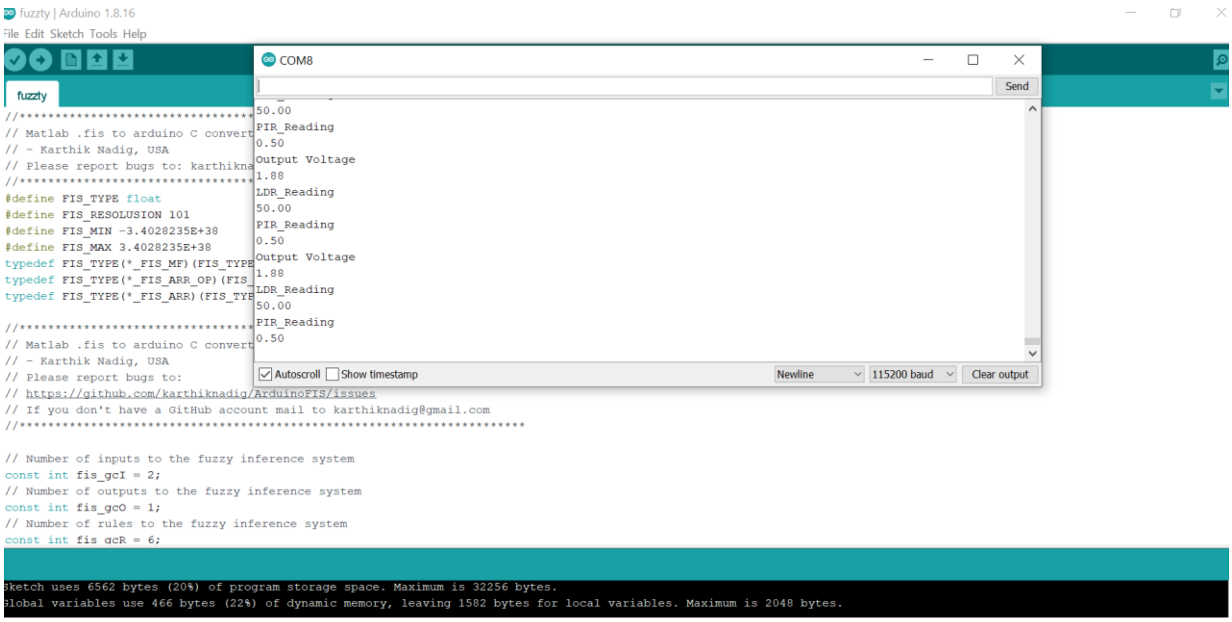

Figure 17: FIS results on the Arduino board

5.4 Simulation Results

From the simulation the torch was used to represent sunlight, as the torch is moved towards the LDR that show more light is detected and it was during the day and so the lights remained off even when motion was detected by the PIR sensor. The toggle pin was used to simulate the detection and non-detection of motion by the PIR sensor.

When the torch was moved away from the LDR, as representation of darkness, and the toggle changed to 1, a representation of motion detected. The LED and the Lamp were on representing the automatic switching on of the street lights as shown in figure 14.

