DESIGN AND DEVELOPMENT OF FUZZY LOGIC ALGORITHM WITH VARYING SETPOINTS FOR FAN SPEED CONTROL SYSTEM USING ARDUINO MICROCONTROLLER

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ABSTRACT

This study presents the design and development of fuzzy logic algorithm for speed control system using Arduino microcontroller. In this study, the proponents control the speed of the fan in meeting the Set Point. The temperature control system makes use of Matlab Fuzzy Logic Toolbox. The Sugeno style of fuzzy inference system and triangular membership functions were used in the control system. Moreover, the fuzzy logic algorithm was derived in C language and realized in Arduino IDE. The proponents make use of the trial and error method to obtain the desirable output in meeting the Set Point. The input parameters are voltage error and change in error. These parameters are classified as "Zero (Z)", "Positive (P)" and "Negative (N). The output parameter is the voltage output, which was classified as "Very Cold", "Cold", "Warm", "Hot" and "Very Hot". The system makes use of a look up table for ease of complexity of the fuzzy control. It was verified experimentally that the results obtained by the proponents were credible.

Keywords: *Speed control system, Arduino IDE, Matlab Fuzzy Logic Toolbox, Fuzzy Logic Algorithm, C Language.*

INTRODUCTION

This section of research aims to explain and deliberate the workings of the study. It includes the statement of the problem and the objectives set by the proponents. Also, it comprises the importance and the limitations of the study. This section measures the viability of the thesis.

Background of the Study

According to Rush Limbaugh, "When you talk about change, you know what makes it really tough for people is on the one hand you've got tradition, and on the other hand you've got change; in many people's mind, change equals modernization." In this quotation that Limbaugh had quoted, he is emphasizing that transformation in today's innovation is needed.

As of our present generation, technology is growing at a rapid pace wherein it serves as the core of innovation, which undergoes significant transformation. In today's generation, there is a certain fad in technology called the automatic control system wherein it is an application of control conjecture for directive of progression with no direct human intrusion. Nowadays, the automatic control system had been used in industrial applications because of its significance in the applications of a certain controller, which compares certain measured value of a process with a desired set of values in such a way the process stays at its set point despite disturbances.

On the other hand, process controlled systems are often nonlinear and tough to control precisely, One of those systems is the Speed Control wherein it is an intentional change of the drive speed to a value required for performing the specific work process [1].

In some studies, the well-known Proportional Integral Derivative (PID) controllers are used in controlling systems like temperature control. Because of its simplicity and efficiency for linear systems, the PID controllers are used for industrial processes. The difference between a measured process variable and a desired set point were calculated by the PID and the manipulated variable is used for adjusting the process of the controller in minimizing error [2].

However, there are drawbacks in PID controllers. It has been proven that fuzzy logic has more efficient results and precise outcomes. Certainly, fuzzy logic has begun as one of the dynamic areas of study particularly in control applications. It is indeed a very prevailing process when measured models are not accessible and input data are inaccurate. Compared to conventional controlled mechanisms such as PID, fuzzy logic is definitely more useful and accurate.

Fuzzy logic system is much closer to human thinking and natural language than traditional logical systems. Fuzzy Logic controller (FLC) based on Fuzzy Logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzification, defuzzification strategies and fuzzy control rules are used in Fuzzy reasoning mechanism [3].

The temperature control system can be implemented using a microcontroller like Arduino IDE. The Arduino is a simple microcontroller board and an open-source physical computing platform. The variety of lights, motors and other physical outputs can be controlled and it can be used to develop interactive objects, taking inputs from a variety of switches or sensors [4].

In this study, the proponents will integrate the concepts and principles of fuzzy logic for temperature control system and realize it in an Arduino microcontroller.

Statement of the Problem

Although PID controllers is the simplest and often the most effective controllers, its mathematical model is difficult to obtain and its capabilities are limited especially when complex processes are required to perform a task. The reason why some specific industries use larger or more expensive controllers is because PID is only capable of measuring varying inputs and calculates the difference between them[5]. In addressing the problem with traditional control techniques, the proponents make use of the fuzzy logic control algorithm.

Fuzzy logic controller has been proposed by many researchers to lighten the dependency on the mathematical model. This tool is very strong considering that it has excellent resistance to external disturbances [6]. Non-linear characteristics can be realized using FLC unlike the conventional controller that exhibits poor performance when applied to non-linear systems. It can work with less precise inputs, more robust in nature and it does not need fast processors [7]. However, due to complex and heuristic assessment, its process requires extensive computational power [6]. In general, for flow measurement and control applications, fuzzy logic controller is a good alternative to conventional controller considering that it has better stability, small overshoot, and has fast response [7].

