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# Design and Implementation of an Industrial and Residential Temperature Based Fuzzy Logic Controlled Fan

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## Abstract
This paper presents a dual-mode fuzzy logic controlled electric fan which can be used for both residential homes and industrial purposes (such as Oil and Gas heat exchangers, Pharmaceutical storage system etc.). The speed of a fan is controlled based on the temperature of the environment using fuzzy logic which was designed using LABVIEW software and programmed onto an Atmel Atmega328p microcontroller. More so, the constructed system consistsof a temperature sensor DTH11, a power supply rail of 5/12V, a 12V DC fan, power driver L298N for the 12V DC fan. The speed of the fan was controlled based on the temperature of the room aided by the DTH11 sensor and the fuzzy logic rules embedded in the microcontroller. To vary the speed of the fan automatically with changes in the temperature of the room, two modes; domestic and industrial modes were implemented. For bothindustrial and domestic modes, the fan enters the OFF state if the temperature of the room is cool i.e. the temperature range is -40$^{o}$C – 8$^{o}$C and 20$^{o}$C – 26$^{o}$Crespectively. The proposed prototype adequately controlled the temperature of the room setup from 37 $^{o}$C to 25 $^{o}$C and 37 $^{o}$C to 27 $^{o}$Cwithout overshoots or steady-state error, within 10s using the industrial and domestic modes respectively.

**Keywords: Speed Control, Fuzzy Logic; LabVIEW; Microcontroller; Temperature Control**

## 1. Introduction

Temperature control cuts across a wide variety of industrial and domestic processes such as temperature-controlled heat exchangers in the Oil and Gas industry, pharmaceutical storage facilities at 25 $^{o}C$, bathtubs, greenhouses, incubators and even inthermally regulated homesetc. Specifically, in Nigeria, the average room temperature range which falls between 20°C to 30$^{o}$Cthat in-turn affects the human body temperature is largely dependent on the prevailing climatic conditions (Mobolade and Pourvahidi, 2020)(Shao, 2021). More so,temperature valueabove or below the desired setpoint of 27 $^{o}C$which is anoptimalconsensus for human body comfort can be detrimental to body organs or tissues and at worse cause death (Zungeru, et al., 2018).Nevertheless, the room temperature parameter is not only stochastic but also a slowly changing process and requires non-trivial heuristic-based control (Iqbal et al., 2017) and (Gao et al., 2020).

In recent times, researchers, have proposed several temperature controls propositions which include the use of automatic Boolean ON/OFF control, if-then-else-iflogic-based control (Zungeru,et al., 2018), conventional proportional-integral-derivative (PID) control, neural network (Design and Analysis of Temperature Control System using Conventional PI and Advanced ANN Controllers by (Halder, et al., 2018).

Specifically, in (Kumar et al., 2019) ON/OFF automatic control of fan speed using ATmega328 Microcontroller was achieved by means of a Passive Infrared Sensor which senses the presence of human within the room and passes the signal to the controller. In (Baligar et al., 2019) a low cost user-friendly standalone automatic fan speed controller with feedback achieved using temperature sensor and embedded technology to drive a transistor which in turn performs the speed control was proposed. Also, in (Mahakud and Das, 2019) a wireless speed control of a fan (with user interface) via internet of thing (IOT) server which interfaces with a fan control module, a fan speed and temperature monitoring device was proposed. In (Alli, et al., 2017) an automatic control system using an Arduino was designed in Proteus and implemented for industrial processes involving temperature control. In (Oduah, 2018) an automatic temperature-controlled electric ceiling fan which adapts its speed based on dynamic weather change was proposed for the vulnerable, in contrast to the existing five speed manually regulated fan. Furthermore, the design and construction of a temperature-based fan controller was proposed with the main objective of controlling the speed of the fan using Arduino microcontroller via the sensed temperature by LM35 temperature sensor in (Singh et al., 2018).

On the one hand, while ON/OFF controldoes not consider the temperature range in controlling the fan and cannot guaranty optimal response, Logic based if then-else logic statements must be defined for every range of the fan speed thus, incurring the curse of dimensionality.On the other hand, while PID controllers are cumbersome to tune due to imprecise plant model, they can lead to undesirable overshoots. The use of machine learning neural network algorithms typically requires large data set and high-speed computation hardware which can be unavailable and/or computationally cumbersome respectively.

