IoT Based Light Control System Using Adaptive Neuro-fuzzy System

By: Abdurrahman Abdella Alle

A Thesis Submitted to the Department of Computer Science and Engineering

Presented in Partial Fulfillment for the Degree of Master of Science in Computer Science and Engineering

School of Electrical Engineering and Computing

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Statement of declaration

I, ***Abdurrahman Abdella*** do hereby declare that this research work is my own and has not been submitted for any other degree award before, and all other materials used have been duly acknowledged.

Declared by:

Name: **Abdurrahman Abdella**

Signature: ______________________________

Date: __________________________________

Confirmed by Advisor:

Name: **Dr. Ketema Adere (Assis Prof)**

Signature: _________________

Date: ___________________

Approval of the Board

We, the members of the board of examiners of the final open defense by **Abdurrahman Abdella,** have read and evaluated his/her thesis entitled "**IoT Based Light Control System Using Adaptive Neuro-fuzzy System**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters in Computer Science and Engineering (MSC).

Dr. Ketema Adere (Ass. Pro)	______________________	____________________
(Advisor)	Signature	Date
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Chairperson	Signature	Date
______________________________	______________________	____________________
Internal Examiner	Signature	Date
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External Examiner	Signature	Date

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Abbreviation

ANFIS - Adaptive Neuro Fuzzy Inference System

ANN - Artificial Neural Network

Dsigmf - Difference sigmoid member function

FIS – Fuzzy Inference System

Gaussmf - Gaussian member function

Gbellmf - Generalized Bell Member Function

GSM - Global System for Mobile communication

IDE - Integrated Development Environment

IoT - Internet of Things

LDR- Light Dependent Resistor

LM35- Linear Monolithic series Temperature Sensor

MAE - Mean Absolute Error

MF - Member Function

PIR- Passive Infrared Motion Sensor

RFID - Radio Frequency Identification

RMSE - Root Mean Square Error

Trapmf – Trapezoidal member function

Trimf - Triangular member Function

Abstract

In the past, few works have been done to automate home appliances using IoT and machine learning technologies. About 20% of a home's use of energy goes to lighting, therefore, improving the energy consumption of buildings for a large saving can be achieved by reducing the electricity usage and improving the way to control them, The need for high-quality and intelligent systems that can monitor and control home devices such as light control is required.

The most efficient way to keep down the electricity use and improve the energy consumption is to implement control of electrical lights based on the presence of occupants, in manual operation People always forget to switch off their light whenever power is gone while using it, to solve this, An Adaptive neuro-Fuzzy Inference System (ANFIS) which is a hybrid combination of Neural network and fuzzy logic, thus having the advantage of both, as a neural network which is good at computing a model to be adaptive by learning from the data, and, fuzzy logic is good at reasoning and decision making. ANFIS is proposed in this thesis to model the parameter such as light intensity, temperature and, motion detection as an input to the model and Light chance as output, each having three membership function Such as High, Medium, and Low (3 3 3), and, MF Type of trimf, trapmf, gbellmf, gaussmf, and digmf with an output type of linear. The model is trained using a hybrid of feedforward and backpropagation optimization algorithm, and which consists of sensors that collect data from the sensor where Fuzzy logic converts the raw data in a linguistic variable that is trained in an adaptive neuro-fuzzy Inference System to get trained model with $3^3 = 27$ Rules.

In the proposed system we used a data set collected using sensors such as PIR, for detecting motion, Lm35 for Collecting Temperature and, LDR for collecting Light data in the room, a total data of **1506, which is** collected from sensors embedded with Arduino micro-controller, out of which **70%** the dataset was used for the training set, the remaining **30% (15%** the data was used for the testing set, and **15%** was used for checking set). The designed controller is based on Adaptive Neuro-fuzzy Inference System to control the light in the room. Based on evaluation test cases results were analyzed and achieved Training error in RMSE = *0.07434*, and average testing Error = *0.273674* was achieved, to achieve the goal and the objective of the system. MATLAB/Simulink-based simulation is used for the experiments and the results show a satisfactory output.

Keywords: Internet of things, fuzzy, neural network, automation, Sensor, ANFIS, MATLAB

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Chapter One: Introduction

1.1. Background of the Study

Today people are looking at ways and means to make their life-style better using the latest technologies that are available. It becomes inevitable to have easy and convenient methods and means to control and operate these appliances. Conventional wall switches that are located in different parts of a house and thus necessitates manual operations like to switch on or off these switches to control various appliances [36], [37]. It gets impossible to manually do these activities for handicapped, old aged, for the sick, and even for a tired person. the problem with the traditional methods used for control home electrical appliances are manual switches that are operated only when we are near them to switch ON/OFF them. In every one of our homes, the electrical equipment is almost always plugged in even while it is not in use, there still has the flow of electricity. Moreover, that may also cause accidents in our absence such as the conflagration, an extensive fire which destroys a great deal of property, resources, even life, from an electrical short circuit. Therefore, many people who always forget to unplug the electrical device have to remind themselves every time they go out. On the other hand, if they go out with forgetting to unplug, they must go home to pull the plug out to avoid dangerous situations, so it is a waste of so much time. again, with traditional methods, the energy consumption, easy control of appliance is not possible. Recently, as Dubois M, Blomsterberg cited in a literature review of energy saving for electric lighting, they show that 80% to 90% of energy is consumed in office and home appliances and as well it have an impact on environment while operating the lighting system in northern Europe [1].

Therefore, improving the energy consumption of buildings for a large saving can be achieved by reducing the electricity usage during operation of the lighting systems, which can be accomplished using existing technology. The most efficient way to keep down the electricity use is to implement control of electrical lights based on presence of occupants [3].

There has been extensive research toward developing smart home automation environments by integrating the internet of things with various machine learning and artificial intelligence techniques into home automation environments that are equipped with sensors and actuators [10]. “Smart Home technology started for more than a decade to introduce the concept of networking devices and equipment in the house and the integration of technology and services through home networking for a better quality of living” [10]. A smart home is a very promising area, which has different benefits such as providing increased comfort, greater safety and security, more rational use of energy, and other resources thus contributing to significant savings.

This research application domain is very important and will increase over time as it also offers a means for helping and supporting the special needs of the elderly and people with disabilities [11]. According to [13], Figure-1.1 shows the primary objectives of a Smart Home are to increase home automation, simplify energy management, and reduce environmental releases. Energy consumption and occupants' comfort are key factors when assessing smart home environments in figure 1.1 [14].

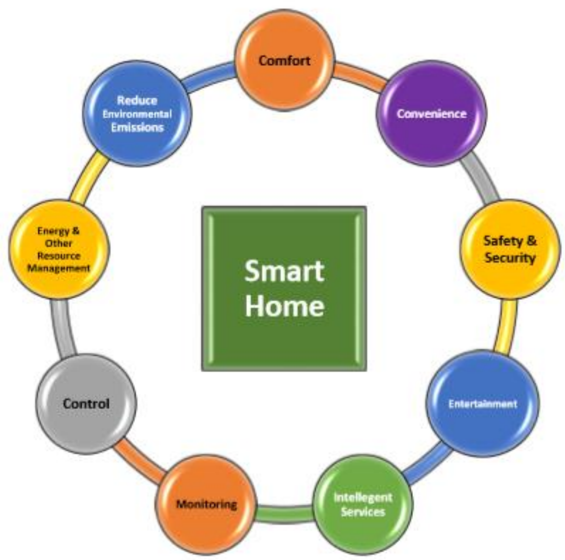

Figure 1.1 Smart home Objectives

For a long time, people have lived in places that provide shelter, basic comfort, and support, but as a society, we live in getting change and technology advance there is a growing interest in improving the intelligence of the environments in which we live and work. A smart home environment is an environment that acquires and applies knowledge about the physical setting and its residents, to improve their experience in the setting. A smart home environment can be treated as an intelligent agent, which perceives the state of the environment using sensors and acts upon the environment using device controllers in a way that can optimize several different goals including maximizing comfort of the residents, minimizing the consumption of resources, and maintaining the safety of the environment and its residents.

Power consumption prediction has remained a concern for power generation companies due to the growing demand for energy caused by the rapid increase in the world population. Scientists believe that if energy consumption is not controlled, it may lead to an energy shortfall after a few years. There are two options to deal with the shortfall of energy: (1) Producing more energy, or (2) minimizing the consumption of already available energy resources and reducing the wastage. The production of energy is a very costly solution to the problem, which requires a lot of time and resources, but on the other hand, by taking some pre-emptive measures, energy consumption minimization can be achieved.

The primary objectives of this thesis are to minimize energy consumption and to increase the comfort of the resident. By having this automated smart home we will have minimum energy consumption and reduced monthly bill of electricity. *Energy consumption* and *occupants' comfort* are key factors when making smart home environments.

The other thing that will be done in this thesis is, we will apply the machine learning technique to make the *system smarter and adaptive* to the users' activities. This can be achieved by using the system to learn from the daily activity of the occupants and adjust itself to that behavior. In the same way, the light sensor senses the intensity of light and turn on the light based on the intensity if it was dark or turn off the light, whenever it is not necessary.

1.1 Motivation

First and foremost, What motivated me to do this research is the problem with the traditional methods used for control home electrical appliances are manual switches that are operated only when we are near them to switch ON/OFF them. In every one of our homes, the electrical equipment is almost always plugged in even while it is not in use, there still has the flow of electricity. Moreover, that may also cause accidents in our absence such as the conflagration, an extensive fire which destroys a great deal of property, resources, even life, from an electrical short circuit. Therefore, many people who always forget to unplug the electrical device have to remind themselves every time they go out. On the other hand, if they go out with forgetting to unplug, they must go home to pull the plug out to avoid dangerous situations, so it is a waste of so much time. However, with traditional methods, the energy consumption, easy control of appliance is not possible [35].

Secondly, the desire to apply the knowledge acquired through education in a problem that happens in our daily life and trying to make life simple.

The potential benefits to automating daily activities give much hope for elder adults and people with disabilities for living independent lives at home.

To avoid manually operating the switches ON/OFF, to help these people with disabilities as well as to use this technology for having a smart life and enjoying in our smart environment. One solution is making our home smarter using this *IoT based Light control using Adaptive Neuro-Fuzzy System*.

1.2 Statement of the Problem

Today people are looking at ways and means to make their life-style better using the latest technologies that are available. It becomes inevitable to have easy and convenient methods and means to control and operate these appliances. Conventional wall switches that are located in different parts of a house and thus necessitates manual operations like to switch on or off these switches to control various appliances [36], [37]. It gets impossible to manually do these activities for handicapped, old aged, for the sick, and even for a tired person. the problem with the traditional methods used for control home electrical appliances are manual switches that are operated only when we are near them to switch ON/OFF them. In every one of our homes, the electrical equipment is almost always plugged in even while it is not in use, there still has the flow of electricity. Moreover, that may also cause accidents in our absence such as the conflagration, an extensive fire which destroys a great deal of property, resources, even life, from an electrical short circuit. Therefore, many people who always forget to unplug the electrical device have to remind themselves every time they go out. On the other hand, if they go out with forgetting to unplug, they must go home to pull the plug out to avoid dangerous situations, so it is a waste of so much time. again, with traditional methods, the energy consumption, easy control of appliance is not possible. If automation was to be used in homes then everyday life would be get eased in a way that can optimize several different goals including maximizing comfort of the residents, minimizing the consumption of resources, and maintaining the safety of the environment and its residents[9, 14].

The above-mentioned challenges and problems occurred in our daily lives so this proposed system is needed to provide a solution to the problem

Research Question:

Therefore, the research will get an answer to the following questions:

- ✓ How Adaptive Neuro Fuzzy Inference System can be used to design and develop an automated light control?
- ✓ How a prototype can be developed based on this model?
- ✓ How to evaluate and test the system?

1.3 Objectives

General Objective

The general objective of the thesis is to develop an automatic control of light using the Adaptive neuro-fuzzy system (ANFIS) While Saving Energy Consumption

Specific Objective

To accomplish the above stated general objective the following specific objectives will be carried out.

- ✓ To develop a model and prototype to control light using Neuro Fuzzy Inference System
- ✓ To simulate the developed prototype
- ✓ To evaluate and test the system

1.4 Methodologies

To be able to answer the research questions stated above, there is a need to choose an appropriate research methodology. To achieve the objective of the study Internet of things and machine learning neuro-fuzzy algorithms will be used.

Relevant literature related to the topic from journals, articles, conference thesis, resources from internet that are related to the Internet of things, Smart home automation System, Smart city, Besides documents related to the topic will be reviewed to assess what others have done in this area and to understand the problem better. The materials and tools as well as different algorithms that will be used for the success of this thesis are explained below.

- **Fuzzy system:** It is the system in which relationships are represented explicitly in the form of if-then rules. In this research implementation, it will be used with the learning capability of neural networks to achieve the research goal.
- **Internet of Things:** In this thesis different sensors will be used for the prototype we are going to set up.
- **Arduino** is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards can read the signal that comes from different sensors.
- **Matlab:** will be used to design and simulate the result of the research.

1.5 Scope and Limitations

The scope of this thesis is only limited to create and develop the internet of things based smart home automation system that controls home appliances like light only by making them adaptive to users and the environment using machine learning technique as well as giving recommendations to the users. The complexity of smart services is not the scope of this research thesis. Simple services will be created to demonstrate user control of the smart home and the communication of data but a comprehensive smart home system will not be built. Further, no laboratory environment will be set up. Other home appliances like Television, refrigerator, stove, iron, curtain, door lock, and other security application is not included in this research, the consideration is due to shortage of time available for this research and unavailability of materials, tools and other resources required to conduct the proposed research as well as expensiveness of the cost of materials.

1.6 Application of Results

This technology can be widely adopted in malls, governmental and non-governmental offices in different shops like supermarkets and mostly used in a residential house. There are different kinds of smart home application areas; Smart homes for security, Smart homes for eldercare, Smart homes for healthcare, Smart homes for childcare, smart homes for energy efficiency, and Smart homes for a better life [23].

1.7 Organization of the thesis

Chapter one, Introduction and Background of the study will be explained in detail, Chapter two, Literature review and Related work, Literature from different source of libraries, Chapter three, Methodology, Chapter four, Proposed Solution, Chapter five Implemantation and Result Evaluation, Chapter Six, Conclusion,Recommendation and Future work of the thesis were shown.

Chapter Two

2.1. Literature Review and Related Work

Relevant works of literature related to the topic from journals, articles, conference thesis, resources from the internet that are related to the Internet of things, Smart home automation System, Smart city, smart Parking, Besides documents related to the topic will be reviewed to assess what others have done in this area and to understand the problem better.

These libraries are the most appropriate to the field study and they provide most of the selected venues. They also provide suitable and easy search engine mechanisms that are simple for the spontaneous search of resources in their database based on the combination of the search term.

2.1.1. Inclusion Criteria

- ✓ The study includes both IOT and Fuzzy logic, ANFIS in the area of home automation
- ✓ Appliance control in the home using ANFIS
- ✓ The fuzzy logic control system in home Automation related topics

2.1.2. Exclusion criteria

- ➢ Publication Language is not in other languages than English
- ➢ The publication not related to the proposed system

The research method used in this study involves experiments covered, explains how the system is built and tested. The results of these experiments will be used to draw up results and conclusions. The goal of this research study was to design and develop a system that makes use of neuro-fuzzy logic decisions to monitor light intensity.

Literature in the area of home automation system using the internet of things will be going to be reviewed and discussed. The review covers an overview of the internet of things, application areas of Internet of things, challenges in developing Internet of things, Internet of things communication models, Technologies Used, and discussion on smart home automation system research with special focus on the internet of things. Review facilitates the comparison of existing home automation approaches to the specific solutions that are been employed in this thesis.

2.2. Overview of Internet of Things

The Internet has become a basic need for millions of people who use it for many purposes according to their needs. It is estimated that about 48 percent of the world's population use the Internet [56, 67]. This means half of the population uses the Internet due to its popularity and benefits that are provided to the people via the Internet. While coming to the Things that can be any object or person which can be distinguishable by the real world. That means here things can be both living things like a person, animals; cow, calf, dog, etc. So at this point, things are real objects in this physical or material world. Due to the benefits of the Internet, another field is growing, which allows objects and machines to connect and communicate with each other with the presence of the Internet, called the Internet of Things (IoT) [67]. There are several technologies and sensors used to implement the idea of IoT. The communication technologies which are used to implement the idea of IoT are radio frequency identification (RFID), near field communication (NFC) and wireless sensor network (WSN) [54, 60, 61, and 59].

2.3. Why the Internet of Things

If the idea of connecting objects to each other and the Internet is not new, it is reasonable to ask, why is the Internet of Things a newly popular topic today; From a broad perspective, the confluence of several technologies and market trends is making it possible to interconnect more and smaller devices cheaply and easily [68, 69].

From this perspective, the IoT represents the convergence of a variety of computing and connectivity trends that have been evolving for many decades. At present, a wide range of industry sectors including automotive, healthcare, manufacturing, and home and consumer electronics[68, 69], and well beyond are considering the potential for incorporating IoT technology into their products, services, and operations

2.4. Application Areas of Internet of Things

There are a lot of application areas in which IoT technology is implemented, to make the system to become smart and perform their work smartly. The first area is the ***health care*** domain, The Internet of Things can be beneficial for health care applications [46]. There are many wearable sensing devices available in the market. They are equipped with medical sensors that are capable of measuring different parameters such as the heart rate, pulse, blood pressure, body temperature, respiration rate, and blood glucose levels [46, 48, 51].