The proponents will incorporate the fuzzy logic algorithm in Arduino microcontroller for temperature control system. There are various Programmable Logic Devices (PLDs) such as FPGA, PIC Microcontroller, DSP and many more, but the proponents choose Arduino because due of its advantages over other PLDs. It is relatively inexpensive compared to other microcontrollers and the software of the Arduino runs on Windows, Macintosh OSX, and Linux operating systems. The programming environment of Arduino is easy-to-use for beginners, so students learning the program in that environment will be familiar with the look and feel of Arduino. Also, the software is published as open source tools, which makes it available for further extension by experienced

The proponents conducted this study to address the following problems:

a) How to program fuzzy logic in Arduino IDE?
b) How to develop fuzzy logic controller using Arduino for temperature control system?

Objectives

1.3.1 General Objective

The main objective of this study is to design and simulate a fuzzy logic controller for temperature control system using Arduino Microcontroller with the aid of Arduino IDE.

1.3.2 Specific Objectives

- To explore the functionality and basic applications of Arduino microcontroller;
- To describe the fuzziness in speed control system;
- To realize the fuzzy logic algorithm for speed control system in Arduino microcontroller; and,
- To test and evaluate the performance of fuzzy logic control system.

Significance of Study

The conventional Proportional Integral Derivative (PID) controllers have been widely used because of its simplicity and effectiveness for linear systems, especially for first and second order systems, but it cannot be used for higher order [8]. However, PID controllers require special calculations for initialization and the specific initialization is dependent on the particular form of the PID control algorithm [9]. It also have limitations such as difficulties in the presence of nonlinearities, may have trade-off regulation versus response time, do not react to changing process behavior, and have lag in responding to large disturbances [10].

Today, fuzzy logic has been adopted by many researchers due to its simplicity in calculation. The proponents will only need to set for fuzzy rules, which will fit the system and any reasonable number of inputs can be processed and numerous outputs are generated [11].

Fuzzy logic is an innovative technology for designing solutions of multi-parameter and non-linear control models. The fuzzy logic has numerous applications and is used to solve the real world problems such as image processing, robotics/motion control, pattern recognition, fuzzy database and industrial engineering [12]. The fuzzy logic can also be used as an alternative design method to nonlinear controllers. [6]

The advantages of using fuzzy logic in temperature control system are: they are cheaper to develop, they cover a wider range of operating conditions, and they are more readily customizable in natural language terms [13].

This study will design, develop and integrate series of machine experiments using Arduino as the microcontroller unit in controlling the temperature wherein the fuzzy logic algorithm will be used. The novelty of this research is the constants to be obtained using Sugeno-style of fuzzy inference system, which would serve as its main controller for temperature control. This research helps the proponents to enhance the knowledge in Arduino technology and fuzzy logic algorithm. This study may also be used as a good reference for future studies.

Scope and Limitation of the Study

In this study, the proponents will use fuzzy logic for temperature control system and it will be implemented in an Arduino Atmega 2560. The proponents will make use of Sugeno style of fuzzy inference system to fine tune constants for desirable crisp output. In this study, the proponents will be performing experiments and simulations for LCD modules, testing of functionality of the Fan with the relay, temperature sensor, Heat Lamps and LED displays. These experiments and simulations will be integrated to produce the whole fuzzy system for temperature control system. In the fuzzy logic algorithm, the triangular membership functions of the FLC will be constructed and it has five (5) classifications such as *“Very Cold”, “Cold”, “Warm”, “Hot”* and “Very Hot”.

Two input variables, error (e) and change in error (de) are used in this fuzzy logic system. A rule table is then constructed on a two-dimensional (2-D) space. This scheme naturally inherits from conventional proportional-integral derivative (PID) controller. The single output variable (y) served as the voltage output. This will be optimized using trial and error method using DevCpp and Matlab Fuzzy Logic Toolbox. The voltage ouput will be fed to the input of the Microcontroller Unit (MPU) that will be used in controlling the temperature.

The code will be uploaded on the Arduino IDE (Arduino Atmega 2560) and based on external temperature condition the MPU will make decisions from the classifications. The output behavior of the Fan and the Heat Lamp will decide whether the temperature needs to be decreased or increased.

METHODOLOGY

Proposed Design

The proposed project aims to develop a speed control system, which can control the speed of the fan. The velocity of the fans will be controlled using fuzzy logic. The speed of the fan depends on the temperature sensed by the system. Speed control is dependent on the constructed triangular membership functions; the speed of the fan will increase/decrease. The triangular membership functions were coded using Sugeno-style of fuzzy inference system fuzzy algorithm.