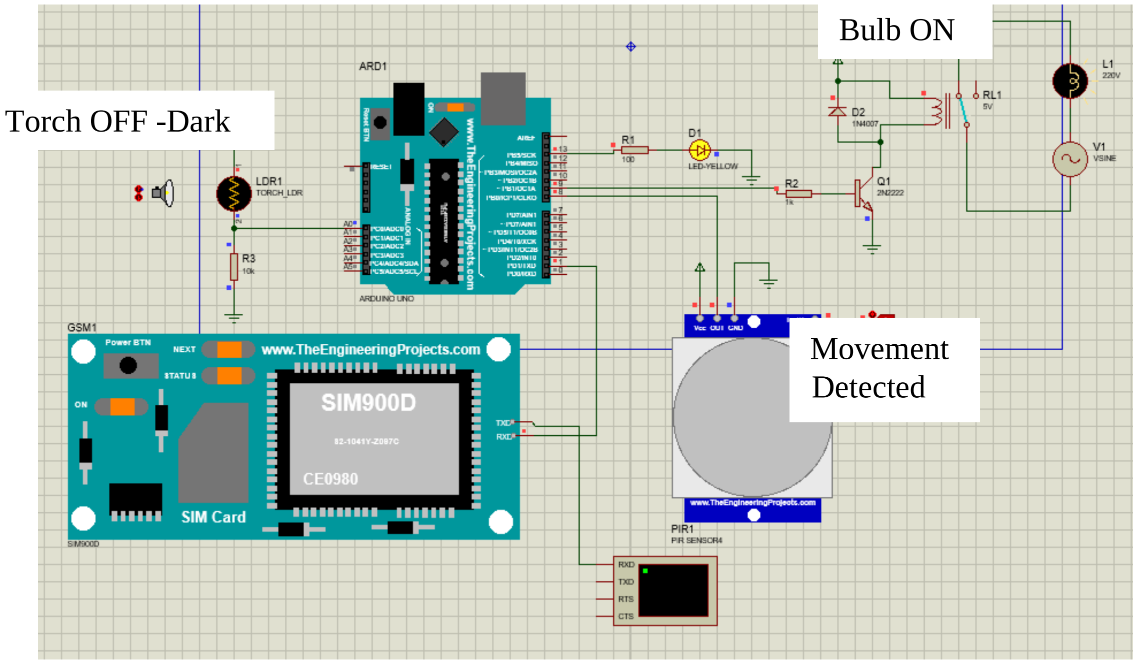

Figure 18: Simulation results

5.5 Prototype results

After setting up the system different scenarios were tested so as to determine the functionality of the solution. The results were accurate and this shows that our objective of embedding fuzzy logic on Arduino was a success. Figure 15 shows the prototype image when the bulb was in an ON mode, the light to the LDR had just been blocked to mimic a night situation and an object moved towards the PIR sensor.