[49]Another application is a ***smart home*** because humans use many electronic things like light, refrigerators, microwave ovens, Lights, heaters, and air conditioners at home It involves the control and automation of lighting, heating, ventilation, air conditioning, and security as well as home appliances.

Smart City this domain includes Smart Transportation, smart energy, smart production, and smart home technologies. Smart city solutions promise to alleviate the real problems of people living in cities these days. IoT solutions in the area of Smart City solve traffic congestion problems, reduce noise and pollution, and help make cities cleaner and safer [46],[47],[48].

Smart grids refer to the electric grid which is a network of transmission lines, substations, transformers that deliver electricity from the power plant to your home or business. This automates the distribution system and reduces power pilferage. It uses information about the behaviors of electricity suppliers and consumers in an automated fashion to improve the efficiency, reliability, and economics of electricity [46]. It has been reported that, in 2018, the number of IoT devices will have more than tripled since 2012 and there will be 50 billion devices that will work on the Internet [46, 47, 52].

2.5. Communications Models of Internet of Things

From an operational perspective, it is useful to think about how IoT devices connect and communicate in terms of their technical communication models. In March 2015, the Internet Architecture Board (IAB) released a guiding architectural document for networking of smart objects (RFC 7452), which outlines a framework of four common communication models used by IoT devices [64].

2.5.1. Device-to-Device Communications

The device-to-device communication model represents two or more devices that directly connect and communicate with one another, rather than through an intermediary application server. These devices communicate over many types of networks, including IP networks or the Internet. Often, however, these devices use protocols like Bluetooth, [43] Z-Wave,[44], ZigBee[42] to establish direct device-to-device communications. These device-to-device networks allow devices that adhere to a particular communication protocol to communicate and exchange messages to achieve their function. This communication model is commonly used in applications like home automation systems, which typically use small data packets of information to communicate between devices with relatively low data rate requirements. Residential IoT devices like light bulbs, light switches, thermostats, and door locks normally send small amounts of information to each other (e.g. a door lock status message or turn on light command) in a home automation scenario.

2.5.2. Device-to-Cloud Communications

In a device-to-cloud communication model, the IoT device connects directly to an Internet cloud service like an application service provider to exchange data and control message traffic. This approach frequently takes advantage of existing communications mechanisms like traditional wired Ethernet or Wi-Fi connections to establish a connection between the device and the IP network, which ultimately connects to the cloud service [64].

2.5.3. Device-to-Gateway Model

In the device-to-gateway model, or more typically, the device-to-application-layer gateway (ALG) model, the IoT device connects through an ALG service as a conduit to reach a cloud service. In simpler terms, this means that there is application software operating on a local gateway device, which acts as an intermediary between the device and the cloud service and provides security and other functionality such as data or protocol translation. Several forms of this model are found in consumer devices [64]. In many cases, the local gateway device is a smartphone running an app to communicate with a device and relay data to a cloud service. This is often the model employed with popular consumer items like personal fitness trackers. These devices do not have the native ability to connect directly to a cloud service, so they frequently rely on smartphone app software to serve as an intermediary gateway to connect the fitness device to the cloud [64, 65].

2.5.4. Back-End Data-Sharing Model

The back-end data-sharing model refers to a communication architecture that enables users to export and analyze smart object data from a cloud service in combination with data from other sources. This architecture supports "the [user's] desire for granting access to the uploaded sensor data to third parties" [64, 65]. This approach is an extension of the single device-to-cloud communication model, which can lead to data silos where "IoT devices upload data only to a single application service provider.[64]

2.6. Elements of Internet of Things

IoT provides many benefits and facilities to users. Thus, to use them properly, there is a need for some elements.

Identification: offer an explicit identity for each object within the network. There are two processes in identification; naming and addressing. Naming refers to the name of the object while addressing is the unique address of a specific object. Both terms are very different from each other because two or more objects may have same name but always different and unique address. There are many methods available that provide the naming facility to the objects in the network such as electron products codes (EPC) and ubiquitous codes [91]. To assign the unique address to each object, IPv6 is used. Firstly, IPv4 was used to assign the address but it could not fulfill the need of addressing due to large amount of IoT devices. Therefore, IPv6 is used because it uses 128 bit number addressing scheme.

Sensing: The process of collecting information from objects is known as sensing. The collected information is sent to the storage media. There are many sensing devices to collect the information from objects such as actuators, RFID tags, smart sensors, wearable sensing devices, etc.

Communication: is one of the main purposes of IoT in which different devices are connected to each other and communicate. In communication, devices may send and receive messages, files and other information. There are many technologies that provide facility of communication like Radio Frequency Identification (RFID), Near Field Communication (NFC), Bluetooth, Wi-Fi and Long Term Evolution (LTE) 44, 45, 46].

Computation: is performed on the collected information from the objects by using sensors. It is used to remove unnecessary information that is not needed. Many hardware and software platforms are developed to perform the processing in applications of IoT. For hardware platforms, Audrino, Rasperry Pi and Intel Galileo are used, while, for software platforms, the operating system plays an important role to perform the processing. There are many types of operating systems that are used like Tiny OS, Lite OS, Android, etc [28, 29].

Services: There are four types of services that are provided by the IoT applications. The first one is an identity-related service. It is used to get the identity of objects that have sent the request. Information aggregation is another service whose purpose is to collect all the information from objects. Processing is also performed by the aggregation service. The third service is a collaborative service that makes decisions according to the collected information and sends appropriate responses to the devices. The last service is ubiquitous service, which is used to respond the devices immediately without rigidity about time and place [30, 31].

Semantics: It is the responsibility of IoT to facilitate users by performing their tasks. It is the most important element of IoT to fulfill its responsibilities. It acts like the brain of IoT. It gets all information and makes appropriate decisions to send responses to the devices.

2.7. IoT Architecture

There is no single and general agreement about the architecture of IoT that is agreed on by the whole world and researchers. Implementation of IoT concept is basically depends on its architecture. In the initial phase of research the 3 layer architecture was introduced [92], which have three layers the perception, network and application layers. Many and different architectures have been proposed by different researchers. According to some researches, IoT architecture has three layers, it is a very basic architecture and fulfills the basic idea of IoT. It was proposed in the early stages of development of IoT [93–94]. It has three layers

- ✓ Perception Layer
- ✓ Network Layer
- ✓ Application Layer

But some of the researchers think that IoT consists of four layers of architecture. The fourth layer is considered a support layer that lie between the perception and network layer of IoT conventional architecture [45, 39, 46].

- ✓ Perception Layer
- ✓ Support Layer
- ✓ Network Layer
- ✓ Application Layer

Due to a challenge in IoT, the architecture of five layers has also been proposed.

Three Layer Architecture

It is a very basic architecture and fulfills the basic idea of IoT. It was proposed in the early stages of the development of IoT [92, 93, 94]. It has three layers. The names of these three layers are perception, network, and application layer

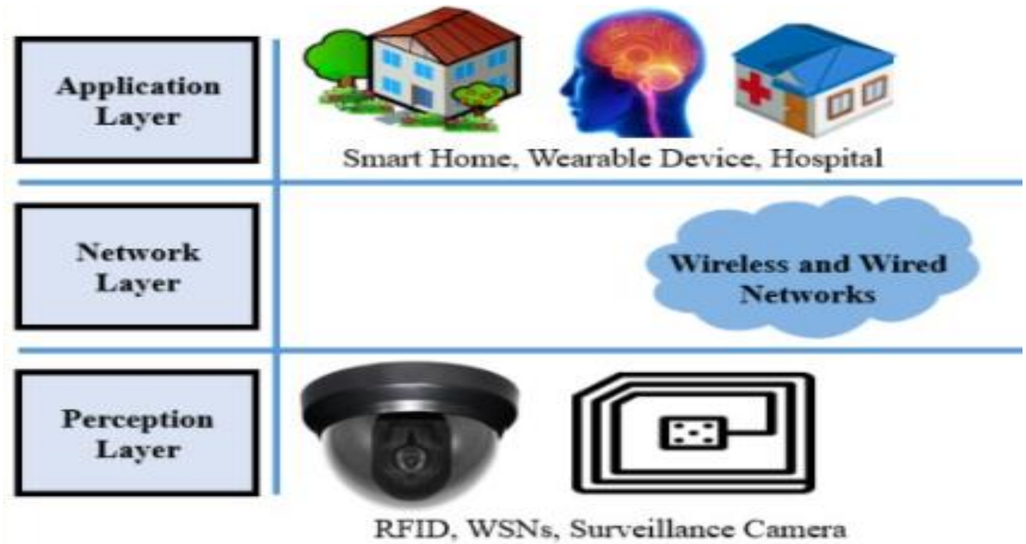

Figure 2: The Three Layered Architecture of IoT [92]

Perception Layer: It is also known as a sensor layer. It works like people's eyes, ears, and nose. It has the responsibility to identify things and collect information from them. There are many types of sensors attached to objects to collect information such as RFID, 2-D barcode, and sensors. The sensors are chosen according to the requirement of applications. The information that is collected by these sensors can be about location, changes in the air, environment, motion, vibration, etc.

Network Layer: The network layer is also known as the transmission layer. It acts as a bridge between the perception layer and the application layer. It carries and transmits the information collected from the physical objects through sensors. The medium for the transmission can be wireless or wire-based. It also takes the responsibility for connecting the smart things, network devices, and networks to each other.

Application Layer: Application layer defines all applications that use the IoT technology or in which IoT has deployed. The applications of IoT can be smart homes, smart cities, smart health, animal tracking, etc. It has the responsibility to provide the services to the applications. The services may be varying for each application because services depend on the information that is collected by sensors. In particular, when IoT is used to make a smart home

2.8. Neural Networks

Artificial Neural Networks are nonlinear mapping systems whose structure is based on the observed human and animal nervous systems; they are mathematical approximations to the human brain function. Nevertheless, they are not directly comparable to the brain, nor are their operation principles, for they do not base themselves solely in biological networks operation, they only emulate a very simple portion of human its functions and are not able to simulate the highly complex relational neurobiological processes that occur within it. Processing units are named neurons. Artificial Neural Networks (from now on Neural Networks) comprise a large number of these processing units, each of which receives weighted input from other units (or nodes) and generates a scalar output depending on the available local information stored internally and the information arriving through the incoming weighted connections.

2.9. Application Area of Neural Networks

System control is the most recent application of Neural Networks and is the field in which most efforts are invested actually. It is also the field in which is developed this study. Applications of Neural Networks are diverse and so are the areas in which they are of use.

The main applications of Neural Networks are those in which the inferring approximation and Use of functions are required via observation or measure, these tasks classify in the following categories:

- Function approximation
- Data classification
- Data processing
- System control

2.10. Adaptive Neuro-Fuzzy Inference Systems

As cited in [10] Adaptive Neuro-Fuzzy Inference Systems (ANFIS) is a class of adaptive neural networks that are functionally equivalent to fuzzy inference systems and offer the combination of learning, adaptability, and nonlinear, time-variant problem-solving characteristics of Artificial Neural Networks plus the important concepts of approximate reasoning and treatment of information provided by the fuzzy set theory.

ANFIS network control systems (or neuro-fuzzy systems) represent a hybrid platform for solving actual complex problems that require the use of intelligent systems and are a viable alternative to the conventional model-based control schemes. They allow dealing effectively with the common issues of uncertainty and unknown variations in plant parameters and structure, hence improving the robustness of the control system [50][51].

As cited in [50], the adaptive neuro-fuzzy inference system (ANFIS) is a type of neural network that is focused on the Takagi–Sugeno fuzzy inference system.

Adaptive neuro-fuzzy inference system (ANFIS), proposed by Jang (1993), is based on the first-order Sugeno fuzzy model. Generally, ANFIS uses either back-propagation or a combination of least square estimation and back-propagation for membership function parameter estimation.

The most significant goal of integrating fuzzy systems with neural networks is to practice the learning ability of neural networks while the learning capability is an improvement from the viewpoint of a fuzzy system, from the perspective of a neural network there are additional Benefits to a combined system.

According to [10], In ANFIS, Takagi–Sugeno type fuzzy inference system is used where the output of each rule can be a linear combination of input variables plus a constant term or can be only a constant term. The final output is the weighted average of every single rule's output. Basic ANFIS architecture that has two inputs x and y and one output z is shown in Figure-2 [10].

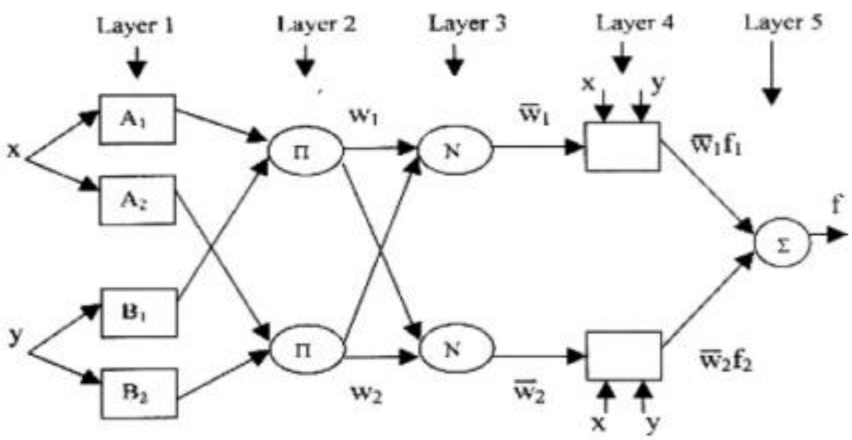

Figure 2.1: Basic ANFIS structure

The rule base contains two Takagi–Sugeno if-then rules as follows: in equation (2.1), (2.2)

Rule 1: If **x** *is* **A1** *and* **y** *is* **B1**, *then, f1* = p1 x+ q1 y + r1--------------- *(2.1)*

Rule 2: If **x** *is* **A2** *and* **y** *is* **B2**, *then, f2* = p2 x+ q2 y + r2……………… *(2.2)*

As cited in [50], by Yilmaz, The neural network structure contains 5 layers excluding the input layer (Layer 0):

(1) Layer 0, input layer, has n nodes where n is the number of inputs to the system.

(2) ***Layer 1*** is the fuzzification layer in which each node represents a membership value to a linguistic term as a Gaussian function with the mean:

Where ai, bi, ci are parameters for the function. These are adaptive parameters. Their values are adapted using the back-propagation algorithm during the Learning stage. As the values of the parameters change, the membership function of the linguistic term Ai changes.

(3) ***In Layer 2***, each node provides the strength of the rule using a multiplication operator. It performs min (AND) operation. The membership values represented by lAi (x0) and lBi (x1) are multiplied to find the firing strength of a rule;

Where the variable x0 has a linguistic value of Ai, and xi has a linguistic value of Bi, in the antecedent part of Rule i. Pn nodes are denoting the number of rules in Layer 2.

Each node represents the antecedent part of the rule (if part of an if-then rule). Here, n is the number of input variables and p is the number of membership functions.

(4) ***Layer 3*** is the normalization layer which normalizes the strength of all rules according to the equation given below:

Where wi is the firing strength of the ith rule which was computed in Layer 2. Node i computes the ratio of the ith rule's firing strength to the sum of all rule's firing strengths. There are pn nodes in this layer.

Layer 4 is a layer of adaptive nodes. Every node in this layer computes a linear function where the function coefficients are adapted by using the error function of the multi-layer feed-forward neural network pi's are the parameters where i =n + 1 and n is the number of inputs to the system (i.e. the number of nodes in Layer 0). This equation was given for two inputs. Finally, wi is the output of Layer 3. These parameters are updated by a learning step. The least-squares approximation is used in ANFIS. In a temporal model, the back-propagation algorithm is used for training.

Layer 5 is the output layer whose function is the summation of net outputs of the nodes in Layer 4. The output is computed as where wifi is the output of node i in Layer 4. It denotes the consequent part of Rule i. The overall output of the neuro-fuzzy system is the summation of the rule consequents.

Li et al. [7] conducted field measurements on daylight control in several cellular offices in a particular office building in Hong Kong [7]. Daylight has the potential to reduce the peak electrical demands and energy consumption related to space cooling. Results showed that with daylight controls an annual electric energy saving of 15.7 kWh/m2 can be achieved compared to conditions without daylight control [7].

2.11. Related Work

The purpose of this part is to establish the scholarly significance of the research problem by showing previous research in the area, to improve my understanding in the area, to update my readers, to find a gap in the literature, and the need for this research.

Publications on IOT based Smart Home from a wide variety of academic publishers, such as Elsevier's Science Direct, Springer, Institute of Electrical and Electronics Engineers (IEEE), Wiley Inter-Science, Human Technology and Institute for Computer Science and Telecommunications Engineering, were identified.