Alternatively, for precise control of a stochastic process variable (temperature), fuzzy logic-based control suffices. Fuzzy logic arises by assigning degrees of truth to propositions in contrast to the standard set of truth values (degrees) is [0,1], where 0 represents “totally false”, 1 represents “totally true”, and the other numbers between 0 and 1 refer to partial truth, i.e., intermediate degrees of truth(Petr et al., 2017;Vlamou and Papadopoulos, 2019). This is in contrast to the Boolean true or false (i.e. ‘1’ or ‘0’) only proposition.Fuzzy logic method emulates the human way of decision making, which considers all the possibilities between digital values of True and False (Tanuja, 2020; Shah et al., 2020; Alhumade et al., 2021).

Fuzzy logic has applications beyond the engineering fields, and is regarded as a powerful decision-making tool for businesses evaluation; stock market predictions; disease diagnoses etc., (Hamid Ebrahimi, 2021; (Alhumade et al., 2021).Many authors have proposed Fuzzy Logic Inference System in dealing with reduction in air conditioning load consumption, temperature control in Room Temperature using IoT, temperature control in fan speed control and sorting/handling of data respectively(Shah et al., 2020; Vistro et al., 2020; Rani et al., 2021; Ravikumar, 2020).Thermal comfort level has been enhance using exact flow rates of hot water and air into the building with modelled modulating percentage globe valve, fans speed, and dampers position using modified fuzzy rules(Abdo-allah, et al., 2018).

This paperaims to design and implement a low-cost closed-loop Fuzzy logic control system embedded on an *Atmel Atmega328p* microcontroller for temperature control facilitatedvia the speed regulation of a 12V DC Fan. Specifically,the fuzzy logic system and electrical circuitry aredesigned and simulated using LABVIEW and Proteus software. The temperature control offers a dual mode option for both domestic homes and industrial environments such as in the oil and gas refineries, manufacturing cells by regulating the speed of a fan. Also, the proposed concept can be extended to varied systems like temperature-based control systems such as air conditioners or speed control systems used in washing machines etc.

## 2. Methodology

The design of the Fuzzy logic-based temperature-controlled fan speed architecture consists,of the hardware and the software parts. The hardware entails the physical sub-components such as the 5V/12V DC power supply rail, an Atmel 328p microcontroller, DTH11temperature sensor, power supply rail of 5V and 12V, a 12V dc fan, L298N power IC driver and a 12 V DC electric fan. While the software part entails the fuzzy logic controller which operates a dual mode (industrial and domestic) is designed in LabVIEW and coded onto the microcontroller. Figure 1 illustrates the concept of the temperature-based fan speed control using Fuzzy logic.

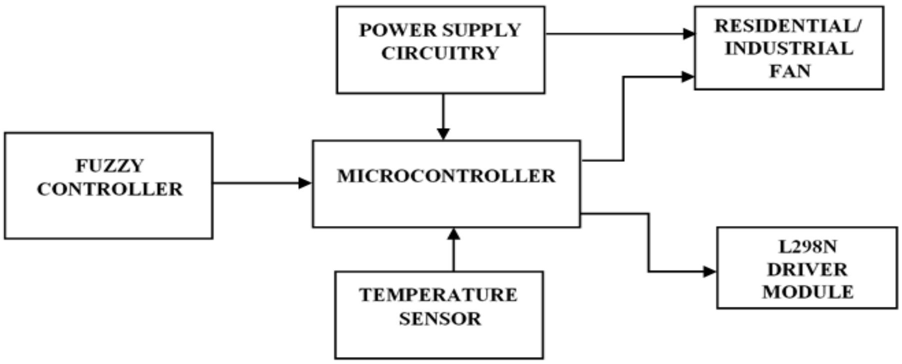


Fig. 1: Schematics of Temperature based Fan speed control using Fuzzy logic.

## 2.1 Hardware Design

The power supply unit comprises a step-down transformer, a battery, a charging circuit, a bridge rectifier, the filter circuit, and the voltage regulator. Figure 3 shows the block diagram of a power supply unit.