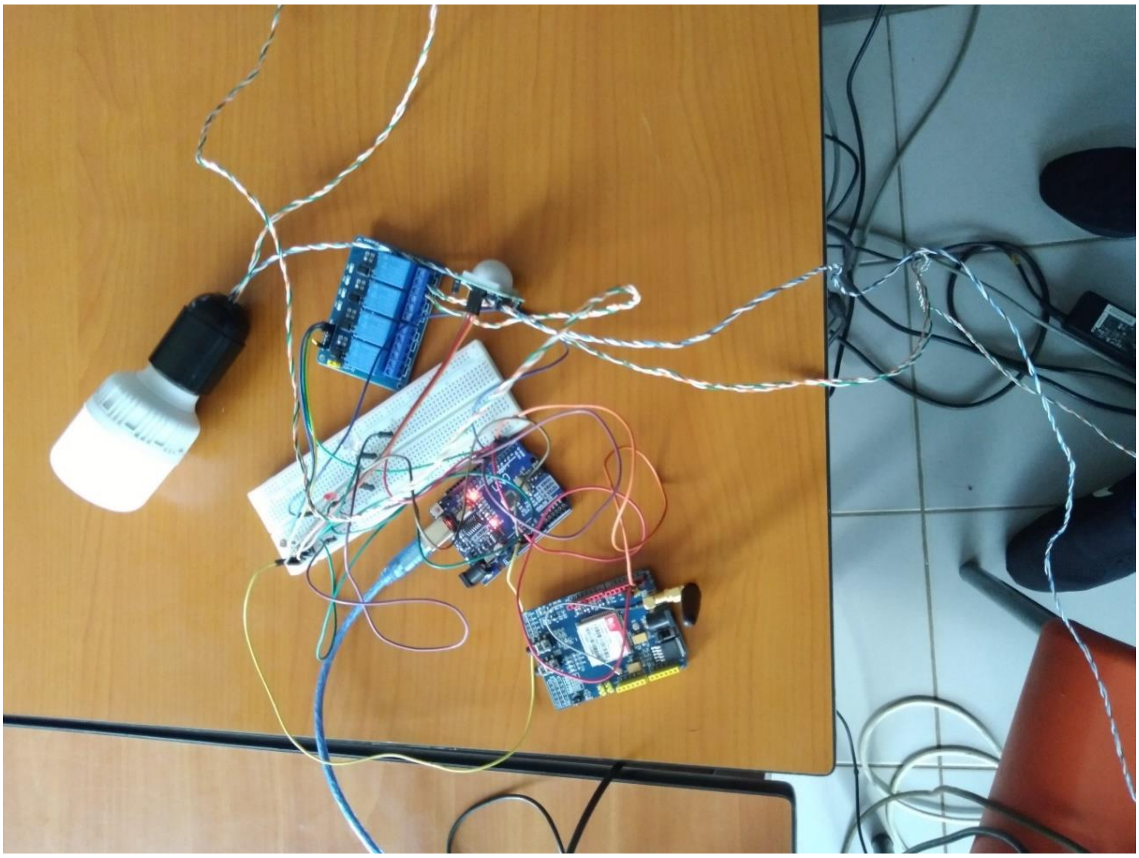

Figure 19: Bulb on an ON mode

5.6 Evaluation on the Objectives

The general objective of this research was to develop a Fuzzy logic driven Arduino based smart street lighting system from smart cities. From the results we were able to meet the general objective. The system was simulated and also prototyped and the results show that a FIS can be implemented on Arduino to control street lights based on the predefined rules and sensed conditions.

On specific objectives we also met each of the objectives as follows

- To investigate the existing techniques used in smart street lighting solutions.
  A comprehensive state of the art analysis was done so as to find out the techniques applied in smart street lighting solutions. The major techniques included, use of timers to set when light come on and off, use of remotely controlled switches and applications to switch the lights on and off, use of different sensing technologies to switch on the lights on and off based on thresholds and use of cloud based fuzzy solutions. For our cases we chose to apply the use of sensing technologies and as an improvement to the solutions implemented the FIS on the device.

- To find out the parameters necessary for context aware street lighting.

  Some of the parameters that were necessary for a context aware street lighting system included; whether there is darkness or not, existence of movement and weather conditions. For our solution we focused on the weather it was dark or not and if movement were detected or not as the main inputs to the FIS with rules being set to determine how light is controlled
- To design a fuzzy-based smart street lighting solution using Arduino.

  We were able to successfully design a fuzzy logic based system and implemented on an Arduino. The FIS was first designed on MATLAB and the converted to an Arduino code for implementation on the embedded device.
- To prototype for a fuzzy logic-driven smart street light.

  We successfully designed, simulated and prototyped the fuzzy logic driven smart street lighting solution.

5.7 Comparison to Existing solutions

As compared to the existing solutions our solution was an improvement in the following way;

(i) As compared to solutions that are either based on time triggers or remote witching on and OFF, our solution is a better solution as it does not depend on human intervention to function. In addition, using timers may be erratic as the light will be kept on for longer periods even if not needed.

(ii) As compared to solutions that monitor existing conditions to determine when to switch on lights based on thresholds, our solution is an improvement since we were able to apply fuzzy rules so as to accurately determine how the light is controlled.

(iii) As compared to other fuzzy based solutions our solution is better since we were able to implement the FIS on Arduino. This makes the solution appropriate to our African setting where connectivity is usually a challenge. Cloud based solution also lead to extra operation costs that we will eliminate with our solution.

Chapter 6: Conclusion, Recommendation and Future Directives

Street lights do play an important role in any city in the world. So as to avoid energy wastages there is a move toward the implementation of smart street lights. Such street light systems are mainly controlled on the basis of a combination of sensor technologies. However, most of the current systems in Kigali are based on thresholds which may lead to errors leading to increased costs and energy wastages.

In this thesis therefore we successfully designed, simulated and prototyped an embedded fuzzy logic driven smart street lighting solution with an aim of solving the problem of having lights on when not needed.

Our study is an improvement to existing solutions in the following ways; (i) For the system to operate no human intervention is needed, (ii) The system monitors the surrounding environment to determine when the lights can be switched on and off, (iii) The solution applies the use of fuzzy logic as opposed to using thresholds to further reduce on energy consumptions, (iv) we implemented the FIS on an Arduino leading to reduced cost of connectivity needed by cloud-based solutions.