The system consists of computer, 5 LEDs, 1 LCD, 2 Fans, 2 heat lamps, Arduino Atmega 2560 as the control unit and the fuzzy logic algorithm to control the temperature of the system. Also, the temperature sensor will be used by the system in reading the temperature. This will give information to the microcontroller. The proponents will implement the prototype in a house wherein it serves as the environment of the whole system.

Fuzzy Logic Controller

The concept of Fuzzy Logic (FL) was presented not as control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. It was conceived and introduced by LotfiZadeh, a professor at the University of California at Berkley. This is the principle behind the Fuzzy Logic System wherein Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control. Furthermore, the Fuzzy Logic (FL) is define as a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. The Fuzzy Logic has an approach to control problems mimics how a person would make decisions, only much faster and it can be implemented in hardware, software, or a combination of both. In addition, FL requires Fuzzy Rules and Inference to transform fuzzy input sets to crisp outputs [14].

The Fuzzy Logic doesn't attempt to model a system mathematically, on the other hand it incorporates a simple rule – based IF X AND Y THEN Z approach to solve a control problems. It was based on the operator's experience rather than the technical understanding of the system. In addition, some numerical parameters are needed in order to operate fuzzy logic [14].

The first step in designing Fuzzy Logic System is to describe fuzzy sets, the information in terms of fuzzy linguistic terms or can be regarded as values equal to 0 or 1 and values within them. The fuzzy membership function is used to assign values with respect to fuzzy sets and its degrees of membership. Moreover, the most commonly used technique requiring four parameters to be specified with respect to its x and y coordinates is called Trapezoidal Membership Function. Also, the Triangular Membership Function can be used in the system which requires three parameter specifications [14].

Arduino Board

Arduino is an open source hardware and single board microcontroller which consists of an Atmel 8-bit AVR microcontroller with complementary components that facilitate programming and incorporation into other circuits. It has USB interface, 6 analog input pins, and 14 digital I/O pins that accommodate various extension boards. The Arduino was introduced in 2005 by Aquino' designers for the student's project at Interaction Design Institute Ivrea in Ivrea, Italy. The named "Arduino" comes from a bar in Ivrea, where some of the founders of the project used to meet. They sought to provide an inexpensive and easy way for hobbyists, students, and professionals to create devices with the used of sensors and actuators to interact with their environment. The Arduino can be runs on regular personal computers using the C or C++ by the aid of integrated development environment (IDE) [15].

Software Flowchart

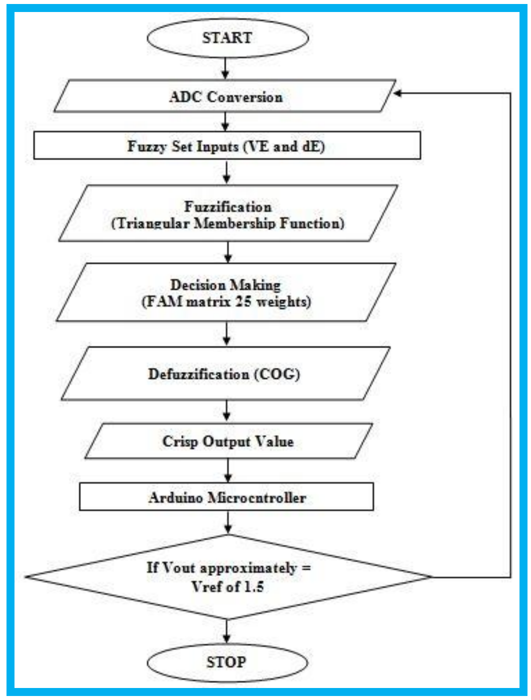

Fig 2.4.1Software Flowchart for Trial and Error

In the figure above, ADC conversion is needed to convert the analog values to digital fuzzy inputs. The fuzzy sets will be deffuzified and it will give a crisp output that will be fed to the speed control system using the Arduino Microcontroller. The cycle continues until the desired output voltage (Vref) is achieved.

Hardware Block Diagram

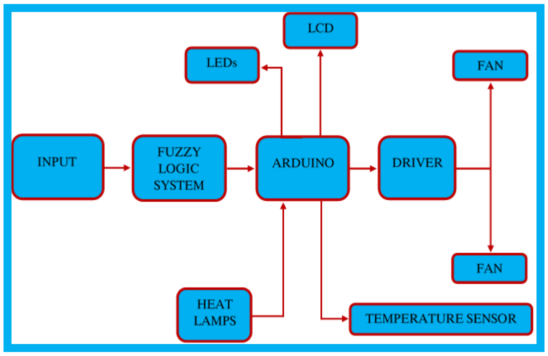

Fig 2.5.1 The Block Diagram of Fuzzy Logic Temperature Controller with Arduino Microcontroller

