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FUZZY TEMPERATURE CONTROLLER BASED ON BLUETOOTH LOW ENERGYFOR INDOOR PET DOGS

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ABSTRACT

Indoor pet dogs have greatly affected our daily lives primarily as our companions, friends, and a source of entertainment. Ownership of these pets imposes diligent, consistent, and cognizant of responsibility as they have rights and needs like human beings. A worrying problem nowadays is the negligence of regular maintenance and check-ups to veterinarians that results in the rise of illnesses among pet dogs. Common ailments by dogs include yeast infection, skin allergies, and a high fever that can be easily prevented and monitored. This research paper proposes a methodology to regulate, control, and monitor the temperature inside a doghouse. The system will be equipped with temperature, humidity, and proximity sensors as well as a 12VDC fan and heating element. A fuzzy logic controller will also be implemented to produce better output response and minimize error rates within the system. NodeMCU ESP8266 will be utilized as the microcontroller of the system and is responsible for processing the data and control commands. Matlab R2019b is used to design and program the fuzzy logic controller. The proposed research will significantly support the necessary maintenance and control of the dog's environment.

Keywords: fuzzy logic, bluetooth, advance sensors, data transmission.

1. INTRODUCTION

Pet animals have always had a great impact on people's lives. Pets play different roles; they can be a sibling, a daughter/son, a best friend, a bodyguard, a therapeutic companion for people who suffer from anxiety, blindness, etc, and many more. Among all of them, dogs are known to be the best in what they do, therefore, it is not uncommon for people to treat their dogs as part of their own family. Dogs, according to studies, help their owners in dealing with stress, in developing social and emotional skills, and also in improving heart conditions. Dogs are considered the epitome of unconditional love because of their unwavering loyalty towards their masters, friends, or whatever relationship they have with their human companions.

Importance in awareness should also be raised to pet owners with regards to their pets' health, well-being, and preventive maintenance. The rise of numerous wireless communication technology and automation can aid as a support system for monitoring physiological parameters of indoor pets. Additionally, automation has evolved and taken action to several real-life applications and industries from robotics, manufacturing, education, home systems, automotive, food, and beverage orders [1]. Adding brainpower and reasoning to different systems and environments can revolutionize quality and efficiency that will elevate comfort, convenience, and quality of life.

Several wireless technologies such as Wifi, Zigbee, Bluetooth, Bluetooth Low Energy, LoraWan, and Radio-Frequency Identification (RFID) are only some of the emerging communication protocols that can be utilized for real-world applications [2]. Bluetooth Low Energy (BLE) is well-known for its low cost, low power consumption, and flexibility developed by the Bluetooth Special Interest Group (SIG). It is specifically designed as an economical solution for control and monitoring applications [3]. The advent of sensors, actuators, and control systems has also transformed people and organizations to bring about innovative solutions. A vast amount of open-source hardware and software can be taken advantage of to be able to tinker as a means of solving a problem.

2. BACKGROUND OF THE STUDY

The origin of how Bluetooth got its name was inspired by King Harald "Bluetooth" Gormsson as he was responsible for uniting Denmark and Norway in 958 and had a dead tooth with a dark blue or grey color [4]. In 1998, the Bluetooth SIG (Special Interest Group) was established with five companies but extended to four thousand companies as the year ended. The Bluetooth 1.0 specification was released the following year and only provided data rates of just approximately 720 kbps and only a range of up to 10 meters at that time. It has sustained and evolved throughout the years to improve the standard's data rate, range, quality, and features to stay competitive and operational. Most recently, the standard gained significant improvements and applications ranging from new transmission modes, different radio designs, communication topologies, and various applications in different industries [5]. Bluetooth Low Energy (BLE) is a wireless communication protocol recently developed by the organization and is designed for very low power operation which is ideal in the field of the Internet of Things (IoT).