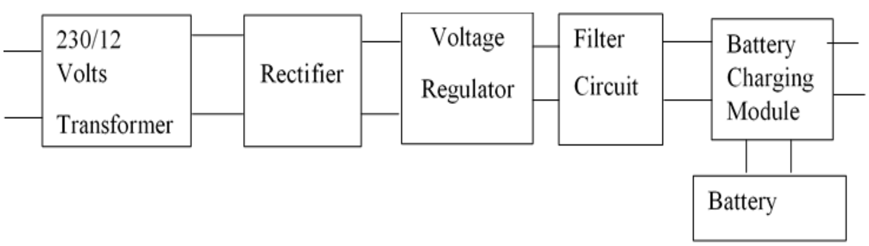


Fig. 2: Power Supply System

The power supply circuit uses a transformer that steps down the 220Vac mains input to 12Vac output. The link between the voltages and the current is:

$$\frac{E_p}{E_s} = \frac{I_s}{E_p} \quad (1)$$

Where:

$E_p = 220Vac$, $E_s = 112Vac$ and $I_s = 1$A

Hence, the primary current $I_p = \frac{E_s \times I_s}{E_p} = \frac{12 \times 1}{220} = 54.4mA$

The stepdown transformer's voltage rating is 220/12v, 50Hz with a current rating of 1.5A.

Therefore, the peak voltage is $\sqrt{2} \times V_{rms}$(2)

Thus, $V_p = \sqrt{2} \times 12 = 16.97$ V

Nevertheless, rectification is required to convert the Alternating Current (AC) to Direct Current (DC). Hence, the bridge Rectifiers which consist of four back-to-backIN4007 silicon diodes were used to form a full-wave bridge. Thus, the maximum output voltage of the bridge rectifier is known as the peak rectified voltage, and it is given as:

$V_{peak\ rectified} = V_p - 2V_{be}$(3)

$V_b$ is the biasing voltage for the diode which is 0.7v for the silicon diodes, since it is a full-wave rectifier with two diodes conducting in each half cycle; therefore, there are two voltage drops of 1.4 V.

Therefore, in this circuit:

$V_{p\ rectified} = 16.97 - 1.4 = 15.57V_{dc}$

Thus, the input voltage to the filter circuit is 15.57 $V_{dc}$.

Furthermore, to minimize the ripple of the rectified DC voltage by 100% an electrolytic capacitor was used.

At 10% ripple, the RMS value $= \frac{10}{100} \times 16.97 = 1.697\ V_{dc}$(4)

$\Delta_{rms} = 16.97 - 1.67 = 15.23V_{dc}$

.

Where, $\Delta_{rms}$ is the change in the ripple voltage

The value of the electrolytic capacitor used to filter the ripple voltage is determined as follows:

The electrolytic capacitance $c = \frac{I}{2V_p f\sqrt{2}} \times fr$

(5)

Where;

The current rating of the transformer (I) is 1.5A, = peak voltage across the rectifier ($v_p$) is 15.57, and the frequency of the transformer (*fr*) is 50Hz.

Therefore, the capacitance value $= \frac{1.5}{2\times15.57\times50\times\sqrt{2}} = 681\mu f$

Therefore, 1000$\mu f$ rated electrolytic capacitors will be used in the design.

Furthermore, 12 V and 5V voltage regulators (7812 and 7805) are used to supply the required outputs to the L298N power IC driver for the 12V fan system and 5V microcontroller circuitry respectively. The Bridge rectifier circuit designed in Proteus is shown in Fig. 3