In the Figure 2.5.1, it shows the block diagram of the Fuzzy Logic Speed Control System. To start, using the fuzzy logic toolbox which comes from the MATLAB sofware, initialize the inputs in the fuzzy interference system for making the fuzzy logic rules. Then, the output (defuzzified values) of the fuzzy logic system will be fed to the input of the Arduino Microcontroller by converting the values to the codes for the Arduino IDE. Program the LED Displays, Temperature Sensor, Fan, the Driver, the Heat Lamps and the LCD with the converted values of the fuzzy logic output values and upload the program to the arduino IDE software. The temperature will be displayed in the LCD and the LEDs will turn on which depends on the temperature. When the temperature is higher than the setpoint the fans will turn on.

DESIGN CONSIDERATIONS

The Prototype

Figure 3.1.1 The Prototype.

Figure 3.1.1 shows the miniature house with electronic speed controller system with the principle of varying an electric motor's speed. It was designed to provide conversion of the sense temperature to its corresponding voltage. The converted voltage corresponds to the speed level of the fan. Basically, the system comprise of heat lamp, fan and temperature sensor. The sensor is placed near the halogen lamp. This heating mechanism has its own AC supply. The amount of power delivered to the fan can be controlled by fuzzy logic algorithm through serial port using ARDUINO microcontroller.

The proponents assigned different set points, which are identical to the constructed five (5) membership functions:

Table 3.1 Membership Function

Very Cold	15°C to 20°C
Cold	21°C to 24°C
Warm	25°C to 28°C
Hot	29°C to 37°C
Very Hot	38°C to 49°C

As shown in Table 4.1.2, the warm category has the range of values 25˚C to 28˚C. In this study, the proponents considered using such values as target set points. This means that the speed of the fan stops whenever the set temperature ranges were achieved. The LM35 sensor is used in sensing the current temperature. The controller calculates the error between set point value and current value. The calculated voltage and change error were used as input functions to the fuzzy logic. The inputs being fed will undergo fuzzification process, so as to calculate its degrees of membership. After gathering data and brainstorming, the proponents decided to designed a miniature house prototype, which composed of two (2) different room sections, one with 2 heat lamp and fan, and the other with 1 lamp and fan which is smaller than the first one. Also the proponents decided to make a separate circuit box in creating the circuitry and in ensuring that all wirings were properly installed. Building the final prototype is composed of low cost resources and salvaged parts; it was very mind-numbing because almost everything is handmade. The components and hardware are composed of 1 ACEduino@2560 board, 1 Liquid Crystal Display, 2 fans, 2 halogen lamp, 1 LM35 sensors, 4 PCB's, 2 transistors BD139, 2 diodes 1N4001, 7 resistors, 2 Capacitors, and 5 LED lights. It took the proponents three (3) weeks to finalize the prototype and make sure that all components are secured and working properly.

Fis Editor of Speed Controller

3.2.1. Sugeno Fuzzy Inference Method

Sugeno Fuzzy model is a method of fuzzy inference proposed by takagi, sugeno used in this study for Matlab Fuzzy Logic Toolbox Simulation, A typical fuzzy rule in Sugeno fuzzy model has the form:

If x is A and y is B then z = f(x,y)

Sugeno has similarity to the mamdani method in several aspects, The fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator are exactly the same, the major distinction is that the sugeno output membership functions are either linear or constants that's why in this paper the proponents used sugeno fuzzy model considering the use of constant as output membership functions.

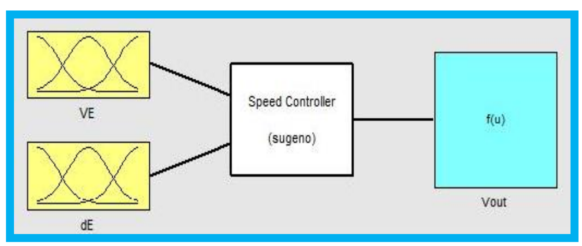

Figure 3.2.1Fis Editor.

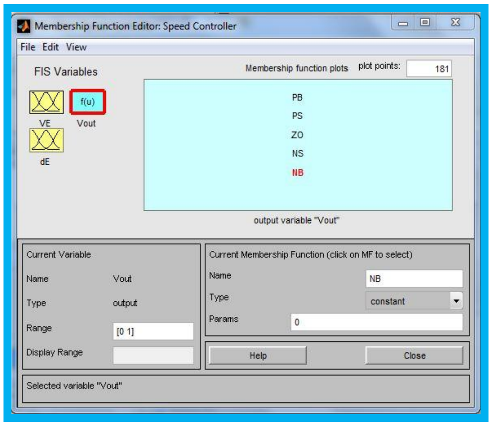

Figure 3.2.2 Membership Functions.