Fuzzy logic is ideally based on inference in which how the controller can infer or deduce new knowledge based on the existing data [6]. It was conceived for a specific purpose that it can enable computers to determine the variance among data between completely false and completely true [7]. In contrast to Boolean logic, the values it can only take is either a 0 (false) or a 1 (true). It

contains rules from the if-then conditions modified by the user to control the decision-making system. The theory was published by Lotfi A. Zadeh of the University of California at Berkeley which laid out the foundations and fundamentals of the logic. It has been applied and is continuously being implemented to a wide variety of applications from control systems, computer software, mathematicians, and Artificial Intelligence.

3. STATEMENT OF THE PROBLEM

It is important to bring awareness to the duty of indoor pet owners for their respective dogs concerning their health and maintenance. It should be advocated that owners must be able to ensure their dogs' safety, convenience, and health by being able to provide quality control and regular preventive check-ups. A simple way of being able to meet this demand is by regulating the environment's temperature within our rooms or homes. Dogs have a unique capability of regulating their body temperature with the help of their insulating skin. In contrast to how humans rely on perspiration during hot weather, dogs find a cool place or shade to lie down and then absorb the coolness [8]. They also find a cool breeze to settle in to transfer their body heat into the air and other ways for them to regulate their body temperature. Their well-being should have a regular place where they can be at ease and easily meet what they need.

4. SIGNIFICANCE OF THE STUDY

The importance of this research is to support the responsibility of pet owners, specifically to the ones having pet dogs indoors, to provide better maintenance and quality of life for their dogs inside our homes. A recent survey conducted by Royal Canin in the Philippines, only 20% of local pet owners consult with their veterinarians at least once a year while the other 80% bring in their pets to veterinarians only when they are already sick. The common cases wherein pet owners consult with their veterinarians when their pets are already having a high fever. This research proposes an automated system installed in a small doghouse that can detect the temperature and humidity of the doghouse and regulate it with the use of fans and a heating element. This will help pet owners monitor and regulate their pet dogs' surrounding temperature whenever they are in and out of their homes. The system can be mainly accessed through Bluetooth to be able to modify and interact with the system when needed. With these alarming situations, there is a need to emphasize the importance of general health for our pets. This research can also provide an opportunity for the pet care industry to look upon as a solution for temperature-controlled environments for their dogs.

5. DESCRIPTION OF THE SYSTEM

The system is comprised of the NodeMCU ESP8266 as the main processor of information acquired from the sensors and actuators. The HYT939 is an industrial-grade temperature and humidity sensor that is precisely calibrated with an accuracy of ±1.8 % RH and ±0.2 °C. The sensor can be accessed through the I2C communication protocol through the SDA and SCL lines. The temperature setpoint is received as the input of the system and will be regulated by the fuzzy logic controller. According to the American Kennel Club (AKC), a temperature of 101 to 102.5 degrees Fahrenheit (38.3 to 39.2 degrees Celsius) is typical for dogs as this will be the temperature range of the system will rely on. TMD26721 Infrared Digital Proximity Detector is utilized as the motion sensor in the system to indicate whether the dog has entered the doghouse to start and stop the operations of the system. Three 12V DC fans are used as the cooling system of the doghouse and are connected to three corresponding 5V relays that will act as the switch. A heating element rated at 40W is utilized as the heating system that is compact and designed for dynamic natural convection heating. It will also be connected to a 5V relay that will act as the switch. The Bluetooth module HC-05 is used as the wireless communication medium to access the system and modify it depending on the users' needs and goals. The Fuzzy Logic Controller will be designed and constructed from Matlab R2019b which will set the rules and conditions of the system.

6. METHODOLOGY

6.1 NodeMCU ESP8266

The NodeMCU is very popular open-source hardware and has a wide range of applications that are composed of a very affordable SoC called the ESP8266. Its pin layout is illustrated in Figure _ and is powered through the micro-USB port from a 5V adapter typically used in phone chargers. It will respectively power the sensors, actuators, and modules through the microcontroller. Figure-1 shows the NodeMCU pin layout.