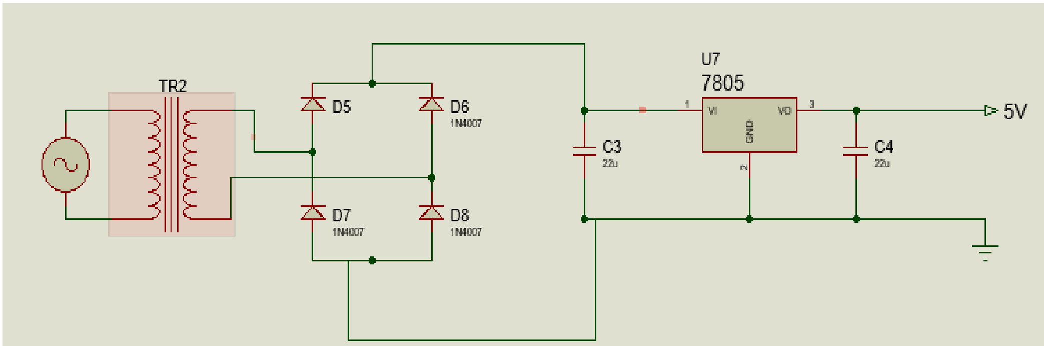


Fig. 3: Bridge Rectifier Circuit Diagram designed in Proteus

**2.2 Software Design**

In implementing the software design, the LAB-VIEW fuzzy logic toolbox was used to design the Mamdani fuzzy logic system. which is thereafter programmed on the Atmel Atmega328p microcontroller while Proteus 8 electronic workbench software was used to design the circuitry.

**2.2.1 Fuzzy logic Controller design**

The prototype is designed for a temperature range of $0°C - 50°C$ for domestic mode and $-20°C - 45°C$ for industrial mode respectively.The speed of the fan is controlled using Fuzzy logic and programmed into the microcontroller, depending on the sensed temperature of the environment. Therefore, increasing/decreasing the speed of the electric fan largely dependents on the construction of the fuzzy logic knowledge/rule base, input and output triangular membership functions developed with LabVIEW software. The generic Mamdanifuzzy inference system consists of four stages; Fuzzification, Inference engine, rule base and defuzzification (Nyong-BasseyandAkinloye, 2016) and (Makkar and Renu Makkar, 2018).

***A. Fuzzification***

The fuzzification stage receives the input parameters which are then mapped to membership functions (MFs) to obtain a degree of membership value(David et al., 2021).In this work, the Fuzzy logic controller consistsof two fuzzified inputs which are the room temperaturesensed by the DH11 sensor mounted in the room and the error difference between the room temperature and the desired temperature of the room respectively as shown in Table 1 and 2 respectively. Furthermore, the output of the controller is a 5V pulse width modulated (PWM) voltage amplified by the 12V L298N IC mapped from [0 to 225] with the fuzzy crisp output to [0 to 100%] for both domestic and industrial modesshown in Table 3.

**Table 1: Temperature Input (1) Membership function states for Industrial and Domestic Modes**

| Membership functions | Temperature Range(°C) | |
|---|---|---|
| | **Industrial** | **Domestic** |
| Very Cold | 0 – 24 | 0 – 26 |
| Cold | 23 – 26 | 25 – 28 |
| Warm | 25 – 29 | 27 – 29 |
| Hot | 28 – 35 | 28 – 33 |
| Very Hot | - | 32 – 50 |

**Table 2: Industrial and Domestic Mode Membership Functions of Error in Temperature**

| | Temperature Error Range (°C) | |
|---|---|---|
| **Membership Function** | **Industrial** | **Domestic** |
| Large Negative (LN) | -60 to -90 | -72 to -7 |
| Small Negative (SN) | -10 to 1 | -12 to -1 |
| Zero (Z) | 2 to 27 | -1 to 4 |
| Small Positive (SP) | 25 to 50 | 3 to 8 |
| Large Positive (LP) | - | 5 to 28 |

**Table 3: Industrial and Domestic Membership functions of the fan speed**

| Membership Function | 12V PWM (%) | |
|---|---|---|
| | **Industrial Mode** | **Domestic Mode** |
| Off | 0 – 25 | 0 – 10 |
| Slow | 4 – 40 | 9 – 35 |
| Average | 35 – 75 | 34 – 60 |
| Fast | 65 – 100 | 59 – 75 |
| Very Fast | - | 74 – 100 |

### *B. Membership Function*

The shape of the input and output membership functions (MFs) which could betriangular or trapezoidal is considered based on the control variable, (Nyong-Bassey andAkinloye, 2016) and(Jain et al., 2020).