The implementation of this solution will indeed lead to saving on cost and energy and thus go a long way towards the attainment of sustainable development goals.

We would like to recommend that the solution should be implemented for further testing and improvement. So as to improve accuracies more powerful sensors for detecting movements can also be applied.

Future works will involve testing the applicability of other sensors with an aim of improving the accuracy of the solution. This project can further be extended and implemented for smart street light control in a city, lighting control in homes and offices and also in industries so as to reduce energy wastages in many areas.

References

[1] D.-I. Curiac and C. Volosencu, “Hierarchical Lighting Control in Urban Environments Based on Wireless Sensor-Actuator Networks,” Accessed: Nov. 24, 2021. [Online]. Available: http://www.aut.upt.ro/~curiachttp://www.aut.upt.ro/~cvolos.

[2] R. H. Abiyev, M. Ma’Aitah, and B. Sonyel, “Fuzzy Logic Traffic Lights Control (FLTLC),” *ACM Int. Conf. Proceeding Ser.*, pp. 233–238, Dec. 2017, doi: 10.1145/3175536.3175572.

[3] A. Priyanga, V. Sivaranjani, S. Subashini, and R. Ezhilarasi, “Street Lighting System using ZigBee Network of Devices and Sensors,” *Wirel. Commun.*, vol. 7, no. 3, pp. 78–80, 2015, Accessed: Nov. 24, 2021. [Online]. Available: http://www.ciitresearch.org/dl/index.php/wc/article/view/WC032015004.

[4] “[PDF] Introduction of Traffic Light Controller with Fuzzy Control System | Semantic Scholar.” https://www.semanticscholar.org/paper/Introduction-of-Traffic-Light-Controller-with-Fuzzy-Mehan/dfb997717aeb30f4032033247cd43aac291e39c0 (accessed Nov. 24, 2021).

[5] Y. Perwej, M. Ahmed, B. Kerim, and H. Ali, “An Extended Review on Internet of Things (IoT) and its Promising Applications,” *Commun. Appl. Electron.*, vol. 7, no. 26, pp. 8–22, Feb. 2019, doi: 10.5120/CAE2019652812.

[6] “Fuzzy Logic - an overview | ScienceDirect Topics.” https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/fuzzy-logic (accessed Nov. 24, 2021).

[7] K. Mittal, A. Jain, K. S. Vaisla, O. Castillo, and J. Kacprzyk, “A comprehensive review on type 2 fuzzy logic applications: Past, present and future,” *Eng. Appl. Artif. Intell.*, vol. 95, p. 103916, Oct. 2020, doi: 10.1016/J.ENGAPPAI.2020.103916.

[8] P. W. Mutua and M. Mbuthia, “Intelligent Multi-coloured Lighting System Design with Fuzzy Logic Controller,” *Aptikom J. Comput. Sci. Inf. Technol.*, vol. 1, no. 3, pp. 128–140, Nov. 2016, doi: 10.11591/APTIKOM.J.CSIT.121.

[9] M. Füchtenhans, E. H. Grosse, and C. H. Glock, “Smart lighting systems: state-of-the-

art and potential applications in warehouse order picking," *Int. J. Prod. Res.*, vol. 59, no. 12, pp. 3817–3839, 2021, doi: 10.1080/00207543.2021.1897177.

[10] "Smart Cities—Opportunities and Challenges: Select Proceedings of ICSC 2019 - Google Books." https://books.google.co.ke/books?hl=en&lr=&id=gJneDwAAQBAJ&oi=fnd&pg=PA29&dq=automatic+lighting+control&ots=PX0QKBFFnr&sig=gEfY8smcED_zVf7Kn5USWTBDBWk&redir_esc=y#v=onepage&q=automatic lighting control&f=false (accessed Nov. 24, 2021).