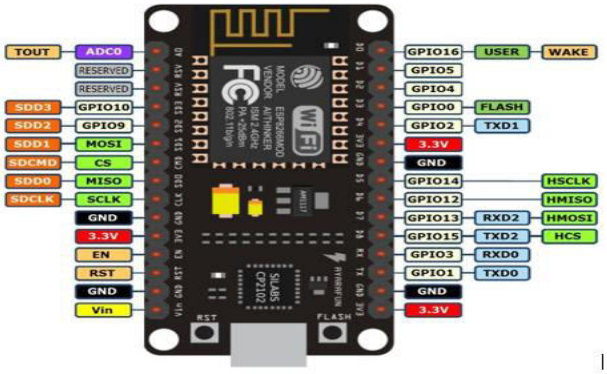

Figure-1. NodeMCU pin layout.

6.2 NodeMCU ESP8266 Compatible I2C Shield

The NodeMCU ESP8266 I2C Shield is specifically designed to easily interface I2C-compatible devices with its integrated I2C expansion port. The NodeMCU microcontroller can easily be inserted on top of it and will still be powered through the microcontroller's power supply. Figure-2 shows the NodeMCU I2C Shield

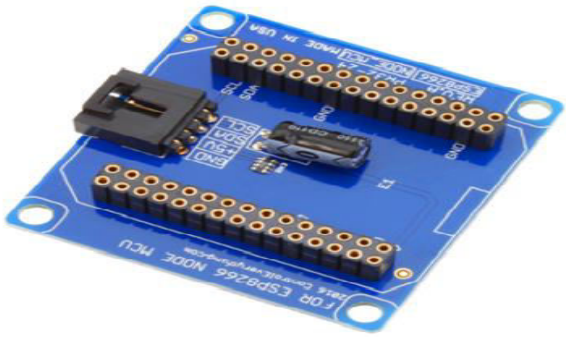

Figure-2. NodeMCU I2C shield.

6.3 Matlab R2019b

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment. Built-in graphics make it easy to visualize and gain insights from data [9]. Figure-3 shows the logo of Matlab R2019b.

Figure-3. Matlab R2019b.

The Fuzzy Logic Designer app lets you design and test fuzzy inference systems for modeling complex system behaviors. Mamdani fuzzy inference systems are utilized as the attempt to control the temperature in the system. This is shown in Figure-4.

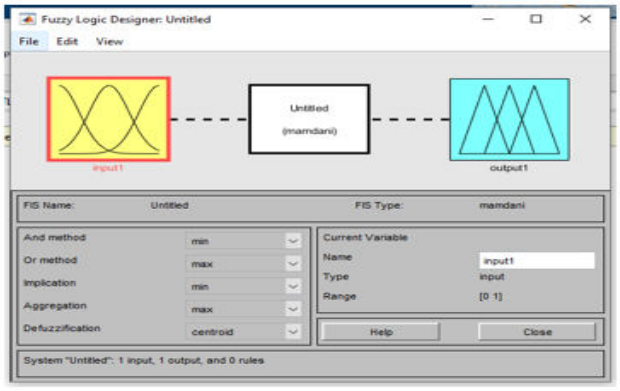

Figure-4. Fuzzy logic designer in Matlab.

6.4 AT-09 BLE Bluetooth 4.0 Module TI CC2541 (HM-10)

The AT-09 is a module that contains a B.L.E. chip (CC2540/CC2541) and allows us to perform serial communication through the RX and TX pins of the module. It can be powered by either 5V or 3.3V from the microcontroller. Figure-5 shows the HM-10 B.L.E. module.