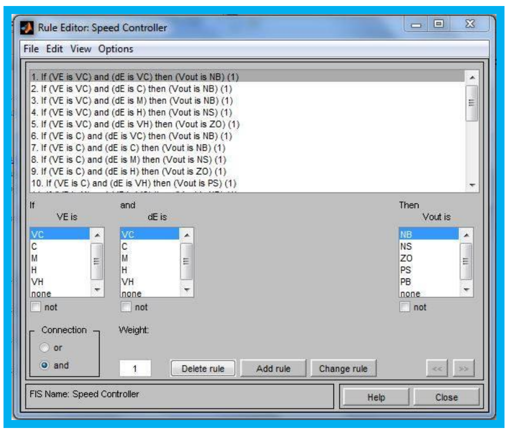

Figure 3.2.3 Rule Viewer.

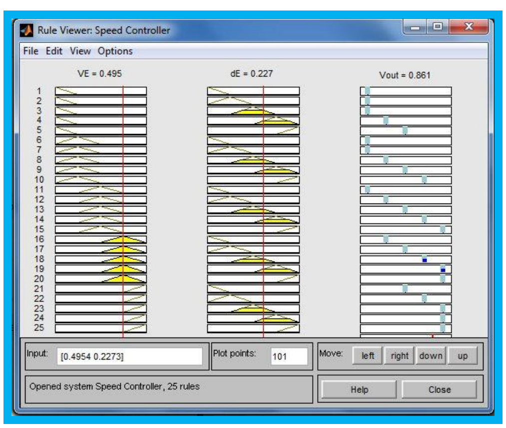

Figure 3.2.4 Fuzzy Rule Editor.

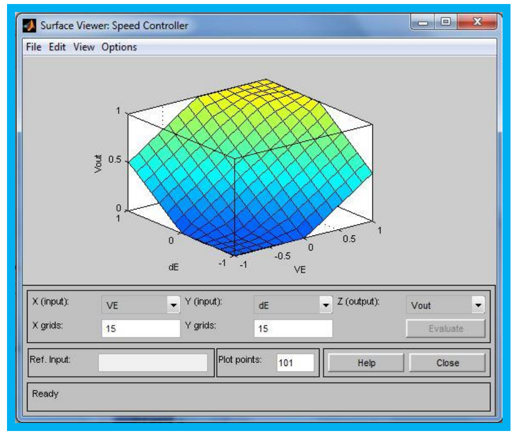

Figure 3.2.5 RULE VIEWER FIS Surface View

Figure 3.2.2, shows the fuzzy rule editor for the speed control system wherein it is constructed using look – up table. On the other hand, **Figure 3.2.3,** the crisp output or duty cycle is shown in the membership function editor and it is the output (Vout) or the crisp output for the fuzzy logic system. The graphical illustration of the rules for speed control system simulation purposes is elicited in **Figure 3.2.4.** The graphical illustration of the rules for the speed control is elicit in **Figure 3.2.5,** it includesthe surface view of the speed control system with voltage error in the x-axis, change in error in the y-axis and duty cycle or the crisp output (Vout) in the z-axis.

3.3 DevCpp Fuzzy Logic Controller

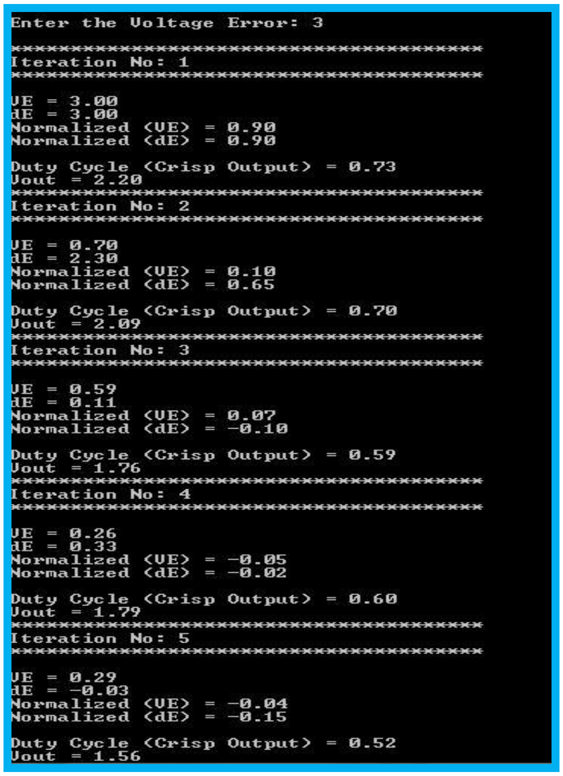

Figure 3.3.1 DevCpp program simulation.