[11] L. P. Maguluri, Y. S. V. Sorapalli, L. K. Nakkala, and V. Tallari, "Smart street lights using IoT," *Proc. 2017 3rd Int. Conf. Appl. Theor. Comput. Commun. Technol. iCATccT 2017*, vol. 3, no. 11, pp. 126–131, 2018, doi: 10.1109/ICATCCT.2017.8389119.

[12] A. Adriansyah, A. W. Dani, and G. I. Nugraha, "Automation Control and Monitoring of Public Street Lighting System based on Internet of Things," pp. 231–236, 2017.

[13] M. C. Viola, S. Mary, G. P. Devaraj, D. J. Pushparaj, and J. M. Esther, "Intelligent Energy Efficient Street Light Controlling System based on IoT for Smart City," *2018 Int. Conf. Smart Syst. Inven. Technol.*, no. Icssit, pp. 551–554, 2018, doi: 10.1109/ICSSIT.2018.8748324.

[14] M. Saifuzzaman and N. N. Moon, "IoT Based Street Lighting And Traffic Management System," pp. 21–23, 2017.

[15] N. T. Tung *et al.*, "Development and Implementation of Smart Street Lighting System based on Lora Technology," *2019 Int. Symp. Electr. Electron. Eng.*, pp. 328–333, 2019.

[16] R. Prasad, "Energy Efficient Smart Street Lighting System in Nagpur Smart City using IoT – A Case Study," pp. 100–103, 2020.

[17] M. Kuzlu and M. Pipattanasomporn, "A LoRa-based Smart Streetlighting System for Smart Cities," pp. 66–70, 2019.

[18] S. Chen and F. Wang, "The Smart Street Lighting System Based on NB-IoT," *2018*

Chinese Autom. Congr., pp. 1196–1200, 2018, doi: 10.1109/CAC.2018.8623281.

[19] Institute of Electrical and Electronics Engineers, Institute of Electrical and Electronics Engineers. India Council, and IEEE Circuits and Systems Society. India Chapter, "ICCS 2017 : IEEE International Conference on Circuits and Systems : 20th & 21st Dec 2017," no. Iccs, pp. 76–81, 2017.

[20] I. O. P. C. Series and M. Science, "Optimizing public street lighting and redesign of public road lighting based on DIALux and fuzzy logic Optimizing public street lighting and redesign of public road lighting based on DIALux and fuzzy logic," 2021, doi: 10.1088/1757-899X/1098/4/042013.

[21] P. Mohandas, J. Sheebha, A. Dhanaraj, and X. Gao, "Arti fi cial Neural Network based Smart and Energy E ffi cient Street Lighting System : A Case Study for Residential area in Hosur," vol. 48, no. March, 2019, doi: 10.1016/j.scs.2019.101499.

[22] A. Afiq *et al.*, "Development of an Intelligence Street Light Using Fuzzy Logic in Control System," vol. 1, no. 1, pp. 1–5, 2020.

[23] M. Wadi, "Smart Hybrid Wind-Solar Street Lighting System Fuzzy Based Approach : Case Study Istanbul-Turkey," *2018 6th Int. Istanbul Smart Grids Cities Congr. Fair*, pp. 71–75, 2018.

[24] T. Y. Kim and N. H. Park, "Design of Path Prediction Smart Street Lighting System on the Internet of Things," vol. 12, no. 1, pp. 14–19, 2019.

[25] G. Chiesa, D. Di Vita, A. Ghadirzadeh, A. H. Muñoz Herrera, and J. C. Leon Rodriguez, "A fuzzy-logic IoT lighting and shading control system for smart buildings," *Autom. Constr.*, vol. 120, no. August, p. 103397, 2020, doi: 10.1016/j.autcon.2020.103397.

[26] "Light Dependent Resistor LDR, Photoresistor » Electronics Notes." https://www.electronics-notes.com/articles/electronic_components/resistors/light-dependent-resistor-ldr.php (accessed Nov. 24, 2021).

[27] "Overview | PIR Motion Sensor | Adafruit Learning System." https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor (accessed Nov.

24, 2021).

[28] “Arduino Uno Rev3 — Arduino Official Store.” https://store.arduino.cc/products/arduino-uno-rev3 (accessed Nov. 24, 2021).