The publications that have occurred from the year 2000 through 2019, were identified through searches of these search engines, i.e. Google Scholar, Scopus, and IEEE Xplore Digital Library. The search terms that were used were '***IoT based light Control system'***, '*Smart Environments', 'smart living', 'intelligent homes', 'Smart Environments'* and ***Fuzzy Logic based Control System***, *'Ambient Intelligence'* '***Neural network***, and combination of both resulting in the selection of more different sources This part presents the previous works done by different authors. Then, it tries to find a research gap to be fulfilled

Fuzzy Logic-based Control System

This thesis describes the design of an intelligent energy-efficient lighting system based on a fuzzy logic controller that uses white LEDs to produce light at the required luminance level in a typical room space. The lighting system incorporates automatic control of a room's window shade opening, conveniently harvesting daylight. The designed lighting system intelligently optimizes the high efficacy LEDs and the natural daylight in illuminating a room to required levels. Electrical energy for lighting the room is used only when the room is occupied and the artificial lighting is required.

As cited in [21], an author has developed an internet-based wireless home automation system for multifunctional devices. A flexible, low cost, wireless solution to home automation is introduced. The thesis discussed the transformation of the control mechanism of devices that had simple functionality in the beginning to more complex devices. All the home appliances are connected through a server to a central node. The system is secured by using the SSL algorithm. During tests, wireless communication was found to be limited to less than 100 meters in a concrete building.

An author in [22], cited that he had developed a prototype electrical device control system using Web. They have developed a web-based controller in place of using a technology like Bluetooth, for controlling electrical devices. Whenever the condition of the server is down they also set their server with auto restart. The system doesn't use mobile technology. This application proved a less effective system.

As cited in [25], Home automation systems using smartphones, Arduino board, and Bluetooth technology which are secured and low cost were developed. The Bluetooth system uses a Personal computer or smartphone as a receiver device. It has a high communication rate, great security, and low cost, so it can be implemented as a real-time system. But Bluetooth network has a limited range of 10 meters if the smartphone is out of range, then it will not be able to control the home appliances, this is one of the main disadvantages of Bluetooth based home automation system [25]. The gap of this system was that it had a limited range of less than 50m in a concreted building and a maximum of 100m range in an open range. The system supports only the Symbian OS cell phones.

The author of [26] also introduces the design and implementation of a less costly, compressed, and secure Android smartphone-based home automation system. A single-chip microcontroller real-time operating system is combined with the system, to increase the receptiveness of the system and make it more dynamic. Here also Bluetooth technology is used by the system. The Bluetooth module is based on the Bluetooth V2.0 protocol and has a range of 10m operating at a frequency of 2.4GHz with a maximum data exchange rate of 2.1Mbps. The problem with this system is that it does not support remote monitoring and controlling of devices.

The author in [23] proposed A voice recognition based home automation system pr and implemented by a researcher. The wireless communication between the smartphone and the Arduino UNO is done through Bluetooth technology. This will be more helpful for handicapped and aged people who want to control appliances by speaking a voice commands. The main drawback of this system is that communication between user and voice recognition tool depends on the signal-to-noise ratio (SNR), if the voice signal is noisy then communication can highly effect and the system will fail to show accuracy.

ZigBee based wireless home automation system has also been studied [28], ZigBee is similar to Bluetooth technology. It is one of the broadly used transceiver standards with low data rates and power. It has a physical range is between 10 to 20 meters, which can increase up to 150 meters by using a direct sequence spread spectrum (DSSS). It is ideal for developing prototypes and research-related activities. The author of [28] cited, the disadvantage of this is that the system does not allow remote monitoring and controlling of appliances.

As cited in [29], In GSM based home automation systems, communication between the main module and appliances is done through text messages. The main drawback of GSM based home automation system is that there is no guarantee text message delivered to the system every time so it is not a reliable system.

A lot of work has been implemented in home automation such as light control, Most of the applications were self-tuning. Almost all of them require a human being to perform the required action in-home, all the systems require more human support and intervention to make final decisions.

Table 2.1 Summary Of Related Work

S.No	Title	Contribution	Gap
1	A Bluetooth based home automation system proposed by R.Piyare and M.Tazil [25].	The highlight of this system is that it doesn't need internet connectivity for appliances that require On-off switching	The problem with this system is that it does not support remote monitoring and controlling of devices
2	A voice recognition based home automation system proposed and implemented by a researcher [23]	This will be more helpful for handicapped and aged people who wants to control appliances by speaking a voice command	If the voice signal is noisy then communication can highly effect and the system will fail to show accuracy.
3	ZigBee based wireless home automation system has also been studied [28],	It supports any kind of microcontroller. The system eliminates the complication of wiring in case of wired automation. A considerable amount of power saving is also possible.	The disadvantage of this is that the system does not allow remote monitoring and

			controlling of appliances
4	A smart home automation system implemented by using Global System for Mobile communication (GSM) [29]	communication between the main module and appliances is done through text messages using a smartphone	There is no guarantee text message delivered to the system every time so it is not a reliable system.
5	Li et al. [7] conducted field measurements on daylight control in several cellular offices in a particular office building in Hong Kong	Daylight has the potential to reduce the peak electrical demands and energy consumption related to space cooling. Results showed that with daylight controls an annual electric energy saving of 15.7 kWh/m2 can be achieved compared to conditions without daylight control	The system does not consider the Presence of Occupant as well as, it only consider cooling system

To overcome this, we will implement IOT based home automation system using a machine learning algorithm and the Internet of things so that the gap mentioned in the literature will be solved by making the System, that automatically performs decision making support for control operations.

CHAPTER 3: Methodology

3.1. Overview

In this chapter, the methods that have been used in this thesis work are stated. It includes modeling, controller design, algorithms, Tools used.

3.2. Procedure of the Study

To attain the objective of the study, the following procedures are undertaken:

- *Literature Review*: Different works of literature that are related to this thesis work have reviewed and different concepts are adopted.
- *System Modeling and Design*: modeling of the system and designing an appropriate Neuro-fuzzy logic controller for the system and Arduino microcontroller.
- *Code Writing*: To simulate the overall control system on a fuzzy logic controller, algorithms are developed and programs are written.
- *Simulation*: the proposed systems will be tested and simulated using Matlab/Simulink tools.
- *Validation*: Validation of results obtained from the simulation and performance will be evaluated

3.3. Proposed system method and architecture

To address the problem, automated smart light control is designed in this thesis. It's an efficient appliance monitoring and controlling design using ANFIS as in Figure-3 below.

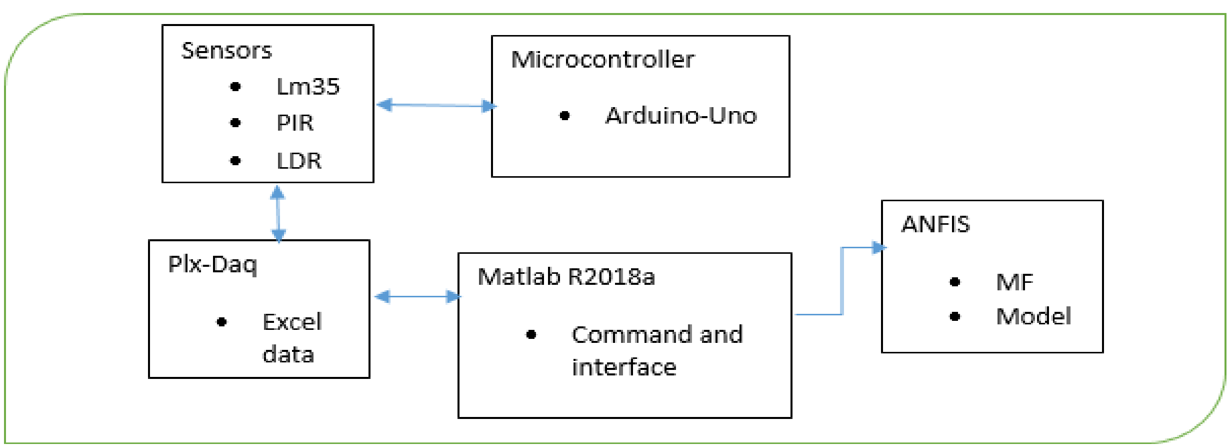

Figure 3.1: Overall Diagram of the Proposed System

Sensing unit: The home automation system consists of sensors that is connected to the Arduino board. The system monitors parameters like temperature level, light intensity, and human presence using LM35, LDR, and PIR sensor.

Decision-making unit: It is responsible for performing the right decision for making the control operation concerning every change taking place in the house, for every change taking place with the sensing unit, based on which the control operation takes place. This is done by adopting a machine-learning algorithm to perform the decision-making operation as per which the changes take place in the hardware.

Control unit: It performs all the control operations concerning every changes happening in the sensing unit. Once the temperature increases more than the threshold level, Motion is detected and, when the light intensity is low the power LED or bulb must be ON and should come back to OFF state when the intensity is high.

The proposed research involves building IoT based automation system using neuro-fuzzy logic for real-time application. An environment made up of tools like hardware, software, and algorithms system. A well-defined methodology will be an important factor to develop the prototype of the proposed home automation system. The proposed system introduces a unique combination of physical and virtual development in which the development of hardware systems and software systems are strongly interconnected.

3.4. Hardware Tools

3.4.1. Sensor Used

Sensors are an electrical/mechanical/chemical device that maps an environmental attribute to qualitative measurement. It provides a usable output in response to a specified measuring input fetches the signal of physical quantities and it converts to the output signal in a usable format for processing. The sensors used in the sensor station were PIR, LM35 sensor, LDR sensor. These sensors were connected to the Arduino inputs. Before looking at the connection of sensors, the sensors are first described.

3.4.3. LM35 Sensor

LM35 is the sensor that is used to measure temperature. In this study, it was used by the sensor unit to measure temperature. The temperature data collected by the LM35 sensor was transmitted to the decision-making station where fuzzy decisions were made to control the Light.

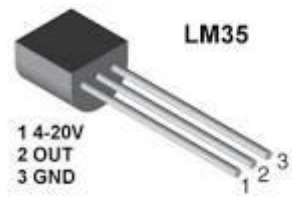

Figure 3.2: LM35 Sensor

3.4.4. LDR sensor

LDR sensor was chosen as the perfect light sensor for detecting the amount of light intensity available in the surrounding environment and or house. The LDR sensor data was transmitted from the sensor station to the decision-making station where fuzzy decisions were made to control the light intensity by switching the bulb on or off as is shown in the following Figure

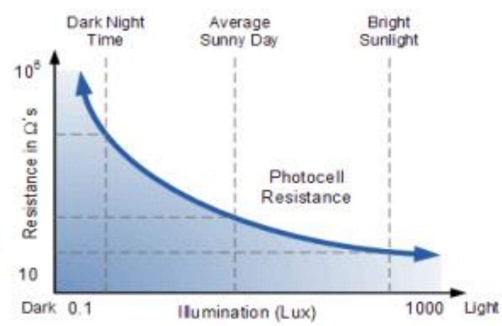

Figure 3.3: (a) LDR Sensor and (b) Characteristic Curve of LDR

3.4.5. Arduino Uno board

Arduino is open-source electronic prototyping of a Micro-controller embedded system. Arduino has hardware and software components to design various electronics systems like home automation, smart parking system, and smart health. The hardware component is a family of ATMEL Arduino development board and the software component contains an open-source IDE (Integrated Development Environment) to design, run, sketch, and upload the code. The circuit board of Arduino is programmed using C or C++ programming language.

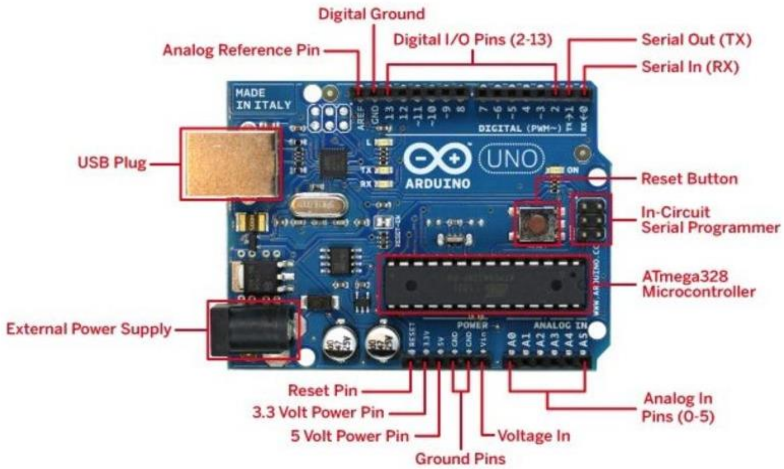

Figure 3.4: Arduino Uno

3.5. Software Tools

Software tools were used to implement the hardware and software. Software's like ***Arduino IDE, MATLAB R2018a, Fritz, Proteus 8 professional, PLX-DAQ***, and **Tera Term** were used. To monitor and control the appliance in real-time software tools must communicate continuously to the hardware tools. To transmit information from the sensor and Arduino to

3.6. Data sources

Collected data are light intensity data based on the detection of motion. This will be done using sensors which will cause actuation depending on the nature of the signal. This data will be sent to a spreadsheet and kept as a record of events. The records can be used to calibrate the system for the best results.

3.7. Data collection techniques

In this study, the physical parameter will be detected by the sensors and will be changed into an analog signal. This analog signal will then be taken to the Arduino board ADC pins which will then be changed over into a proportionate digital signal. The digital signal of the microcontroller will be used in the ANFIS model that will be developed, this Data set will be dumped in an Excel database, or if not the information will be sent to the PC through the USB serial port. The serial port information will then be transported in MATLAB graphical display.

The temperature was measured in degrees Celsius. The collected log data is put in an Excel spreadsheet. To conduct this experiment, an LED/Bulb was used. The sensor was covered to change the signal state. The result was recorded and put for later use. The measured results were given in an analog reading of the microcontroller steps.

3.8. Design and Simulation Method

The toolbox is used to model complex system behaviors using simple logic rules, and then implement these rules in a fuzzy inference system. Additionally, this toolbox used fuzzy inference blocks in Simulink, to compute the membership function, and simulates the ANFIS systems based on the given input/output data.

3.9. Neuro-Fuzzy Designer

For designing, training, and testing of the ANFIS (Adaptive Neuro-fuzzy Inference System) using input-output training data for tuning membership function parameters of Sugeno-type fuzzy inference systems, the first thing is Generating an initial inference system structure based on training data, Modifying the inference system structure before tuning, this helps for preventing over-fitting to the training data using additional checking data will be used, Testing the generalization ability of our tuned system using testing data will also be done, Export your tuned fuzzy inference system to the Mat lab R218a workspace.

3.10. Simulink Model

In this thesis, we develop an ANFIS controller based design program that controls the light using '*If antecedent then consequent'* rule-based system. The performance of the system is simulated using Simulink of the MATLAB Fuzzy Logic toolbox. The program is designed so that to control excess consumption of power, the system can maintain a normal condition and improve the comfort of the resident.

In the thesis, it is used to simulate the FIS model by using the neuro-fuzzy designer app called Simulink. Fuzzy Logic Controller that have a Rule viewer block is used in Simulink to evaluate and simulate the created FIS.

CHAPTER 4: Proposed Solution

4.1. Modeling and Designing Solution

4.1.1. Fuzzy logic Based controller

Fuzzy logic is work based on a mathematical model that deals with uncertainty and imprecise, ambiguous, noisy, or missing input information. It compares an analog input signal to a predetermined logic variable membership function or fuzzy sets that correspond to values in the range 0 and 1. It is implemented in a control system to emulate human-like decisions in control.

4.1.1.1 Fuzzy logic controller structure

The fuzzy logic controller consists of four components: fuzzification interface, knowledgebase, interface engine, and de-fuzzification interface.

The fuzzifier transforms crisp inputs into the fuzzy subsets to obtain degrees of memberships that define them with linguistic terms, which in turn are used to activate rules. The fuzzy inference engine with this data to get the needed output. The de-fuzzifier finally converts them to the fuzzy outputs to gain crisp variables to control objectives. Every fuzzy set can be represented by its membership function. Several different shapes exist depending on the designer's interest. They can be triangular, trapezoidal, Gaussian, bell-shaped, sigmoidal will be used later.

4.1.1.2 Fuzzy interface procedure

Among several techniques for performing the fuzzy interface process the Mamdani method and Takagi-Sugeno_Kang (TSK) method are the most commonly used methods in fuzzy controllers. Mamdani method is usually more popular for most control applications due to its computationally more efficient and has better interpolative properties than the other interface methods. Mamdani fuzzy logic uses the linguistic variables to describe the process states and uses these variables as inputs to control rules. The terms of the linguistic variables are fuzzy sets with a certain shape. Mamdani fuzzy logic usually uses the trapezoidal or triangular fuzzy set but other shapes are possible.

4.1.1.3. Fuzzy logic controller for Light controller system

The electrical light is the most important factor in the automation of electrical energy. Hence, this fuzzy logic-based system is proposed to optimize the system.

4.1.1.3.1. Fuzzy Inference System Modeling

Mamdani and Sugeno systems are created by formulating an input-output mapping by the process of a fuzzy inference system. To achieve this the following process must be followed

1. Create a fuzzy system
2. Specifying fuzzy membership functions
3. Specifying fuzzy rules
4. Evaluate and visualizing the system

4.1.1.3.2. Create a fuzzy system

The Matlab R2018a tools were used for building a fuzzy inference system where the fuzzy logic designer was used to define, membership function editor, rule editor, rule viewer, and surface viewer of the inference system.