On the Figure 3.3.1, the simulation for finding the crisp output or the duty cycle and the Vout is exhibited. Basically, the proponents make used of the trial and error method for the simulation in finding the Voltage Reference (Vref), which is 1.5 as set by the proponent. The voltage error and change in error is being computed in the program. In the simulation, the Vref was achieved after five iterations.

3.4 Arduino Simulation Output

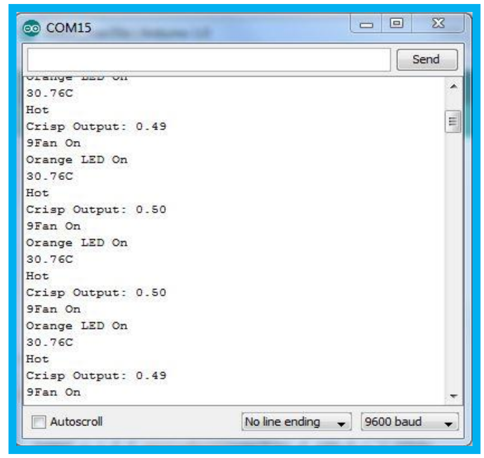

Figure 3.4.1 Serial Monitor Simulation (With fuzzy Logic Code).

In the figure shown above, it is the Serial Monitor where the data are being shown. It is made after verifying and uploading the codes to Arduino microcontroller in order to see what will be the output of the program. In the data shown, Fan is on when the temperature is above the set point temperature, fan will be off when it reaches the set point or the temperature is below the set point. When the temperature reaches the max temperature, the fan will be at full speed which is 100%. Also the temperature reading is also displayed in the serial monitor.

3.5 Project Capabilities

The main goal of the project study is the analysis of speed control in such system; that uses fuzzy logic algorithm into ARDUINO microcontroller. The prototype is a closed environment so that set points can be easily obtained. The systems includes Halogen lamps which will be the heating mechanism, the speed of fan is directly proportional to temperature sense by the temperature sensor, the proponents also includes indicators such as Liquid Crystal Display (LCD), and LED lights. The LCD displays the temperature in ˚C and ˚F as well as the Percentage Fan Speed. LED lights indicates changes in temperatures, Blue led for Very Cold; Green for Cold; White for warm; Orange for hot and Red for Very hot. Fan Speed is expected to be 100% at maximum temperature 45˚C and 0% for temperature 28˚C below.

3.6 Project Limitations

The system is not designed to control the temperature of the proposed environment, therefore the tests conducted and the results provided focuses on the response of the fan whenever the temperature changes, Also the system only use small scale of voltages which cannot support devices with outsized outputs.

3.7 Operation Guide

The prototype was designed to be a miniature house; it represents a closed environment that will make the temperature to be compact. When the sensor sense a temperature ranges from 29˚C up to Max Temperature of 49˚C the fan will operate. The speed of the fan is directly proportional to the sense temperature, when cooling down the Fan will automatically turn off when it reaches a temperature of 28˚C below.

3.8 Images of Connections

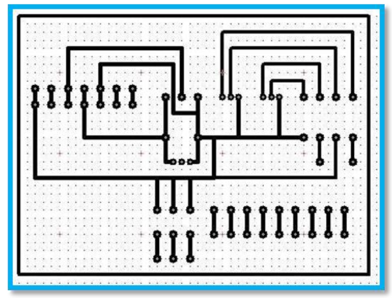

Figure 3.8.1 PCB connection of the main Board.

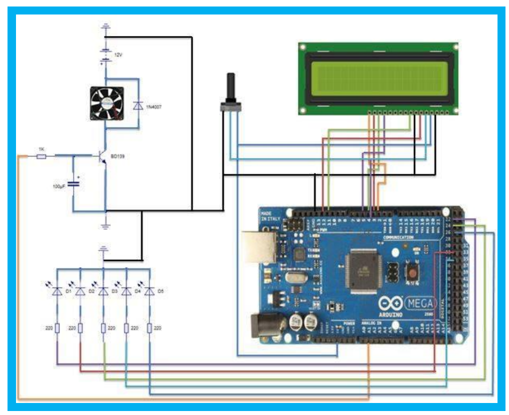

Figure 3.8.2 Wiring connection of the system.

EXPERIMENTS AND ANALYSIS OF RESULTS

The purpose of this chapter deals with the analysis and interpretation of data that was gathered by the proponents during the series of assessments and study of the entire system. Including the summarization of the thesis research the research suggestions and policy recommendations for further analysis.