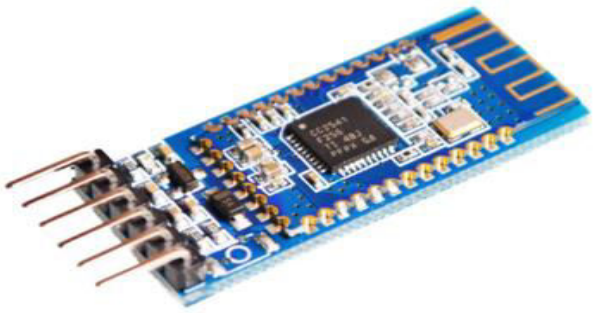

Figure-5. HM-10 B.L.E. module.

6.5 Sensors

6.5.1 HYT939

The HYT939 Humidity and Temperature Sensor is an industrial-grade sensor used to measure humidity and temperature. It can operate at temperatures ranging from -40C to 125C. It also has an accuracy of 1.8 % RH (humidity) and 0.2 C (temperature). It requires 2.7V to 5.5V input to operate. Figure-6 shows the HYT939 Temperature and Humidity Sensor.

Figure-6. HYT939 temperature and humidity sensor.

6.5.2 TMD2672

The TMD26721 is an infrared digital proximity detector and has a data rate of up to 400 kbit/s. This device includes improved features, such as signal-to-noise frequency and accuracy. Figure-7 shows the TMD2672 I.R. Proximity Sensor.

Figure-7. TMD2672 I.R. proximity sensor.

6.6 Actuators

6.6.1 12V DC Fans

Corsair 12VDC magnetic levitation fans will be utilized in this research and will be powered through a 12V battery. It will also be connected to a 5V relay that will serve as a switch in the system whenever it will be activated or deactivated. Figure-8 shows the Corsair 12VDC Fan.

Figure-8. Corsair 12VDC fan.

6.6.2 Heating Element

Blizzard-50H PTC heating element is rated at 40W and is connected to a voltage supply ranging from 100-240 VAC. Its features include dynamic natural convection heating, self-regulating, compact, and powerful design. Figure-9 shows the Blizzard PTC 40W heating element.

Figure-9. Blizzard PTC 40W heating element.

7. REVIEW OF RELATED LITERATURE

The paper of [10] presented in their paper a detailed and innovative approach in terms of utilizing Bluetooth Low Energy as a medium of wireless communication among home devices and applications. The research paper also proposed an effective power management system with the help of a fuzzy logic controller that determines the sleeping time of the devices according to the battery level and throughput to workload. Bluetooth Low Energy (BLE) has been a considerable technology in regard to the application of the Internet of Things due to its inexpensive cost, low power, and small-scale [11]. The evolution of internet-connected devices has given additional features and solutions in multiple ways of accessing the network and communicating with other devices. Smart home systems have a number of wireless communication mediums to lean on ranging from Bluetooth, BLE, IEEE 802.15.4, and IEEE 802.11. Energy efficiency is an important aspect that makes a wireless protocol ideal as many nodes or devices are battery powered. The research paper proposed B.L.E. due to the instability of other wireless protocols to be able to meet low power consumption, cost, and network efficiency. A comparison of the mentioned wireless protocols was also demonstrated in the research paper with its different applications which made BLE stand out in terms of simplicity and economical purposes. The proposed system architecture comprised of light control, smart energy, security, safety, and application of fuzzy logic control. The simulations of the master and field nodes were conducted and built with Matlab and Simulink. Sleeping time and transmission power were set as the input parameters through a feedback loop system.