To create a Sugeno fuzzy inference system, the fuzzy logic designer was used that enables to decide a number of input and output with their names, *'Lightl'* is a fuzzy light control system with three input that is *'LightIntensity'*, *'Temperature'*, and '*OccupancyDetection'* as well as one output which is '*LightChance'* as in figure-9 below. The following commands were used to work with the Matlab R2018a development framework. The following are some of the Matlab commands from Appendix A, that reads and plots system input and output.

```
a= readfis('lightl');
>> plotfis(a)
```

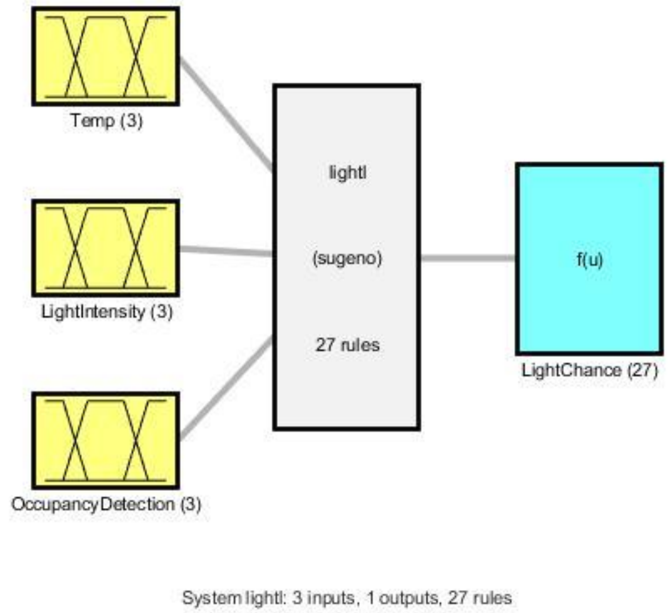

Figure 4.1: Plot FIS system

>> plotmf(a,'input',1)

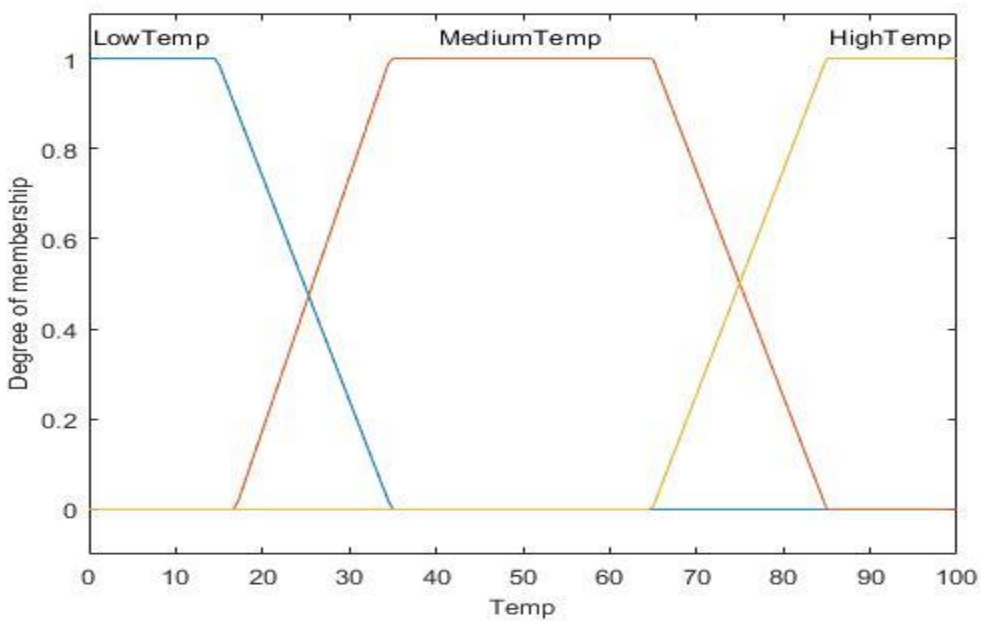

Figure 4.2 : Temperature Input Membership

4.1.1.3.3. Specifying Fuzzy Membership function

The input Membership Function for light intensity are displayed in figure 4.3 below with a membership function *LowIntensity, MediumIntensity, and HighIntensity* where displayed in a Sugeno type trapezoidal membership functions as shown below.

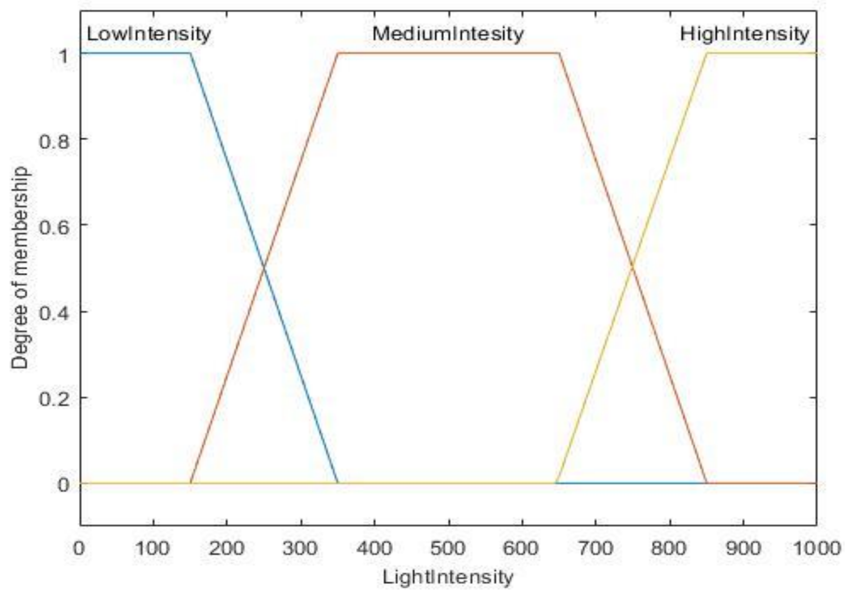

Figure 4.3: Membership function of light Status Variables of FIS

4.1.1.3.4. Fuzzy rules Specification

Based on the specification of the input and output dataset defined, statements of the rule were constructed using rule editor tool. The following are the if-***then*** rules generated in our system.

Using the command, Showrule (a)

ans =

27×101 char array

'1. If (Temp is LowTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'2. If (Temp is LowTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is LessMotion) then (LightChance is Low) (1) '

'3. If (Temp is LowTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is MotionDetected) then (LightChance is Low) (1) '

'4. If (Temp is LowTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'5. If (Temp is LowTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is LessMotion) then (LightChance is Medium) (1) '

'6. If (Temp is LowTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is MotionDetected) then (LightChance is Medium) (1) '

'7. If (Temp is LowTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'8. If (Temp is LowTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is LessMotion) then (LightChance is Medium) (1) '

'9. If (Temp is LowTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is MotionDetected) then (LightChance is High) (1) '

'10. If (Temp is MediumTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'11. If (Temp is MediumTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is LessMotion) then (LightChance is Low) (1) '

'12. If (Temp is MediumTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is MotionDetected) then (LightChance is Low) (1) '

'13. If (Temp is MediumTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is NoMotion) then (LightChance is Medium) (1) '

'14. If (Temp is MediumTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is LessMotion) then (LightChance is Medium) (1) '

'15. If (Temp is MediumTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is MotionDetected) then (LightChance is High) (1)'

'16. If (Temp is MediumTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is NoMotion) then (LightChance is Medium) (1) '

'17. If (Temp is MediumTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is LessMotion) then (LightChance is Medium) (1) '

'18. If (Temp is MediumTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is MotionDetected) then (LightChance is High) (1) '

'19. If (Temp is HighTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'20. If (Temp is HighTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is LessMotion) then (LightChance is Low) (1) '

'21. If (Temp is HighTemp) and (LightIntensity is LowIntensity) and (OccupancyDetection is MotionDetected) then (LightChance is Low) (1) '

'22. If (Temp is HighTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'23. If (Temp is HighTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is LessMotion) then (LightChance is Medium) (1) '

'24. If (Temp is HighTemp) and (LightIntensity is MediumIntesity) and (OccupancyDetection is MotionDetected) then (LightChance is Medium) (1)'

'25. If (Temp is HighTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is NoMotion) then (LightChance is Low) (1) '

'26. If (Temp is HighTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is LessMotion) then (LightChance is Medium) (1) '

'27. *If (Temp is HighTemp) and (LightIntensity is HighIntensity) and (OccupancyDetection is MotionDetected) then (LightChance is High) (1)* '

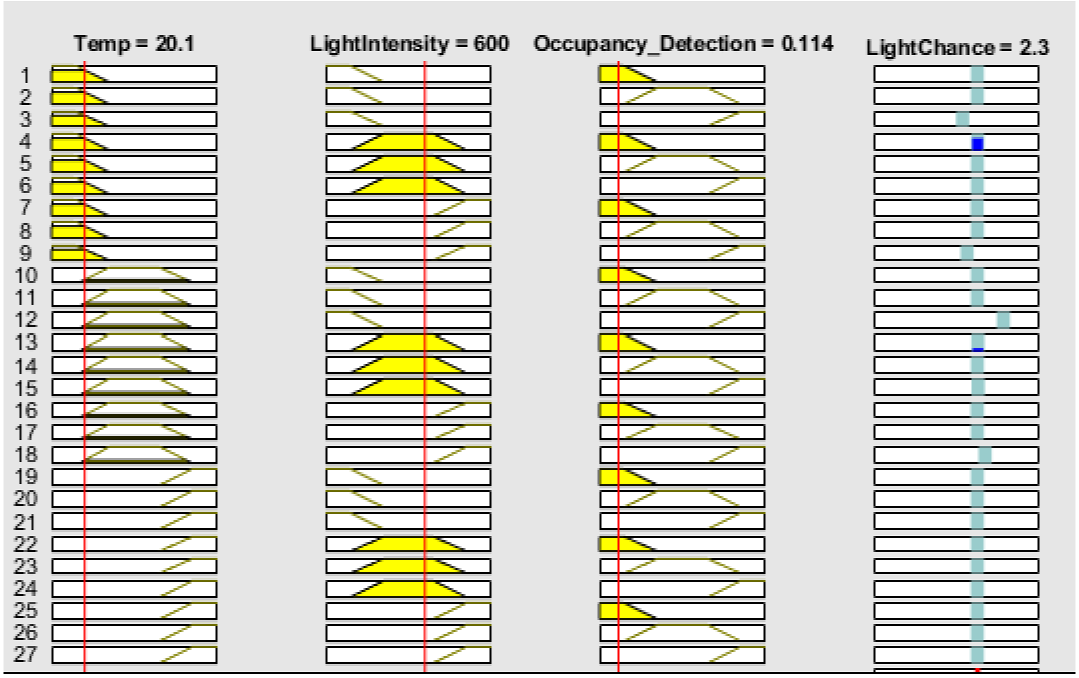

Figure 4.4: Fuzzy if then rules for light control

4.1.1.4. System Parameter and Fuzzy Rules

The linguistic variables used and input and output parameters are defined and documented in tables following fuzzy logic parameters. The Tables have three columns Sensor data, fuzzy logic membership, and Action taken in the tables presents different conditions of the light intensity levels which accordingly represent various changes in the indoor environment. Accordingly, a set of twenty-seven 27 fuzzy rules for light intensity is used in this study. The rules are set to change the output parameters according to the different conditions of input parameters. Command to show rules differently,

Showrule (a, [1:27],'symbolic')

Showrule (a, 1:27)

Table 4.1: Universe of Discourse

Light sensor data (Analog readings)	Physical condition detected	Action taken
0 - 350	Light	See Fuzzy rule
351 -550	Average	See Fuzzy rule
551 - 1023	Darkness	See Fuzzy rule

4.1.1 ANFIS Designer

Adaptive neuro-fuzzy inference system process this input to find the accurate output based on Sugeno fuzzy inference method. In this system, the hybrid algorithm is used to train the dataset to reduce the trained error and enhance the accuracy of the result. The model is created using input-output training data collected from different sensors through the embedded with a microcontroller. Collected datasets are divided into training, testing, and checking data. The flow diagram below indicates the process followed in ANFIS as shown in figure-4.5.

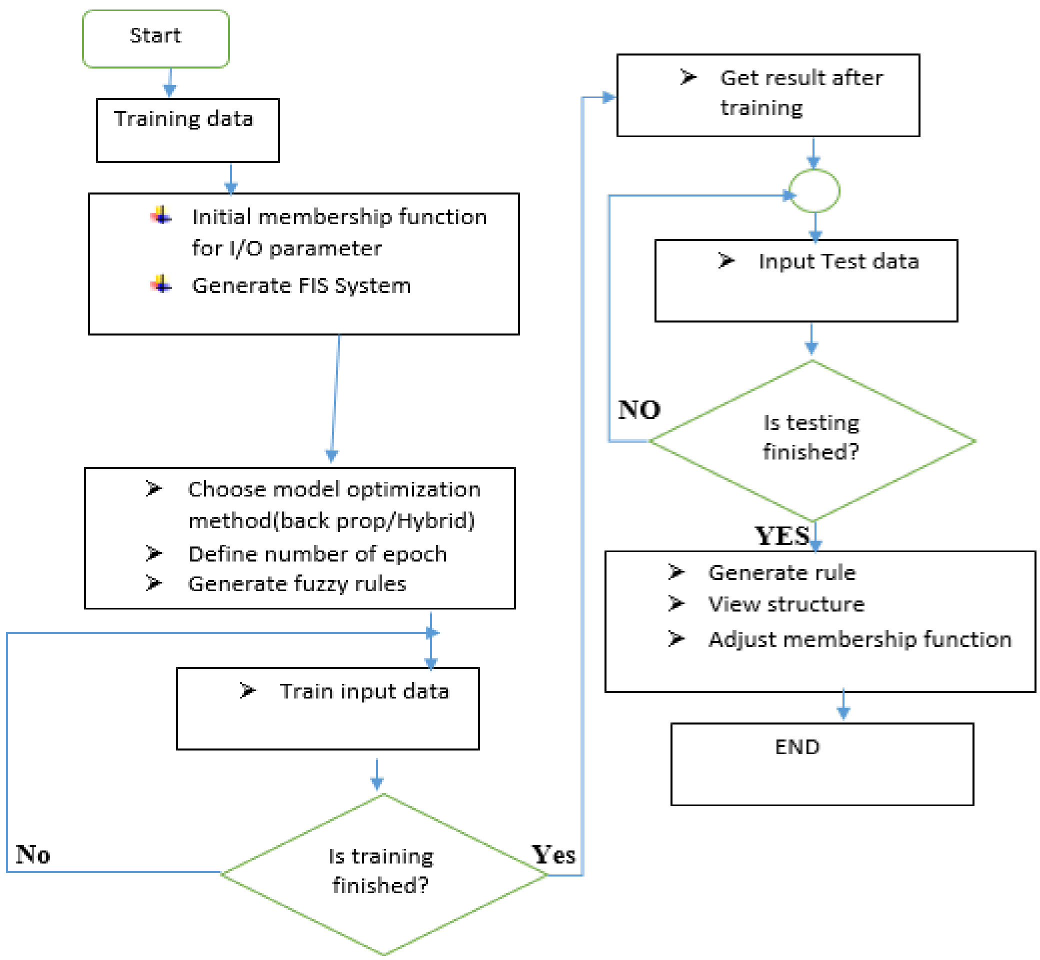

Figure 4.5: ANFIS Flow diagram

4.2. Data Preparation Method

4.2.1. Dataset split ratio

Now that we have collected a dataset we need to model with, then we have to split our dataset into Training, Validation, and Test sets. Depending on the parameter in our data, the number of datasets, and the model we need to build. In this thesis, the train, test, and validation split ratio are based on Cross-validation. The total dataset is first divided into Training and Testing sets (70% for training, 15% for testing) then keeping aside the testing set, and randomly choose validation dataset from the total dataset using cross-validation to avoids overfitting.

4.2.2. Training Dataset

This is a subset of a given dataset that is used for fitting the learning model parameters, out of the total datasets collected 70% are the actual data for training the model. The training data is an input-output data pair followed by output.

4.2.3. Test Dataset

This is a subset of a given dataset used to evaluate a final model fit on the training dataset.

4.2.4. Validation Dataset

This is a subset of a given dataset used for the evaluation of a model fit on the training dataset while tuning model. Based on the explained split ratio, the collected data for the training of the model is divided into three parts. These are 70% for training, 15% for Checking, and 15% for testing as shown in Table-2.

Table 4.1: Collected data and how it is divided using cross-validation

Total data	70%Traininng	15%Testing	15%Checking
1506	1054	226	226

A total of one thousand and five hundred and six data is collected **(1506)** as input/output data pairs from this amount of dataset **1054** are used as a training set, **226** is used validation/checking set, and the remaining **226** is used test set. The training data set is used to train the model. As the name implies, the testing subset is used for testing the performance of the built model. The grid partition technique is used to frame the fuzzy rule of this system.