The proponents records the voltage and Speed of fan (%) in every change in temperature, the experiments were done into two different environments "Controlled and Uncontrolled" as per of what our prototype represent. The results of the experimentations in ARDUINO are tabulated in the preceding pages including its respective graphs.

Table 4.1 Theoretical Values.

Temperature ˚C	Speed of fan	
	Voltage	(%)
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0.24	4.76
30	0.48	9.52
31	0.72	14.28
32	0.96	19.04
33	1.2	23.8

Temperature ˚C	Speed of fan	
	Voltage	(%)
33	1.2	23.8
34	1.44	28.56
35	1.68	33.32
36	1.92	38.08
37	2.16	42.84
38	2.4	47.6
39	2.64	52.36
40	2.88	57.12
41	3.12	61.88
42	3.36	66.64
43	3.6	71.4
44	3.84	76.16
45	4.08	80.92
46	4.32	85.68
47	4.56	90.44
48	4.8	95.2
49	5.04	99.96

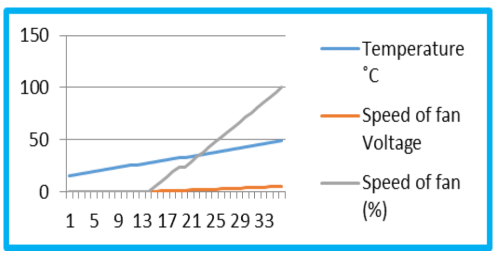

Figure 4.1 Graphical Representation of Theoretical Values.

The Figure shows the output voltage and the response of the fan in every change in temperature, each variable is directly proportional to each other. This is the expected system response of the study. In table 4.1 values highlighted with color orange are default to have zero output; the system starts to run at 29 °C.

Table 4.2 Data of 1st Trial "Controlled Environment"

Temperature ˚C	Speed of fan	
	Voltage	(%)
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29.3	0.13	4
29.79	0.73	4
29.79	0.73	4
29.79	0.73	4
30.27	0.94	9
30.27	0.94	9
30.27	0.94	9
30.27	0.94	9
30.76	0.94	9
31.25	1.15	14
31.74	1.15	14
31.74	1.15	14
32.23	1.36	19
32.23	1.36	19
32.71	1.36	19
32.71	1.36	19
33.2	1.57	23

Temperature ˚C	Speed of fan	
	Voltage	(%)
33.2	1.57	23
33.69	1.57	23
33.69	1.57	23
33.69	1.57	23
34.18	1.76	23
34.67	1.76	28
35.16	1.91	29
35.16	1.91	33
35.64	1.91	33
35.64	1.91	33
36.13	2.18	33
36.62	2.18	38
37.11	2.39	38
37.11	2.39	42
37.6	2.39	42
38.09	2.59	42
38.57	2.59	47
39.06	2.78	47
39.55	2.78	52
40.04	2.99	52
40.53	2.99	57
41.02	3.2	61
41.5	3.2	61
42.48	3.41	66
42.97	3.41	66
43.95	3.62	71
44.92	3.81	76
45.9	4.02	80
47.85	4.74	90
49.8	4.74	100

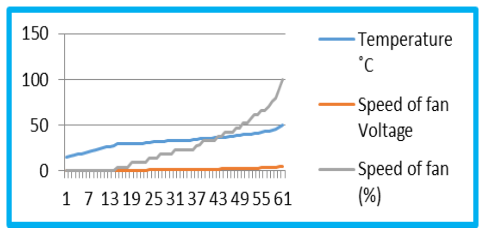

Figure 4.2 Graphical Representation of 1st Trial "Controlled Environment".

For the Controlled Environment the cover of the house is attached to the house. The fan turns on at 29.3˚C with fan speeds of 4% until it reach the Maximum Temperature of 49.8˚C with fan speed of 100%. There are 47 recorded temperatures, voltages and fan speed.

1.1 Statistical Tool

The proponents used Correlation to test the reliability of the data gathered. It is a technique that measures the strength of the association between two variables; the proponents used Fan Speed Percentage as the input variables for the test.

Table 4.4 Correlation Coefficient.

Correlation Coefficient	Remarks
0.00 TO (+/-) 0.20	Negligible Correlation
(+/-) 0.21 TO (+/-) 0.40	Low Correlation
(+/-) 0.41 TO (+/-) 0.50	Substantial Correlation
(+/-) 0.51 TO (+/-) 0.80	Marked Correlation
(+/-) 0.81 TO (+/-) 1.00	High to very high Correlation

Table 4.5 Theoretical and Actual Values.