The paper of [12] performed a comprehensive study and research about latency performance of Bluetooth Low Energy (BLE) networks. The goal of Bluetooth Low Energy is to provide wireless communication among devices with the direction of low power consumption and low cost. The research paper focused on the performance of the BLE protocol, specifically on discovery probability and discovery latency, which are important parameters in evaluating the technology. Transmission of data through BLE is noteworthy as it has a functionality that can receive and transmit a vast amount of data. Technical specifications were also discussed as to how Bluetooth Low Energy is considerable compared to classical Bluetooth. Classical Bluetooth uses 79 channels while BLE is operating in the 2.4GHz ISM band using 40 channels. The latter has a unique functionality that 3 channels out of the 40 are being used for broadcasting purposes and device discovery while the other channels are used for data transmission. It may operate in three distinct manners such as advertising, scanning, and initiating. The research team extensively simulated and undertook several procedures in measuring the discovery latency and sensitivity of BLE which fully complies with the protocol specifications. An increasing number of BLE devices, delays of device discovery show an exponential growth despite the usage of three advertising channels and tiny-sized frames.

The paper of [13] presented a control system that can regulate the temperature with the aid of sensors, fuzzy controller, actuators, and an input keypad. The research paper demonstrated the important functions and steps needed to understand as to how the fuzzy controller plays a major role in the system. The main goal of the system is to control the temperature by using the LM35 temperature sensor as the feedback element in the system. A setpoint temperature is given as an input from the user with the help of the 4x4 matrix membrane keypad. The error signal is determined by subtracting the temperature sensory data from the setpoint value which is passed onto the controller as an input. The purpose of the controller is to assure that the desired output temperature is met and controlled. The output of the controller is fed to the actuator, which is the fans and heater, in the form of PWM. A systematic approach in creating a fuzzy logic system is discussed and is comprised of four significant parts: Fuzzification, Membership functions, Rules, and Defuzzification. The importance of the algorithm behind the system is that the rules must be evaluated and clearly defined to produce the desired output which will then be compared to the sensory data. Triangular and trapezoidal membership functions were utilized as the means of input fuzzification.

The paper of [14] performed experiments on unanesthetized dogs measuring and monitoring their temperature regulation resting at various standardized thermal conditions. The "thermal clamp" was utilized to manipulate the hypothalamic temperature. Hypothalamic, rectal, and skin temperatures were constantly monitored and recorded in the experiments in which the dogs were settled in hot (35-38 °C), warm (30°C), neutral (25°C), and cold (10-15°C) environments. The research paper presented that the dog's initial hypothalamic temperature remains at about the same level during steady-state experiments in widely different thermal environments. The dogs were able to demonstrate valuable heat production and heat loss in regard to their body temperature regulation even in controlled environments.

8. THEORETICAL CONSIDERATIONS

There are 3 main versions of the Bluetooth technology that cater to different applications and specifications, namely: Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR), Bluetooth Low Energy (BLE), and Bluetooth Mesh. Bluetooth technology supports a variety of networking topologies that ensures interoperability among other devices equipped with the same technology [15]. Bluetooth Basic Rate was first introduced in 2002, Enhanced Data Rate was established in 2004, Bluetooth Low Energy was launched in version 4.0 in 2010 and Bluetooth Mesh was implemented as a computer mesh networking system that was conceived in 2014 as well [16]. The first version operates in the 2.4GHz ISM band with Radio Frequency channels spacing at 1MHz. Basic Rate utilizes Frequency Modulation to minimize transceiver complexity while Enhanced Data Rate uses PSK modulation. The operation of Bluetooth is made up of several protocols such as radio, baseband, RFCOMM, SDP, LMP, L2CAP, and HCI [17]. Data is transmitted through the 79 channels that are divided into 625-microsecond time slots [18]. Bluetooth Low Energy has a unique functionality of low duty cycles that guarantees the application of the technology to many types of health and fitness devices [19]. To enable reliable operation in the 2.4 GHz frequency band, it leverages a robust frequency-hopping spread spectrum approach that transmits data over 40 channels. BLE supports data rates from 125 Kb/s to 2 Mb/s, multiple power levels, from 1mW to 100 mW power consumption, and multiple network topologies that make it flexible. Bluetooth Mesh was standardized as a publishing and subscribe model similar to MQTT in which it acquires a unique unicast address whenever joining a network [20].
I2C is commonly utilized as a serial communication protocol in connecting devices and peripherals like microcontrollers, Analog-to-Digital converters, input and output interfaces, and other components used in embedded systems. The protocol mainly uses two signal lines which are the SCL (Serial Clock) and SDA (Serial Data) lines that both are needed to be pulled up with a resistor to +VDD [21]. Virtually, the number of nodes and devices that can be connected within the protocol is limitless [22]. Master devices generally must consist of an onboard processor capable of programming I2C signals and they are the ones initiating the communication process. Slave devices need a unique address in order for the master to identify them distinctly. Several conditions and signals are being processed by the master to relay data and commands to and from the slave devices.