The sample dataset we used for training was shown in table4.3 below

Table 4.3: Sample Training data

Temperature	Light	Occupancy	Light Chance
23.18	426	1	1
23.15	429.5	1	1
23.15	426	1	1
23.15	426	1	1
22.945	0	0	0
22.945	0	0	0

CHAPTER 5: Simulation and Performance Evaluations

5.1. Simulating proposed system

In this section how the proposed system is implemented will be explained. To implement the proposed system, a prototype will be developed based on the dataset built, the development involves hardware and different sensors for data collection, the collected data from sensors such as LDR for collecting light intensity data, PIR, for motion or occupancy detection, and LM35 for collecting temperature data will be used. The solution will be modeled using fuzzy logic and “ANFIS (Adaptive Neuro-fuzzy Inference System)”.

5.2. Prototype Development

The integration of hardware, software, Sensors makes up the prototype. The microcontroller embedded with sensors makes the system. Three sensors that will be used for data collection are integrated with the Arduino-Uno board. The schematic diagram of the prototype will be shown in the figure 5.1 below.

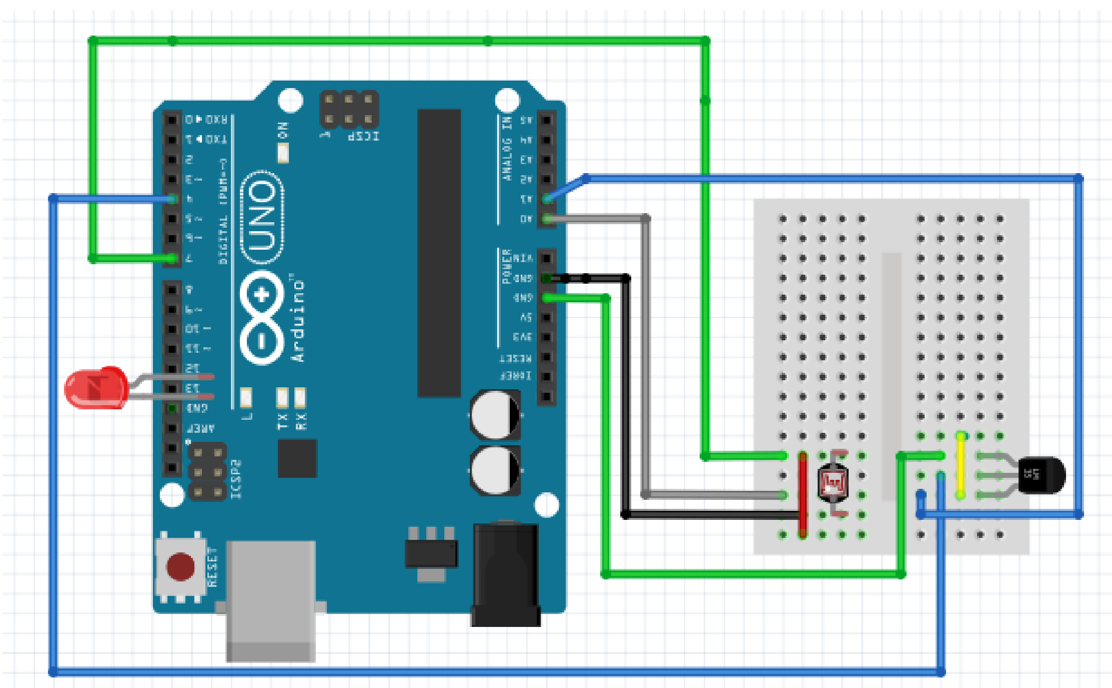

Figure 5.1: Schematic diagram

5.3. Modeling the solution

5.3.1. Train Adaptive Neuro-Fuzzy Inference Systems

In this thesis, we used to create a variable from the Matlab R2018a command interface and paste the data to workspace [array] with.

Variable train1054 = [ ], test226 = [ ], check226 = [ ].

5.3.2. NeuroFuzzyDesigner

This command imports the training and testing data to the Matlab workspace. We can also load the data directly by creating a variable in the Matlab command and then load it to the neuro-fuzzy designer by typing the name of the data.

5.3.3. Epoch and Error Tolerance

An epoch is the number of iterations an algorithm can perform, while training an input/output dataset, in this thesis work, we used to train the model by increasing the number of the epoch from 10 to 40, again by observing the number of output error in each epoch we increased to 100 epoch until we obtain a model with minimum error. For the training, an error tolerance of zero point zero one was selected and this is used as a criterion to the training, so the training will stop after the training data error remains within this tolerance.

5.3.4. Load the Dataset

The hybrid optimization algorithmic method is used from available options for the training. The creation of an ANFIS model using the collected dataset, it is important to load training and testing data to Sugeno fuzzy systems using the Neuro-Fuzzy Designer. The user interface of the Neuro-fuzzy designer will be opened by typing Anfisedit or neuroFuzzyDesigner command in the Matlab command interface.

To load a dataset to the Matlab workspace we use either a command such as

```
Load train1054.dat
Load check226.dat,
Load test226.dat.
```

Modeling of the solution will be done in Matlab 2018a. The ANFIS model will be generated from input and output data collected from the sensor for generating an input and output membership function, fuzzy rules, and optimization parameters.

The fuzzy inference system with three inputs *(Temperature, Light intensity, Occupancy)* and, one output (*control option*) and having twenty-seven rules which are $\mathbf{3^3 = 27}$. After transforming crisp input to fuzzy input membership function and will be transformed into an output membership function by de-fuzzification.

From the ***1506*** dataset, ***70% (1054)*** of the data will be used for training data displaying input and output side by side. As shown in figure 5.2

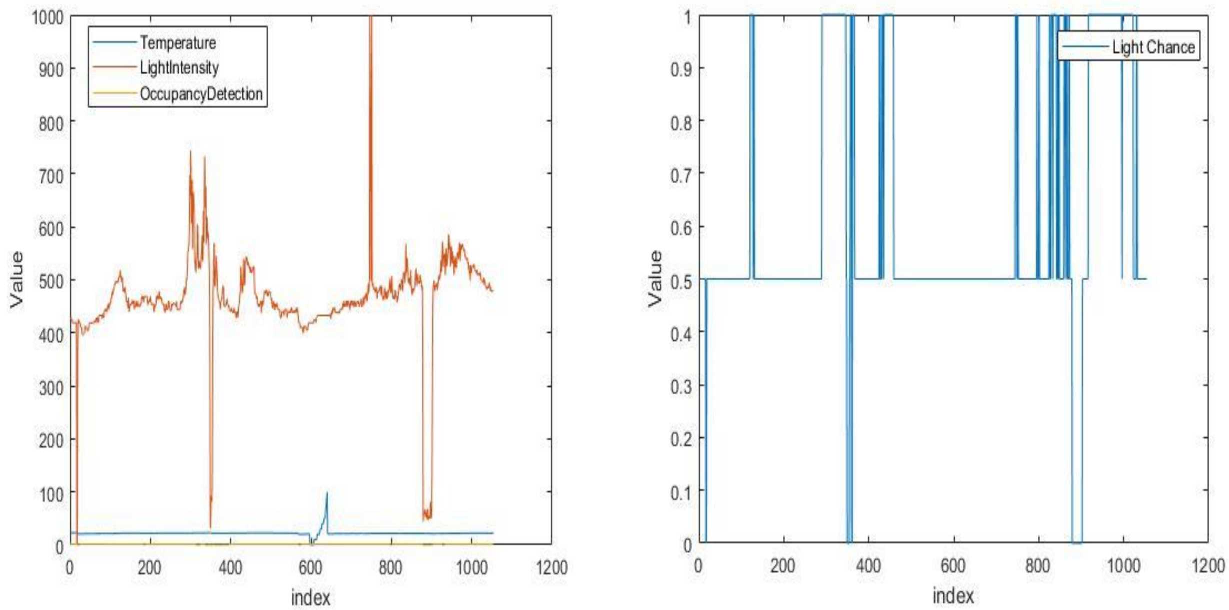

Figure 5.2: Temperature Light intensity and Occupancy Detection for training as Input-Output dataset

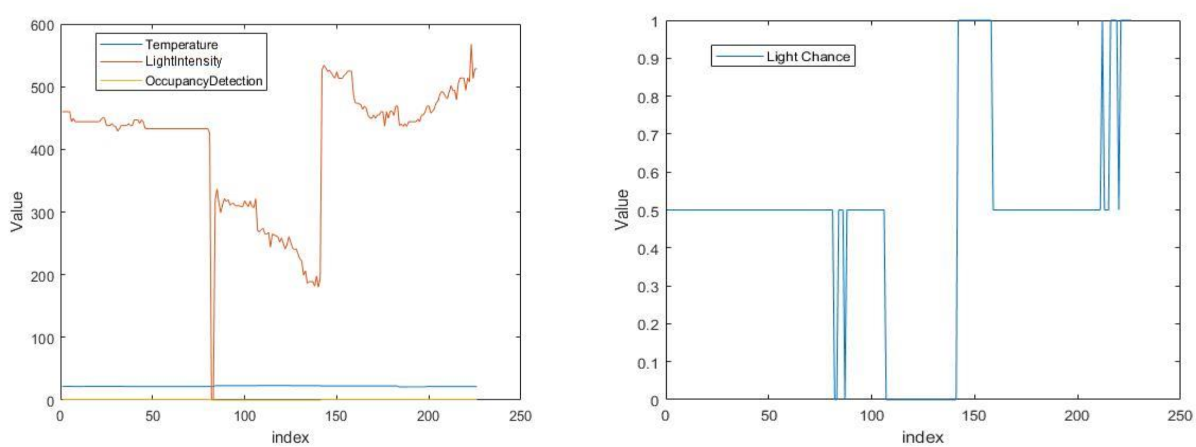

Figure 5.3: Temperature Light intensity and Occupancy Detection testing input-Output dataset

From the ***1506*** dataset, **15% (226)** of the total data will be used for the model testing as shown in figure 5.4 below

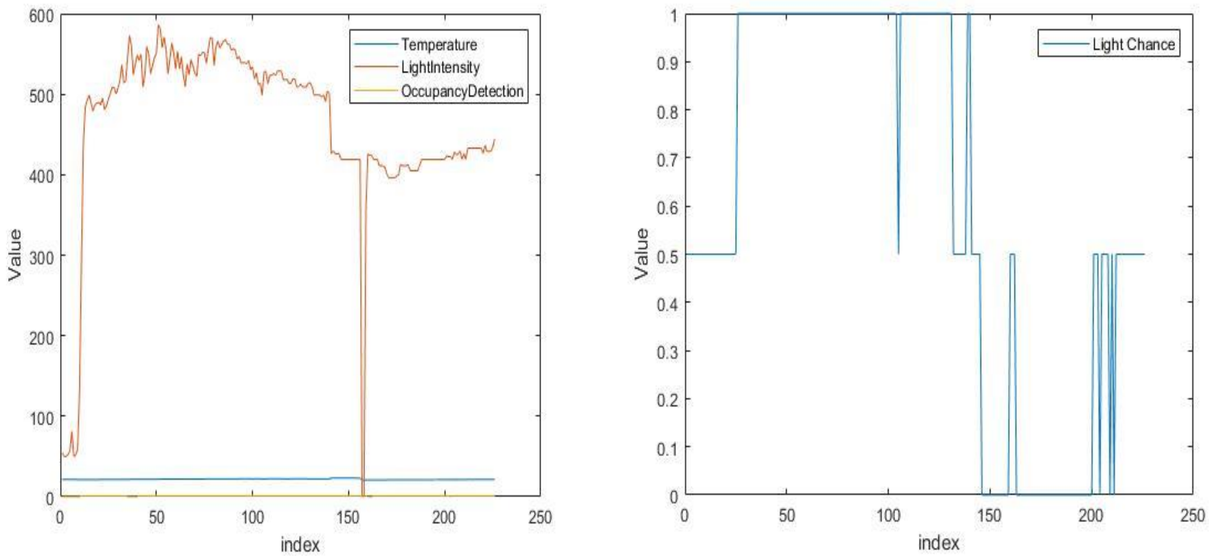

Figure 5.4: Temperature Light intensity and Occupancy Detection for testing data as the Input dataset

15% of the total data ***226*** will be used for checking the model validation, the figure below shows the checking data with its output data.

Just after Loading the training, testing, and validation/checking dataset we begin training the model under different conditions, generating member function types,

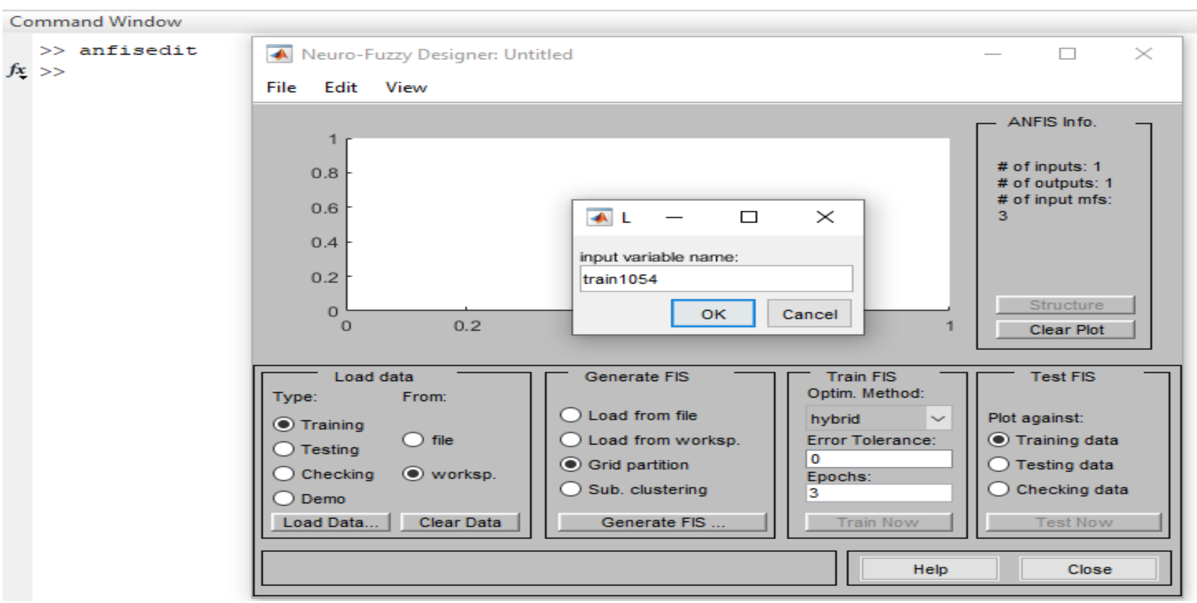

Figure 5.5: loading dataset for training the model in Matlab environment

Just before beginning the training, determining the member function while generating a fuzzy inference system is very essential, in this thesis, grid partition was selected as the data input method. As an input number of a member function is set 3 3 3, for parameters such as Temperature (High, Medium, Low), Light Intensity (High, Medium, Low) and Occupancy detection (High, Medium, Low) as an input, for each MF types such as trimf (triangular member function),

This membership is related to the trimf that is, y = trimf (x, parameters) this returns fuzzy MF in a triangular MF, mathematically expressed as , in equation (5.1)

$$f(x: a, b, c) = \begin{cases} 0, & x \leq 0 \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.1)$$

Trapmf (trapezoidal member functions), it is a built-in MF where a function of vector x, depends on four scalar parameter a, b, c, d mathematically expressed as, y = trapmf (x, [a b c]) expressed as in Equation (5.2),

$$f(x: a, b, c, d) = \begin{cases} 0, & x \leq 0 \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{d-x}{d-c}, & c \leq x \leq d \\ 0, & d \leq x \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.2)$$

Gbellmf (generalized bell member function), built-in member function having three parameters a, b, c mathematically expressed as, y = gbellmf (x, [a, b, c]) were, expressed as in Equation (5.3),

$$f(x: a, b, c) = \frac{1}{1+\left|\frac{x-c}{a}\right|} 2b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (5.3)$$

Gaussmf (Gaussian member function) , a Gaussian membership function always has a maximum value of 1, To specify the standard deviation, *σ*, and mean, *c*, for the Gaussian function, expressed as in Equation (5.4), use parameters.

$$f\ (X; \sigma, c) = e^{-\frac{(x-c)2}{2\sigma 2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (5.4)$$

Dsigmf (sigmoidal member function), this function computes fuzzy membership values using the difference between two sigmoidal membership functions as shown in equation 5.5 below.

Y = dsigmf (x: a, c)

$$f(x; a, c) = \frac{1}{1+e^{-a(x-c)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.5)$$

The above equation was used for an input option and a linear MF type is selected and results with fewer errors will be selected as a final model. For training FIS a hybrid optimization method is selected with an error tolerance of zero (0) with alternatively changing an epoch 10, 40, and 100, and finally, an epoch with minimum error will be selected.

5.4. Evaluating the Performance of Proposed System

After completing the training using the collected data the model with less error was selected. To select the best model that fits member functions such as trimf, trapmf, gbellmf, gaussmf, and dsigmf are compared using 3 by 3 member functions producing an output of constant member functions. ANFIS model structure was generated after training as in figure 5.6.