In the industrial mode, the input (1) (temperature) MFs are made up of four triangles, defined asVery Cold, Cold, Warm and Hot, while in the domestic mode, a fifth triangular MF is included for the end-user's comfort. The LabVIEW implementation of the temperature membership for the industrial and domestic modes are shown in Figures 4 and 5 respectively

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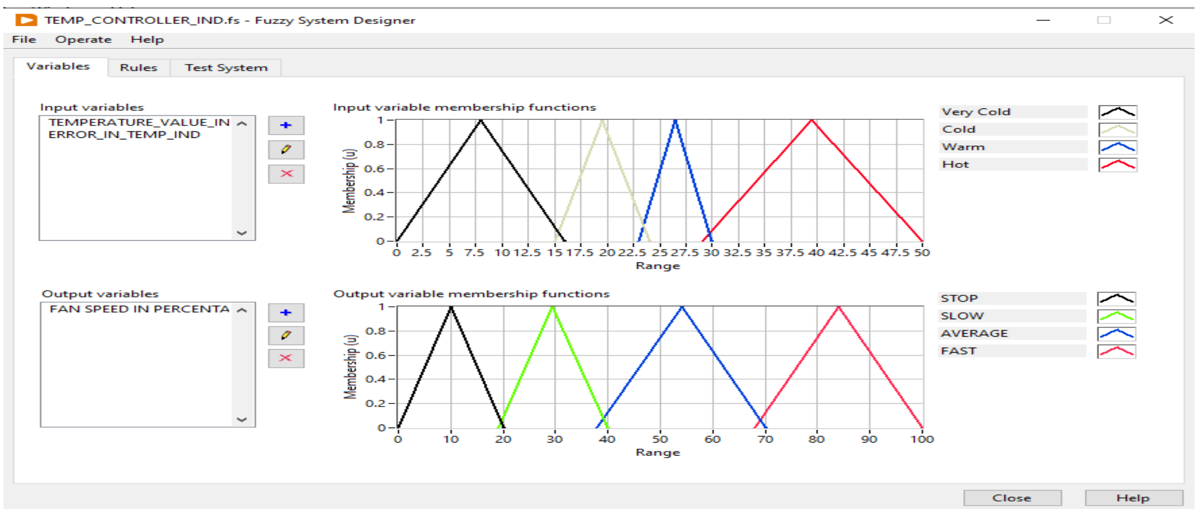


Fig. 4: Temperature Input (1) Membership Function plot for Industrial Mode

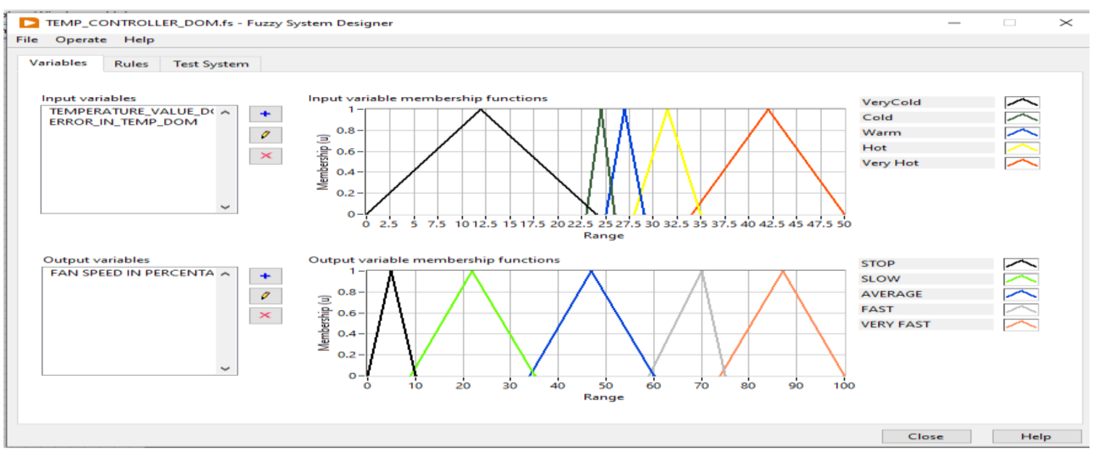


Fig. 5: Temperature Input (1) Membership Function plot for Domestic Mode

Similarly, the temperature error i.e. input (2)'s MFs designed inLabVIEW is made up of four overlapping triangles as shown in Figures 6 and 7 respectively implementation.