The concept of Fuzzy Logic was first introduced as the Fuzzy Set theory and is continuously evolving with numerous applications from Economics, Robotics, Programming, Decision Making, Control Systems, and Education. There may come a time in our lives that some definitions do not have a clear meaning and boundaries [23]. A number of processes and patterns are programmed as inputs, outputs, and rules in fuzzy logic systems to aggregate data and form a number of partial truths which in turn, will produce minimized error in our desired results. Its architecture consists of a rule base, fuzzification, inference engine, and defuzzification. Membership functions play a major role in the system in which it defines how each point in the input space is mapped to membership value between 0 and 1. Triangular, trapezoidal, and Gaussian membership functions are commonly utilized in several applications [24].

9. DATA AND RESULTS

Figures 10 and 11 shows the sensor readings.

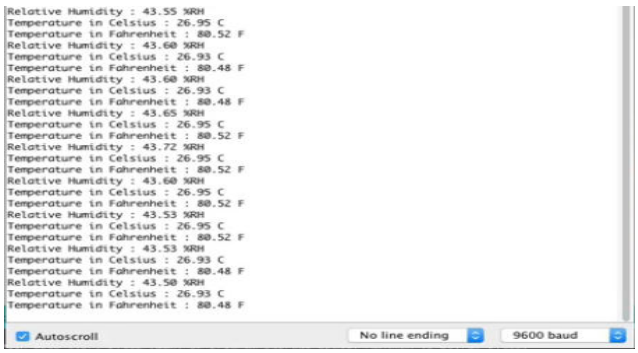

Figure-10. HYT939 temperature and humidity readings.

Figure-11. TMD26721 proximity sensor readings.

Table-1 shows the Actuator states vs Temperature data range.

Table-1. Actuator states vs temperature data range.

ACTUATOR	STATE	TEMPERATURE RANGE
12V DC Fan	Low	Cold (0-20°C), Neutral (20-30°C)
	Medium	Warm (30-35°C), Average (35-40°C)
	High	Hot (40-50°C)
Heating Element	ON	Cold (0-30 °C)
	OFF	Warm (30-40°C), Hot (40-50°C)

Figure-12 shows the user interface.

Figure-12. Blynk App User Interface.

Figures 13, 14, and 15 presents the Mamdani fuzzy logic design, fuzzy rule system, and surface map using Matlab.

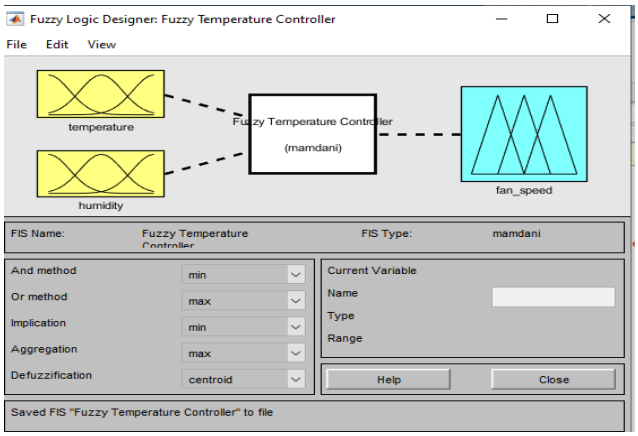

Figure-13. Fuzzy Logic Designer (F.L.D.) GUI.