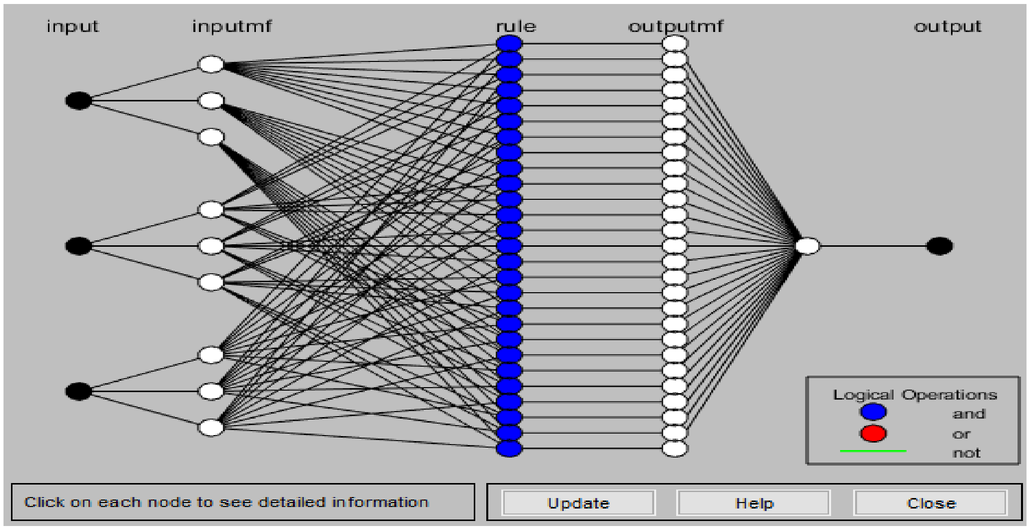

Figure 5.6: ANFIS Model Structure

Using these functions the model is built with 1054(70%) training data out of 1506 data set using a hybrid of least-square and back-propagation, the results were compared and the result with minimum error output compared with other will be used for the final model

Table 5.1: ANFIS Property Structure for Different MF

ANFIS	μ=3				
info:	Trimf	trapmf	Gbellmf	Gaussmf	Dsigmf
Nodes Number:	78	*78*	78	78	78
linear parameters Number:	108	*108*	108	108	108
Nonlinear parameters Number:	36	*36*	27	18	36
The Total number of parameters:	135	*144*	135	126	144
Training data pairs:	1054	*1054*	1054	1054	1054
Checking data pairs:	226	*226*	226	226	226

Fuzzy rules:	27	*27*	27	27	27
Root mean squared training RMSE error	0.103527	*0.073848*	0.075295	0.08165	0.077142
Root mean squared checking RMSE error	2.79E-01	*0.273674*	0.278365	0.279795	0.279564
average testing error with check data	0.27875	*0.27367*	0.27836	0.27979	0.27979
Epoch	100	*100*	100	100	100

From table 5.1, above it was observed that the trapezoidal membership function shows the better minimum error result as compared to triangular, gbellmf, gaussmf, and Dsigmf. The training results will be shown for each of the membership functions in section 5.4.1.

5.4.1. Training Results

5.4.1.1. Results Obtained from trimf

As can be seen in table-4, the training has been made on epoch 100 and results in an error of **0.103527** RMSE, an error of **2.79E-01 checking error** resulted, the training took place on the same dataset for each number of epoch mentioned above in the result section, it was obtained that training in triangular member function with 100 epochs show that the minimum error of root mean squared error of **0.103527** was achieved as shown in table-5.2.

Table 2.2: Result of Triangular member function

MF Types	Trimf
Number of epoch	100
Training error(RMSE)	**0.103527**
Checking error	**2.79E-01**

The Results of the training were checked using available checking data, as in figure 18 below,

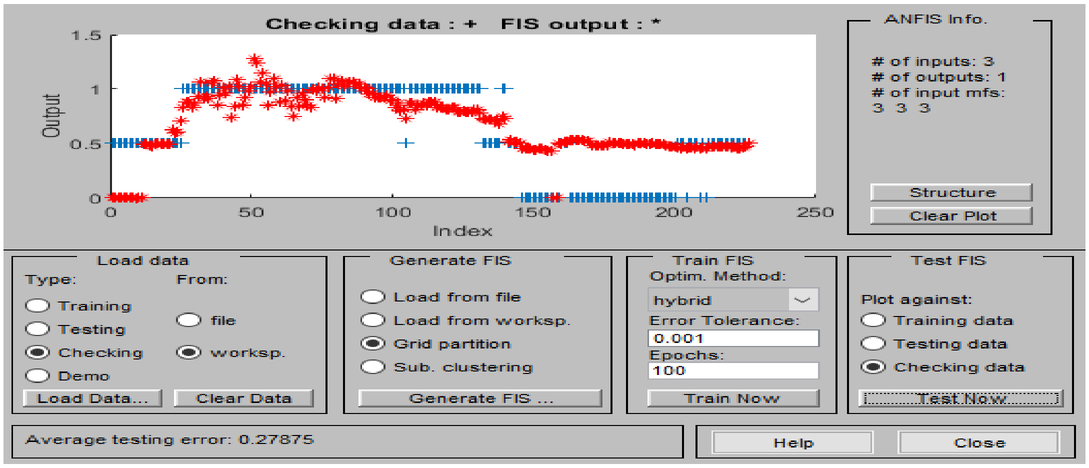

Figure 5.7: Plot of checking data VS Anfis Output

5.4.1.2. Results obtained from trapmf

The training continues by changing the type of member function to the trapezoidal member function, the training took place in the same way as in triangular member function. As can be seen in table-5.1, training on a dataset mentioned above in result section 5.4.1, it was obtained that training in trapezoidal member function shows that the minimum RMSE = *0.07434*, Minimal checking RMSE = *0.273674* error of root mean squared error was achieved as shown in table-5.1.

Table 5.3: Result of Trapmf member function in 100t epoch

MF Types	Trapmf
Number of epoch	100
Training error(RMSE)	*0.073848*

Checking error	*0.273674*
Testing Error	*0.27367*

The Results of the training were checked using available checking data, for trapmf were shown in figure below

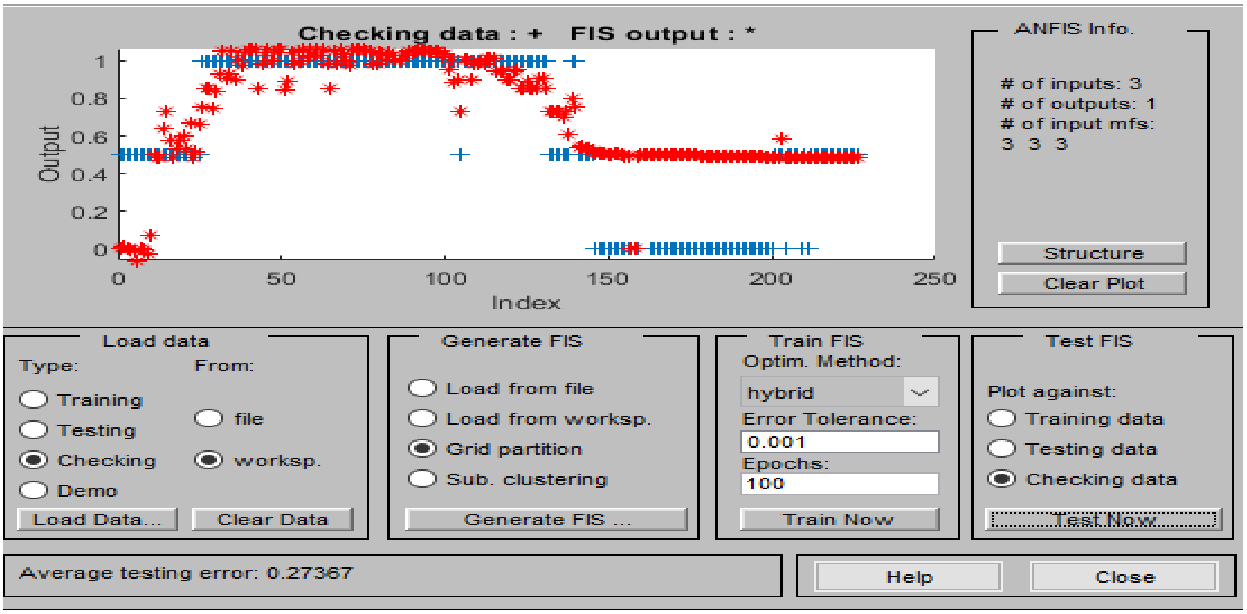

Figure 5.8: Trapmf Checking Data Plot

5.4.1.3. Results obtained from Gbellmf

From the training on generalized bell membership, it was obtained that training in a generalized bell member function with three different epochs shows that the minimum error of root mean squared error of 0.075295 was achieved as shown in table-5.4.

Table 5.4: Result of a generalized bell member function in 100 epoch

MF Types	Gbellmf
Number of epoch	100
Training error(RMSE)	0.075295
Checking error	0.278365

Testing Error	0.27836

The Results of the training were checked using available checking data, gbellmf were shown in figure 5.9 below

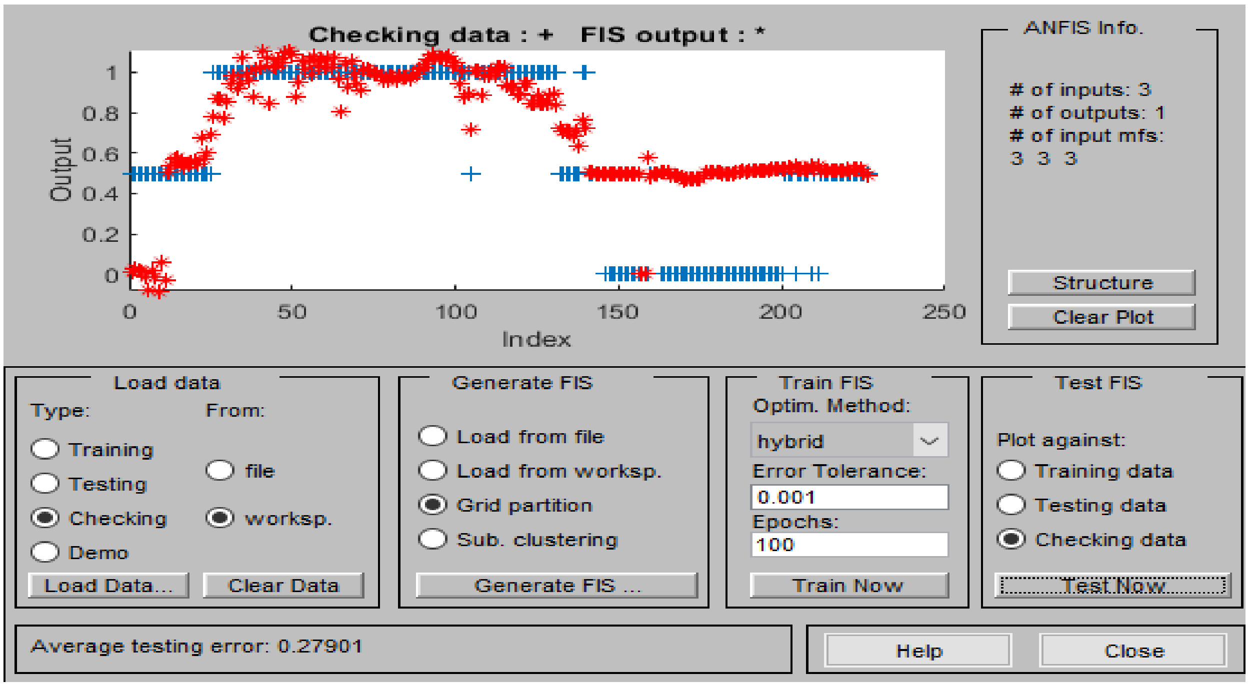

Figure 5.9: Gbellmf member function checking Result

5.4.1.4. Results obtained from Gaussmf

The same way for training in a gaussian member function, it was obtained that training in a Gaussian member function with three different epochs show that the minimum Minimal training RMSE = 0.08165, Minimal checking RMSE = 0.279795 error of root mean squared error was achieved as shown in table-5.5.

Table 5.5: Result of a gauss member function in 100 epoch

MF Types	Gaussmf
Number of epoch	100
Training error(RMSE)	0.08165
Checking error	0.279795

Testing Error	0.27979

The Results of the training were checked using available checking data, for gaussmf were shown in figure 5.10 below

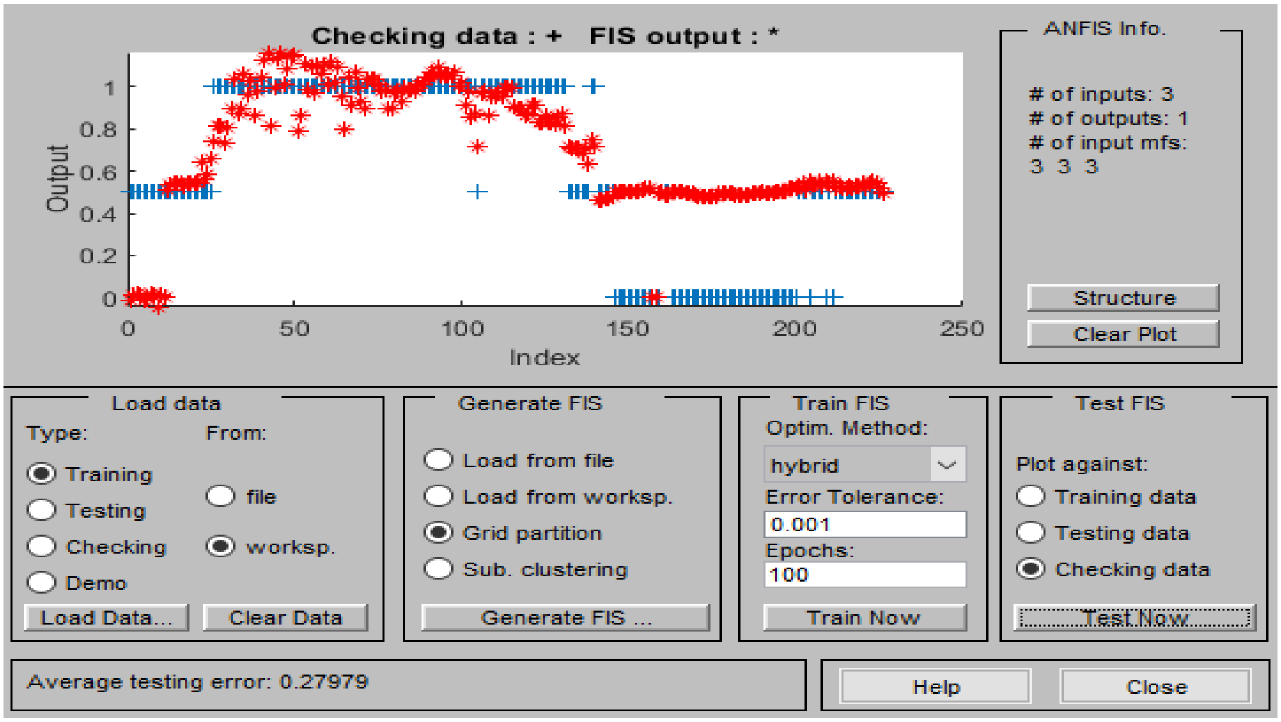

Figure 5.10: Results checking for gaussmf

5.4.1.5. Results obtained from Dsigmf

As shown in table-5.6, it was obtained that training in a sigmoidal member function with three different epochs shows that the minimum error of root mean squared error of 0.000003 was achieved as shown in table 5.6.

Table 5.6: Result of Sigmoidal member function

MF Types	Dsigmf
Number of epoch	100
Training error(RMSE)	0.077142
Checking error	0.279564

Testing Error	0.27979

The Results of the training were checked using available checking data, for dsigmf were shown in figure 5.11 below

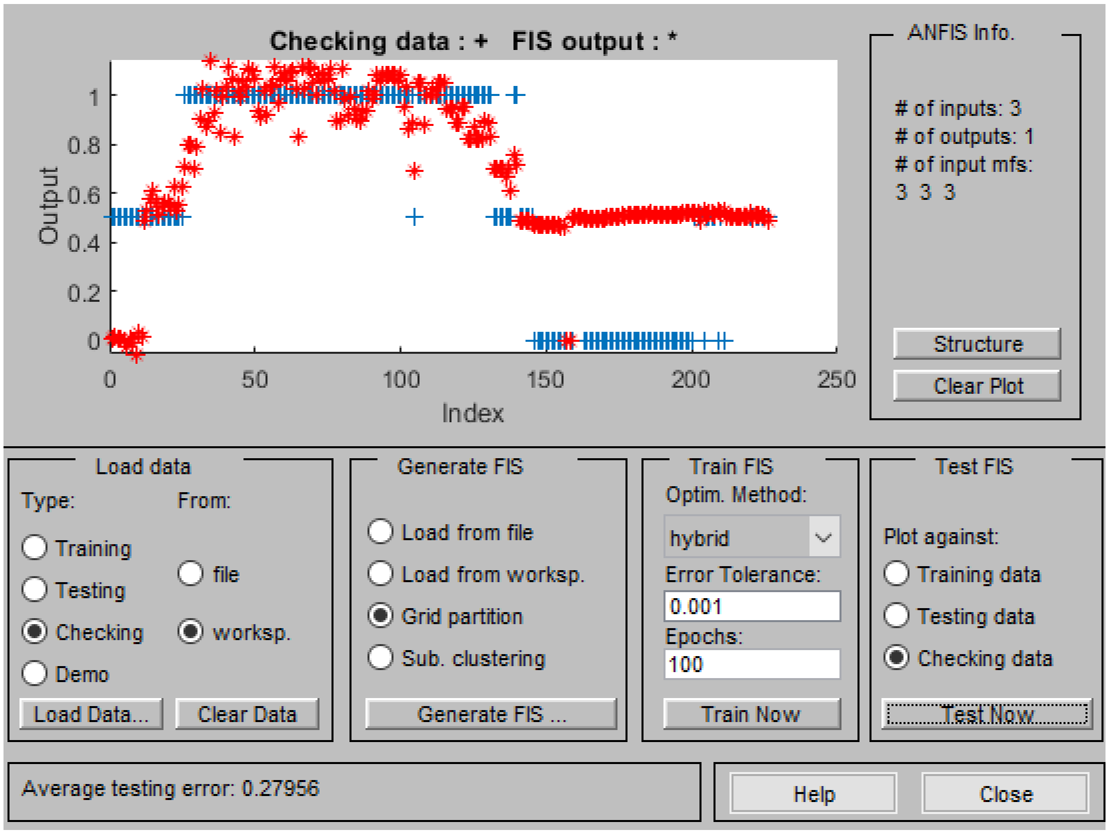

Figure 5.11: Result checking for dsigmf

5.4.1.6. Summary of Results

The training took place on one thousand fifty-four 1054 training dataset, with five member functions such as trimf, trapmf, gbellmf, gaussmf, and dsigmf, for each member function three by three μ=3 were used for training and the results were compared. It was found that the trapezoidal member function shows a minimum error of ***0.07434*** RMSE, from this we decide that the best model will be built using the trapezoidal member function, the comparison of the result were shown in table-5.7.