Correlation Coefficient for Theoretical and Actual Values of Fan Speed (%)		
Temperature (°C)	Speed of Fan (%)	
	"Controlled Environment"	"Open Environment"
29	4	4
30	9	9
31	14	14
32	19	19
33	23	23
34	28	28
	29	28
35	33	XXXX
36	38	38
37	42	42
38	47	47
39	52	XXXX
40	57	57
41	61	61
42	66	XXXX
43	71	71
44	76	76
45	80	XXXX
46	85	XXXX
47	90	90
48	95	95
49	100	100

The table shows the data that are going to use to calculate for the correlation coefficient, the characters "XXXX" means don't care or no corresponding values.

Table 4.6 Calculations for Correlation Coefficient "Controlled Environment"

Correlation Coefficient for Theoretical and Actual Values of Fan Speed (%) "Controlled Environment"					
Temperature (°C)	Theoretical Values Speed of Fan (%)	Actual Values Speed of Fan (%)	xy	x^2	y^2
29	4.76	4	19.04	22.6576	16
30	9.52	9	85.68	90.6304	81
31	14.28	14	199.92	203.9184	196
32	19.04	19	361.76	362.5216	361
33	23.8	23	547.4	566.44	529
34	28.56	28	799.68	815.6736	784
	28.56	29	828.24	815.6736	841
35	33.32	33	1099.56	1110.2224	1089
36	38.08	38	1447.04	1450.0864	1444
37	42.84	42	1799.28	1835.2656	1764
38	47.6	47	2237.2	2265.76	2209
39	52.36	52	2722.72	2741.5696	2704
40	57.12	57	3255.84	3262.6944	3249
41	61.88	61	3774.68	3829.1344	3721
42	66.64	66	4398.24	4440.8896	4356
43	71.4	71	5069.4	5097.96	5041
44	76.16	76	5788.16	5800.3456	5776
45	80.92	80	6473.6	6548.0464	6400
46	85.68	85	7282.8	7341.0624	7225
47	90.44	90	8139.6	8179.3936	8100
48	95.2	95	9044	9063.04	9025
49	99.96	100	9996	9992.0016	10000
	Σx	Σy	Σxy	Σx^2	Σy^2
	1128.12	1119	75369.84	75834.9872	74911

Table 4.6 shows the results of the Correlation Coefficient for -1 and 1 for "Controlled" Environment respectively. Meaning there's a perfect correlation "Very High Correlation" between values referring to table 4.4, the relationship that appears to exist is positive; thus the data is reliable.

CONCLUSION

The whole system of this paper entitled "Design and Development of Fuzzy Logic Algorithm with Varying Set points for Fan Speed Control System using Arduino Microcontroller" is coded in a fuzzy logic Algorithm and it has been implemented in Arduino Microcontroller. The proponents make used of Matlab to simulate the fuzzy logic wherein it has two inputs the voltage in error and change in error. For trial and error method, the proponents used the Sugeno style fuzzy logic interference system for If – else rules. It uses FAM matrix with 25 weights for specifying the classification set on the fuzzy rules. By the use of Dev C programming plat form, the proponents fine-tuned the inputs to verify and find the precise crisp output value.

The proponents set different range of temperature for the classification of the membership functions such as 15 □C to 20 □C for Very cold, 21 □C to 24 □C for cold, 25 □C to 28 □C warm (set point), 29 □C to 37 □C for hot and 37 □C to 49 □C for Very hot. The LEDs has corresponding colors such as blue for Very cold, green for cold, white for warm, orange for hot and lastly red for Very hot. The LEDs will turn on whenever it reaches the required temperature. If the temperature is higher than 49 C, the fans have 100% fan speed. The Fan is the output of the system while the heat lamp serves as the heating mechanism of the system.

Based on the simulation and data analysis, it has been experimentally verified that Fuzzy Logic Algorithm can be implemented in Arduino Microcontroller. The temperature, output voltage and the speed of fan is directly proportional to each other. The results satisfied the classification of membership function of the fuzzy rules. It is properly and accurately working which satisfy the objectives of this study.

RECOMMENDATIONS AND FUTURE DIRECTIVES

Below are recommendations of this study:

1. Considering that the device is limited solely in controlling the speed of the fan, the proponents recommend having a cooling system with outsized outputs;
2. Improvement of the miniature house thus controlling the temperature accurately;
3. Use another output instead of fan like dc, servo, stepper motors and etc.;
4. Use different kinds of heating mechanisms to precisely control the temperature;
5. Future researchers can use larger number of rules and membership functions such as trapezoidal and gaussian both for the input and output parameters;
6. The proponents make use of Sugeno-style of FIS; future researches may opt to use theMamdani Fuzzy Inference Method; and,
7. Use of other computational intelligence other than fuzzy logic and implement it on other hardware device.

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