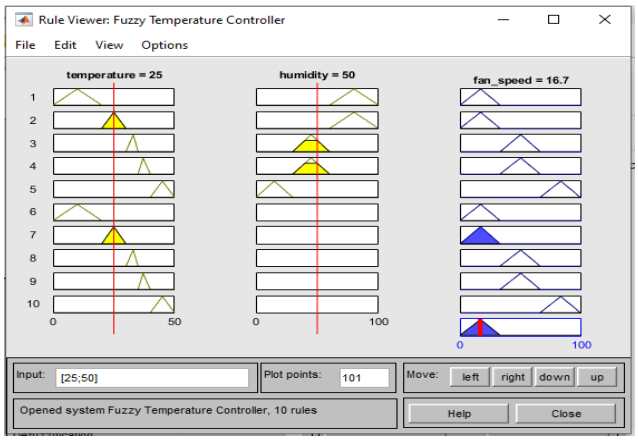

Figure-14. F.L.D. rule viewer.

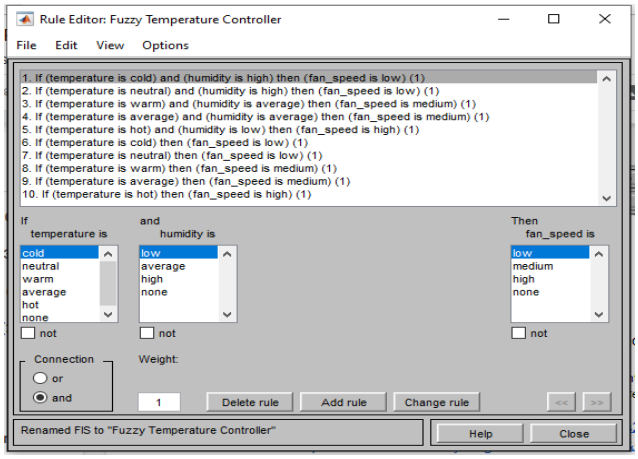

Figure-15. F.L.D. rule editor.

Figure-16 shows the Surface Map.

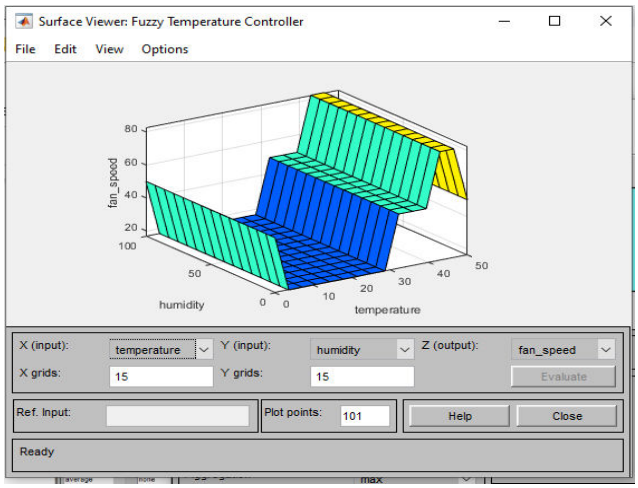

Figure-16. F.L.D. surface map.

10. ANALYSIS OF DATA

The resulting data was sufficient, and the corresponding output produced by the fuzzy logic controller was crisp. The NodeMCU ESP8266 microcontroller is powered by the micro-USB port and is also responsible for powering the different nodes connected to it. The microcontroller was integrated with the HM-10 Bluetooth Low Energy module as the mode of transmitting and receiving data wirelessly within the range. HYT939 yielded temperature data in terms of degrees Celsius and Fahrenheit while relative humidity in terms of percentage R.H. TMD26721 produced a digital output from the infrared proximity sensor that whenever an object or the dog, in this case, is nearby, the output value decreases and vice versa. The operations of the whole system will only activate whenever the pet is in the doghouse to improve power consumption whenever the pet is not nearby. The microcontroller and nodes will be in standby mode and will receive input from the infrared proximity sensor.