Table 5.7: Comparison Result of training between member function

Measure metrics	μ=3				
MF	Trimf	trapmf	Gbellmf	Gaussmf	Dsigmf
Minimal training RMSE	0.103527	***0.07434***	0.075295	0.08165	0.077142
Minimal checking RMSE	2.79E-01	***0.273674***	0.278365	0.279795	0.279564

average testing error with check data	0.27875	***0.27367***	0.27836	0.27979	0.27979
Epoch	100	*100*	100	100	100

As shown in table-5.7, the results of different member functions with their minimum root mean squared error was compared, and the trapezoidal member function with 100 epoch shows a minimum error of ***0.07434***. From the comparison it was observed that the minimum for each member function was shown on epoch 100, this shows that as we increase the number of iteration in the training dataset the error goes down to the possible minimum error.

The Model that was to be implemented uses 226(15%) testing dataset, where grid partition were used with three membership function, an input member function type of trapezoidal member function with an output of linear type. The model outputs minimum Minimal training RMSE = ***0.07434***, Minimal checking RMSE = ***0.273674*** at an epoch of a hundred 100 when checked with testing data to check that the model fits the new data that the model did not train on.

5.5. Model Evaluation

5.5.1. Performance Evaluation

To show how well a model performs, it is important to measure the performance of the model. To know how accurate the model is, to generalize the model to have the ability to properly categorize new unobserved data. The trained data in case of supervised learning should have the capability to generalize to the new untrained data.

Table 5.8: Evaluation Results

Measure metrics	μ=3				
MF	Trimf	trapmf	Gbellmf	Gaussmf	Dsigmf
Minimal training RMSE	0.103527	***0.07434***	0.075295	0.08165	0.077142
Minimal checking RMSE	2.79E-01	***0.273674***	0.278365	0.279795	0.279564
average testing error with check data	0.27875	***0.27367***	0.27836	0.27979	0.27979
Epoch	100	*100*	100	100	100

5.5.2. Triangular member function Evaluation

The performance of the model for trimf was evaluated using RMSE from the actual output and the predicted model output and the result value of 0.103527 RMSE were found, the predicted value with the testing data was shown in table-5.9. The error RMSE was used to evaluate the model using equation 5.6 was shown below.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(a-m)^2}{n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.6)$$

Where, ‘a’ is actual output, and, ‘m’ is model output and, ‘n’ is the number of test data set.

Table 5.9: Trimf Predicted Output Sample data

Temperature	Light	Occupancy	Actual Output	Predicted output
21.7675	460	1	0.5	0.502648
21.7675	460	1	0.5	0.501839
21.79	460	1	0.5	0.501268
21.79	460	1	0.5	0.501268
21.79	460	1	0.5	0.499029
21.7675	444	1	0.5	0.5006
21.76	449.3333	1	0.5	0.5006
21.7225	444	1	0.5	0.5006
21.745	444	1	0.5	0.5006

The table-5.9, shown above shows that after evaluating the membership function the result obtained from the model prediction were shown. The figure below shows the plot of trimf obtained from evaluation

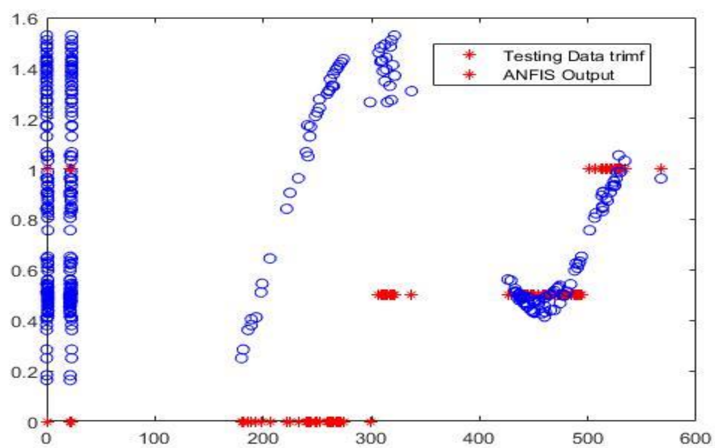

Figure 5.12: Trimf Evaluation with ANFIS Output

5.5.3. Trapezoidal Member Function Result Evaluation

The performance of the model for Trapmf was evaluated using RMSE in the same way as trimf using equation-5.6 above, and the results show the RMSE of 0.07434 was obtained, and the results were displayed in table-5.10

Table 5.10: Sample output of Trap evaluation

Temperature	Light	Occupancy	Actual Output	Predicted Value
23.18	426	1	0.5	0.502647643
23.15	429.5	1	0.5	0.501838558
23.15	426	1	0.5	0.501267751
23.15	426	1	0.5	0.501267751
23.1	426	1	0.5	0.499028636
23.1	419	1	0.5	0.500600061

The table-5.10, shown above shows that after evaluating the membership function the result obtained from the model prediction were shown. The figure below shows the plot of trapmf obtained from the evaluation results.

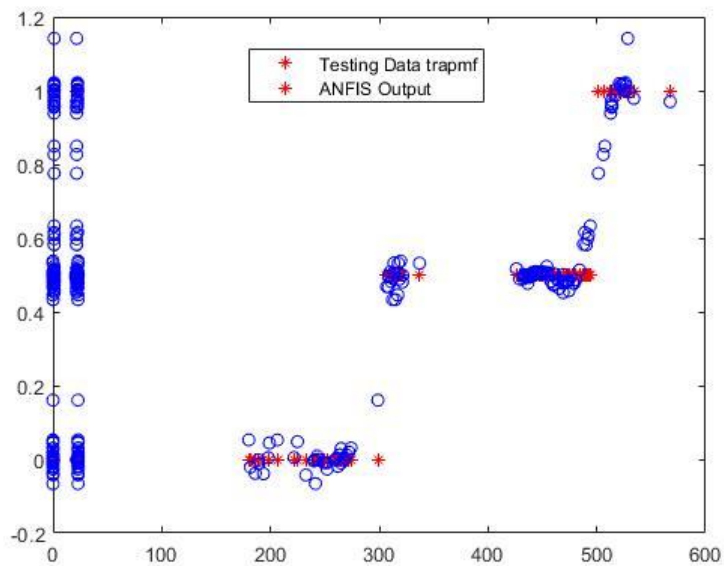

Figure 5.13: Trapmf Testing plot

As shown in figure 5.13, the testing data shows the best fit to the trained model, as compared to the other member functions.

5.5.4. Generalized bell Member function Evaluation

The performance of the model for gbellmf was evaluated using RMSE using equation 5.6, and the results shows the RMSE of 0.075295 was achieved, and the results were displayed in table-5.11

Table 5.11: Gbellmf evaluation Result Sample data

Temperature	Light	Occupancy	Actual Output	Predicted Value
21.7675	460	1	0.5	0.486587
21.7675	460	1	0.5	0.486587
21.79	460	1	0.5	0.487473
21.79	460	1	0.5	0.487473
21.79	460	1	0.5	0.487473
21.7675	444	1	0.5	0.432835
21.76	449.3333	1	0.5	0.448888

The graphical plot of this membership function was shown, and the result of this plot shows there are plenty of errors, of the data.

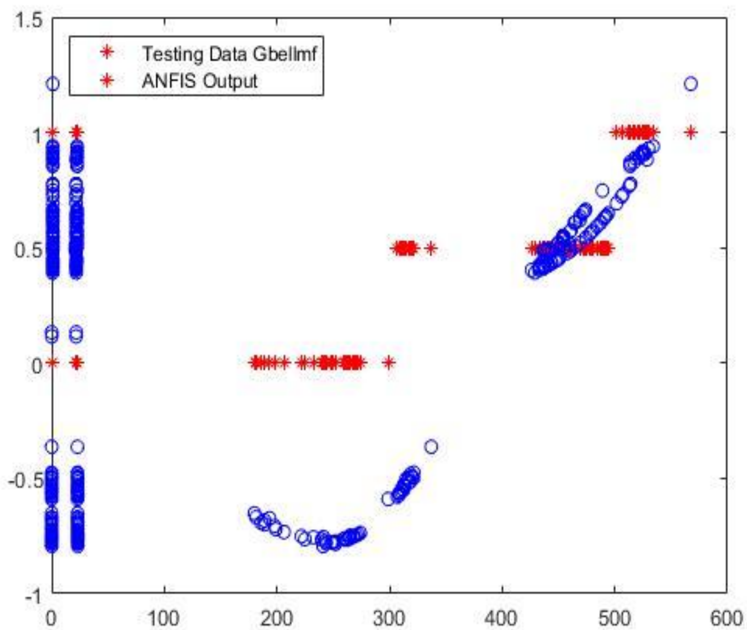

Figure 5.14: Gbellmf evaluation plot.

5.5.5. Gaussian Member Function Evaluation

The performance of the model for gaussian member function was evaluated using RMSE using equation-5.6, and the results show the RMSE of 0.08165 was achieved, and the results were displayed in table-5.12

Table 5.12: Sample gaussian output

Temperature	Light	Occupancy	Output	Predicted Output

21.7675	460	1	0.5	0.472359
21.7675	460	1	0.5	0.472359
21.79	460	1	0.5	0.473086
21.79	460	1	0.5	0.473086
21.79	460	1	0.5	0.473086
21.7675	444	1	0.5	0.508905
21.76	449.3333	1	0.5	0.505741

The graphical plot of the gaussian member function shows a good fit, as shown in figure 5.15 below

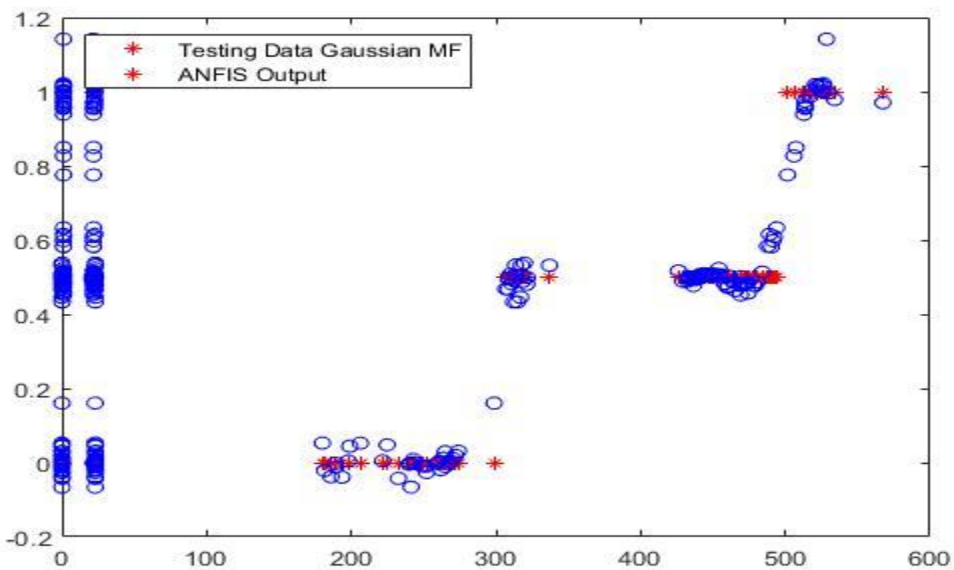

Figure 5.15: Gaussian Evaluation Plot

5.5.6. Sigmoidal Member function Evaluation

The performance of the model for gaussian member function was evaluated using RMSE using equation-8, and the results show the RMSE of 0.077142 was achieved, and the results were displayed in table-5.13

Table 5.13: Sample Sigmoidal output

Temperature	Light	Occupancy	Output	Predicted Output
21.7675	460	1	0.5	0.4724
21.7675	460	1	0.5	0.4724

21.79	460	1	0.5	0.4731
21.79	460	1	0.5	0.4731
21.79	460	1	0.5	0.4731
21.7675	444	1	0.5	0.5089
21.76	449.3333	1	0.5	0.5057

The graphical plot of gaussian member function shows a good fit, as shown in figure below

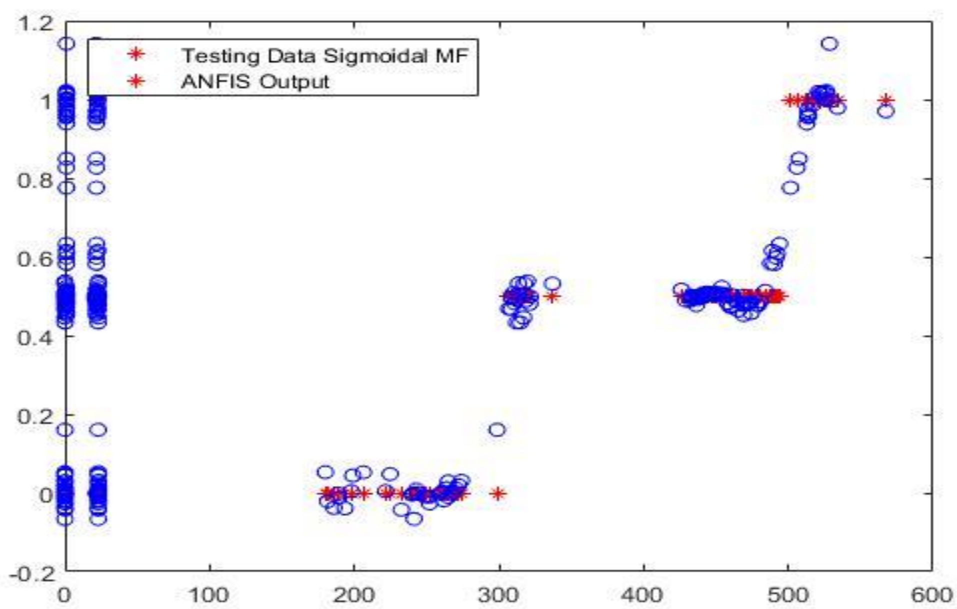

Figure 5.16: Sigmoidal Evaluation Plot

So far we have observed that the evaluation of the model with different member function such as Trim, Trapmf, Gbellmf, Gaussmf, Gbellmf, and Dsigmf was evaluated and trapmf results show that it was a well-performing model, so the trapmf with an error of 0.07434 RMSE is our final model and the results are satisfactory.

5.5.7. FIS Evaluation

To evaluate the fuzzy Inference system, the Sugeno model Matlab command Evalfis were used, with three input and, one output structure having 27 rules.

Fis = readfis ('lightl.fis')

Fis =

Strut with fields:

Name: 'lightl.fis'

Type: 'Sugeno'

And Method: 'prod'

Or Method: 'probor'

DefuzzMethod: 'wtaver'

Imp Method: 'prod'

AggMethod: 'sum'

Input: [1×3 struct]

Output: [1×1 struct]

Rule: [1×27 struct]

To evaluate the output of a fuzzy system for a given input, use the function evalfis, for instance, to evaluate for Temperature value of 21, light intensity value of 500 and motion detection value of 1, it has been observed from the evaluation of the sample input that the model performs well

Evalfis ([21 500 1], a)

Ans =

0.6635

5.6. Simulation of the Result

To simulate a fuzzy inference system (FIS) in Simulink using the Fuzzy Logic Controller with Rule viewer blocks. The trapezoidal member function with three inputs and one output is simulated. During the simulation, we can evaluate the value in input against the rule in a fuzzy set with the rule viewer.

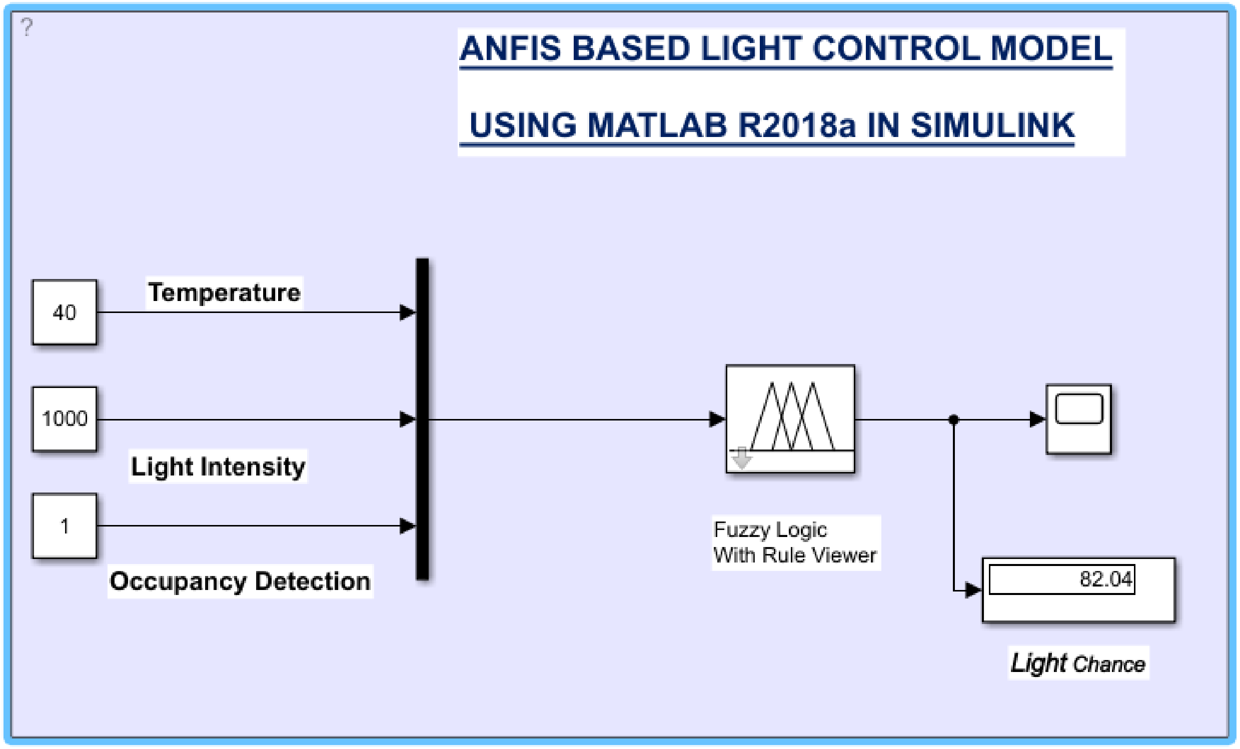

Figure 5.17: Simulink Simulation

As we can see from the simulation result that was done based on a fixed variable for the input-output against the obtained model, here we can visualize the output in two ways, one way is as soon as we simulate our Simulink the result will be directly observed in the display as in figure-5.17, for instance for an input 40 degree centigrade for Temperature, 1000 lux for light intensity, and 1, for occupancy detection, analyzing from previously trained data that is stored in our fuzzy rule, it has predicted that there is a chance of light which is 82.04, the same result will be observed in our rule viewer with same input/output result. The figure for rule viewer has been shown in figure 5.18, the surface viewer in figure-5.19.

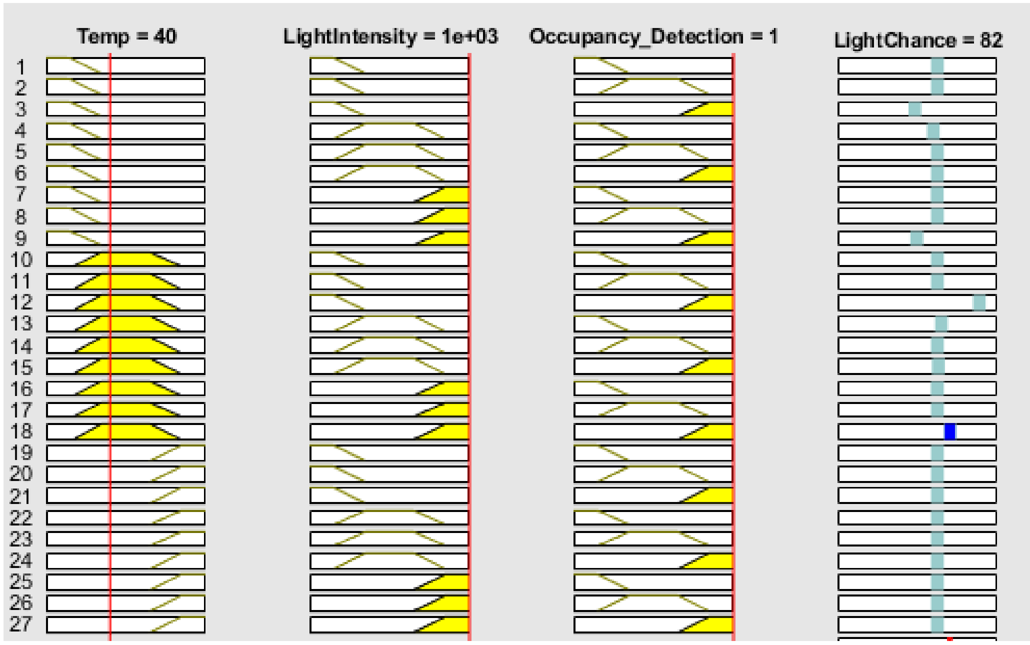

Figure 5.18: Simulation Result In rule viewer

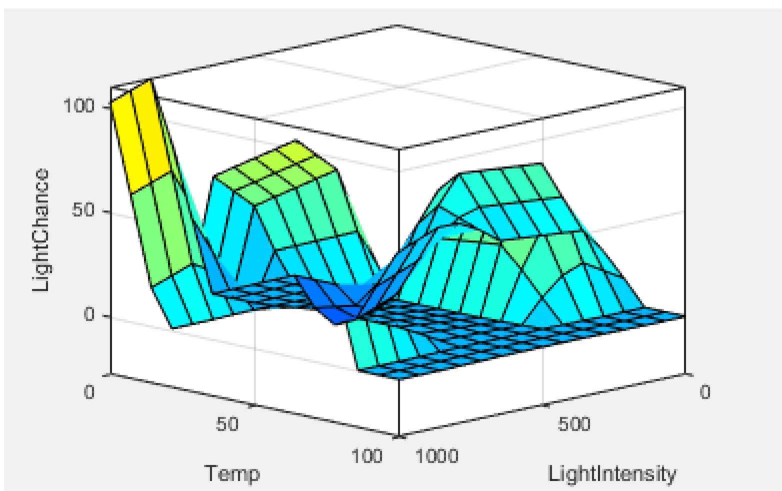

Figure 5.19: Surface View of Simulation Result

5.7. Discussion

Here we present the results of the proposed model in the previous section. The design was performed using MATLAB (R2018a) with available libraries using the Arduino Uno microcontroller. the results of the changes in LDR where power led is on when the intensity of light is high, results of LM35, where there exist high temperature, PIR sensor whether a motion is detected or not. On the other hand, the value found in the performance metric, RMSE in trapezoidal member function, The accuracy obtained by ANFIS has good performance obtaining the training error of *0.07434* % was observed. The results of different member functions with their minimum root mean squared error was compared, and the trapezoidal member function with 100 epoch shows a minimum error of ***0.07434***. From the comparison it was observed that the minimum for each member function was shown on epoch 100, this shows that as we increase the number of iteration in the training dataset the error goes down to the possible minimum error.

The Model that was to be implemented was based on 226(15%) testing dataset, where grid partition was used with three membership function, an input member function type of trapezoidal member function with an output of linear type. when checked with testing data to check that the model fits the new data that the model did not know before.

Chapter 6: Conclusions, Recommendations, and Future Work

6.1. Conclusion

We have presented in this thesis the design and model of ANFIS for controlling light based on occupancy detection, using parameters such as Temperature, Light intensity, and, Occupancy based on Sensors such as Lm35, LDR, PIR respectively, that collect data to provide to the MATLAB R2018a for training the model that was developed in a hybrid algorithm of backpropagation and Least square learning. A prototype was developed and simulations were run to show the effectiveness of this system in a Simulink of the Matlab R2018a. the model is evaluated to validate the performance of the system and the result was measured in a root mean squared error in trapezoidal member functions.

Results of different member functions with their minimum root mean squared error was compared, and the trapezoidal member function with 100 epoch shows a minimum error of ***0.07434***. From the comparison it was observed that the minimum for each member function was shown on epoch 100, this shows that as we increase the number of iteration in the training dataset the error goes down to the possible minimum error.

The Model that was to be implemented based on 226(15%) testing dataset, where grid partition was used with three membership functions, an input member function type of trapezoidal member function with an output of linear type. The model outputs Minimal training RMSE = ***0.07434***, Minimal checking RMSE = ***0.273674*** at an epoch of a hundred 100 when checked with testing data to check that the model fits the new data that the model did not know before.

6.2. Recommendations

The model was designed and developed in Arduino Uno, a low-cost microcontroller, however, it is better to use the Raspberry pi microcontroller to design the control system which is far better in performance, Storage capability expandability and, many more advanced features. At the same time using multiple sensors, adding a security system to the model using the camera will make the system more advantageous, again as an Energy consumption reduction method if Temperature and humidity were considered to control the Heater will also be very important.

6.3. Future Work

Future research will be focused on improving the control system to connect it to the web interface and control the device, view status of the device when we are not around. For this we have to use Rapberry pi, which is an advanced microcontroller.

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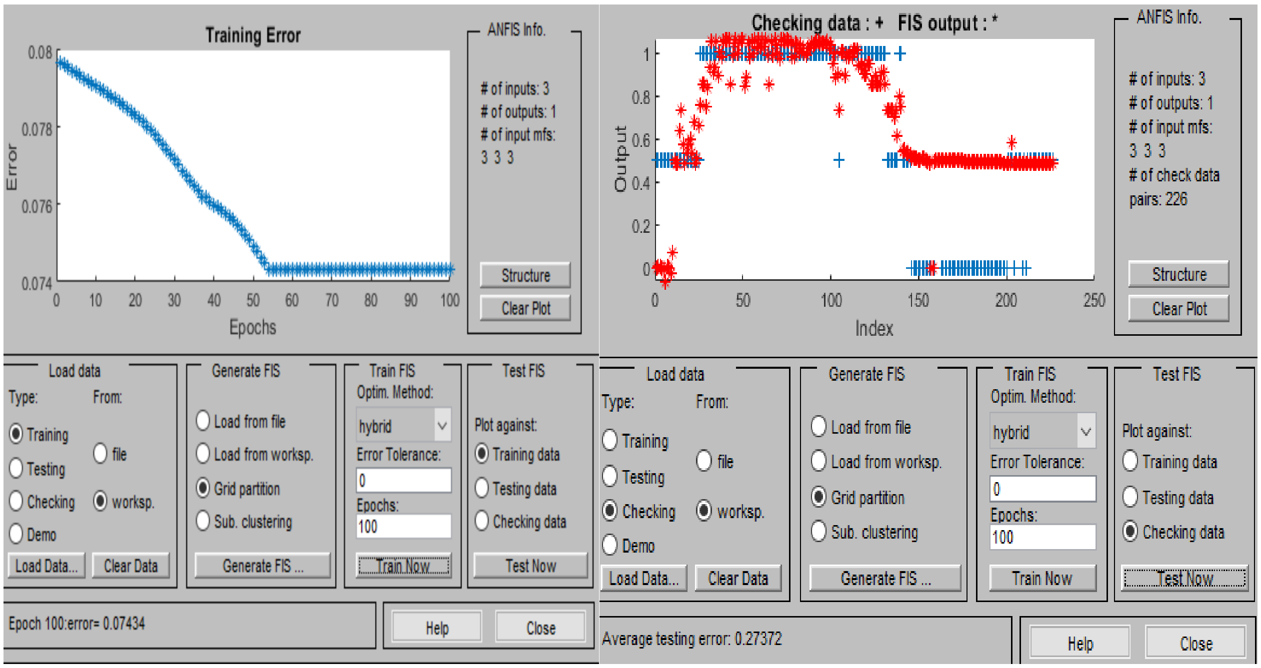
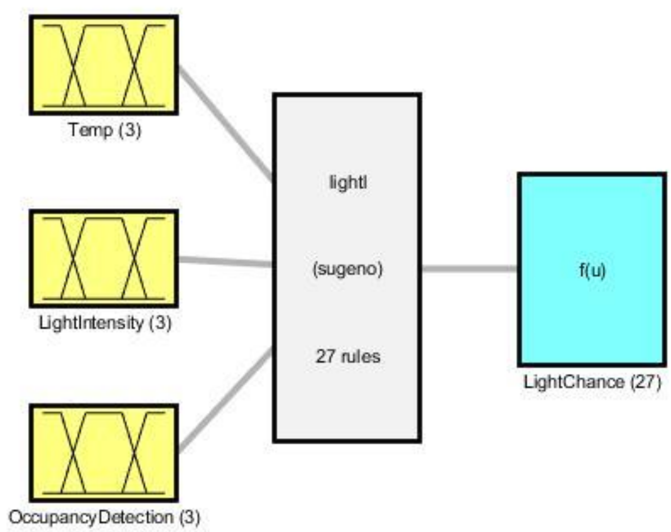
APPENDIX A : Matlab training Command

Training error and testing error plots



>> a= readfis('lightl');
>> plotfis(a)



System lightl: 3 inputs, 1 outputs, 27 rules

```
% Input of the training data Matlab graphical plot command Assuming we are in the
same directory and the data is loaded to the workspace %

x=train1054(:,1:3)
```

```
plot(x)

legend('show')

legend({'Temperature','LightIntensity','OccupancyDetection'})

xlabel('index')

ylabel('Value')

==========================

% Output of the training data Matlab graphical plot command %

y=train1054(:,4)

plot(y)

legend('show')

legend({'Light Chance'})

xlabel('index')

ylabel('Value')

=========================

% Input of the Test data Matlab graphical plot command %

x=test226(:,1:3)

plot(x)

legend('show')

legend({'Temperature','LightIntensity','OccupancyDetection'})

xlabel('index')

ylabel('Value')

===========================

% output of the Test data Matlab graphical plot command %

y=test226(:,4)

plot(y)

legend('show')

legend({'Light Chance'})

xlabel('index')

ylabel('Value')

% Input of the Check data Matlab graphical plot command %

x=check226(:,1:3)
```

```
plot(x)
legend('show')
legend({'Temperature','LightIntensity','OccupancyDetection'})
xlabel('index')
ylabel('Value')
===============================
% output of the Test data Matlab graphical plot command %
y=check226(:,4)
plot(y)
legend('show')
legend({'Light Chance'})
xlabel('index')
ylabel('Value')
% Model creation from training Data%
% Load training Data from Matlab Workspace %
load train1054.dat;
x=train1054(:,1:3);
y=train1054(:,4);
genOpt = genfisOptions('GridPartition');
genOpt.NumMembershipFunctions = 3;
genOpt.InputMembershipFunctionType = 'trapmf';
inFIS = genfis(x,y,genOpt);
opt = anfisOptions('InitialFIS',inFIS,'EpochNumber',1000);
outFIS = anfis([x y],opt);
writefis(outFIS)
```

Appendix B : Arduino Data Collection Command

```
% Data Collection in Arduino %
#include <LM35.h>
int sensorPin = A0;
int sensorValue = 0;
int sensValue = 0;// variable to store the value coming from the sensor
const int lm35_pin = A1;  /* LM35 O/P pin */
const int ldr_pin = 7;
const int led_pin = 13;
void setup() {
      pinMode(ldr_pin,INPUT);
    pinMode(lm35_pin,INPUT);
    pinMode(led_pin,OUTPUT);
Serial.begin(9600);
Serial.println("CLEARD0ATA");
Serial.println("CLEARSHEET");
Serial.println("LABEL,Light,Temp,OutP");
  }
void loop() {
  // read the value from the sensor:
   int Light_adc_val;
  float OutP;
  Light_adc_val = analogRead(lm35_pin);  /* Read Temperature */
  sensorValue = (Light_adc_val * 4.88);
  sensorValue = analogRead(sensorPin);
  sensValue = analogRead(lm35_pin);
   //if( digitalRead( ldr_pin ) == 1)
if(sensorvalue>=0 && sensorvalue<=350){
      digitalWrite( led_pin,LOW);
```

```
      outP=0;
   }
   else if (sensorvalue>350 && sensorvalue<=550){
      digitalWrite( led_pin ,HIGH);
       outP=0.5;
}
else if (sensorvalue>551 && sensorvalue<=1023){
      digitalWrite( led_pin ,HIGH);
       outP=1;
   }
     int temp_adc_val;
  float temp_val;
  temp_adc_val = analogRead(lm35_pin);  /* Read Temperature */
  temp_val = (temp_adc_val * 4.88); /* Convert adc value to equivalent voltage */
  temp_val = (temp_val/10); /* LM35 gives output of 10mv/°C */
Serial.print("DATA");
Serial.print(",");
Serial.print(temp_val,4);
Serial.print(",");
Serial.print(sensorValue,4);
Serial.print(",");
Serial.print(outP,4);
Serial.print(",");
Serial.println();
delay(10000);
}
```