The states of the actuators (12VDC fan and heating element) are demonstrated in Table-1 and will act accordingly depending on the temperature range. The temperature range for cold is from 0°C to 20°C, neutral is from 20°C to 30°C, warm is from 30°C to 35°C, the average is from 35°C to 40°C, and hot is from 40°C to 50°C. The speed of the fans will be regulated from a low, medium, and high by utilizing Pulse Width Modulation depending on the temperature data acquired from HYT939. Figure-11 presents an overview of the Blynk mobile application User Interface that is configured to connect with NodeMCU via Bluetooth Low Energy. The surface map summarizes the output surface of the fuzzy system with the two inputs as temperature and humidity while the corresponding output is the fan speed.

11. CONCLUSIONS

This research paper focuses on the aim of wirelessly connecting a fuzzy-based temperature controller via Bluetooth Low Energy for indoor pet dogs. Bluetooth Low Energy stands out as a considerable wireless communication protocol as it consumes low power and is low-cost [25]. The approach is to utilize Bluetooth Low Energy and implement a Mamdani fuzzy logic controller to regulate the environment's temperature inside the dog house within the ideal range of 38.3°C to 39.2°C. A variety of sensors such as HYT939 and TMD26721 were put to use as the feedback element in the system which will then be analyzed by the controller to produce the necessary output to the 12VDC fans. The application of a fuzzy system is indeed remarkable in terms of regulating the temperature within an environment. It is ideal to acquire robust and accurate sensors to produce accurate outputs as a result. Visual representation of the data was achieved through the open-source platform, Blynk, that is configured to interact and communicate with NodeMCU and Bluetooth Low Energy. An alarming matter has been raised due to the ignorance of pet owners to their pet dogs' health and well-being. This prototype will significantly assist the need of pet owners to control the environment's temperature of their respective dogs. It offers convenience and automation for both the pet dogs and the owners to improve their quality of life

12. RECOMMENDATIONS

This research paper has demonstrated a fuzzy approach to regulating temperature and humidity for indoor pet dogs as well as providing a heating and cooling system. There are more ways for improvement such as researching and modifying the system for other indoor pets, using other types of fuzzy inference systems can yield better output response and other features built with it, measuring signal strengths of Bluetooth Low Energy protocol, an in-depth analysis, and comparison of other wireless communication protocols, and applying the technology in the Internet of Things. Takagi-Sugeno Fuzzy Inference Systems differ from the Mamdani approach with the output membership functions, aggregation and defuzzification, mathematical rules, and more adjustable parameters [26]. Adaptive Neuro-Fuzzy Inference Systems is an artificial neural network system based on the Sugeno Fuzzy Inference System and

integrates both neural networks and fuzzy logic. ANFIS is useful whenever you have a collection of input and output data that you want to model and train data accordingly. Matlab is fully equipped to deal with the said different methods of fuzzy logic and neural network applications.

A comprehensive study can also be done with Bluetooth Low Energy as long as the specifications of the technology are followed and referenced. Distance estimation can also be studied with regard to the protocol [27]. Wireless Sensor Networks play a major role in the field of the Internet of Things (IoT) and measuring their respective Received Signal Strength Indicator, latency, and propagation speeds will ensure the reliability and performance in certain environments [28]. There are other available Application Programming Interface (API) that is compatible with Bluetooth Low Energy to determine the flexibility and performance of the protocol as compared to other interfaces [29]. It will be substantial to learn how BLE discover devices, query for services, and transmit information in other applications and implementations. It is also important to be aware of possible interferences that Bluetooth Low Energy might encounter so as to minimize the signal errors [30].

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