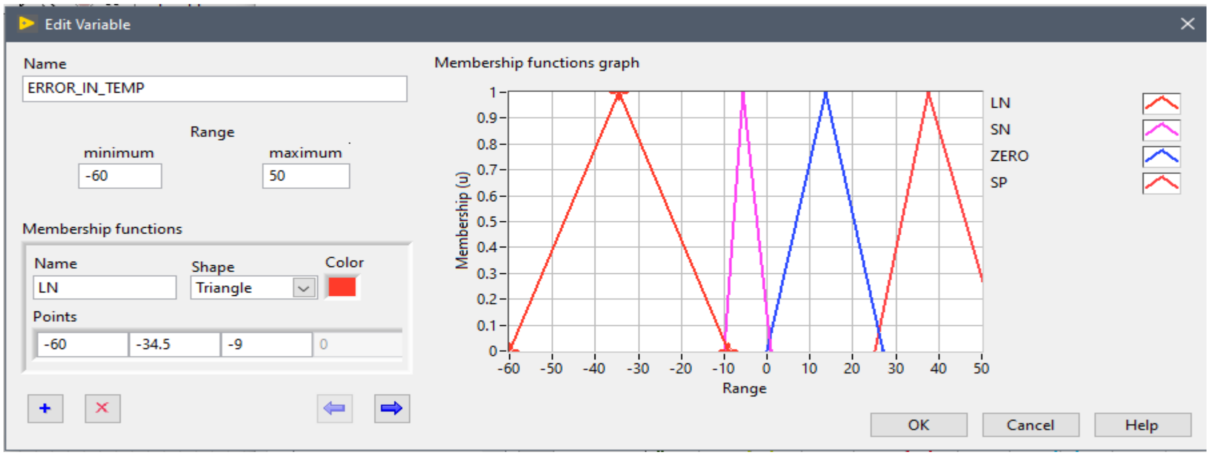


Fig. 6: Temperature Error Input (2) Membership function plot for Industrial mode

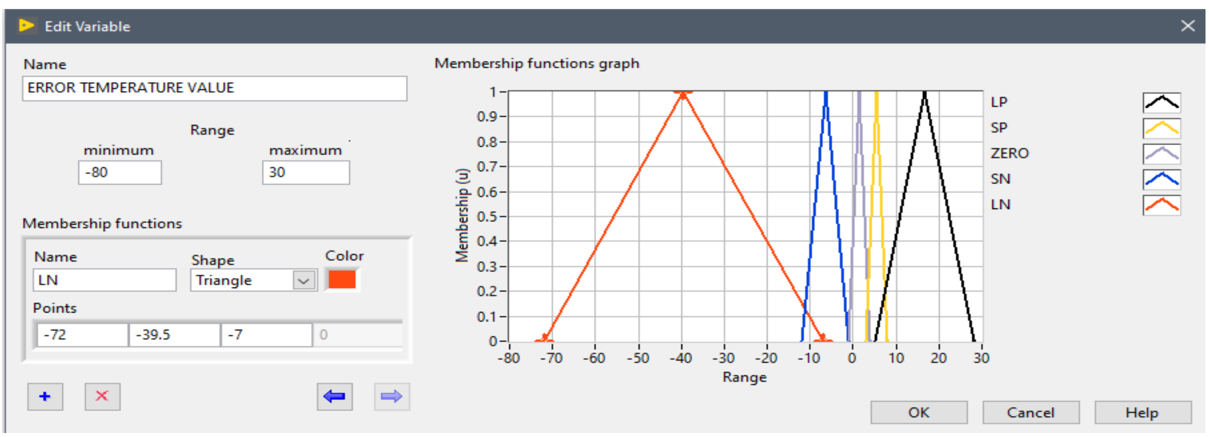


Fig. 7:Temperature Error Input (2) Membership function plot for Domestic mode

The fan speed is the output variable of the system. Therefore, the fuzzy logic controller evaluates the rule condition to infer the speed of the fan. Hence, if the room temperature is greater than the set temperature, the fan automatically turns on and varies its speed according to its temperature difference. The fan speed is categorized into five different fuzzy states which are off, slow, average, fast and very fast for the domestic mode and four different fuzzy states which are off, slow, average, and fast for the industrial mode. respectively. Figure 8 shows the LabVIEW implementation of the membership functions of the fan speed.

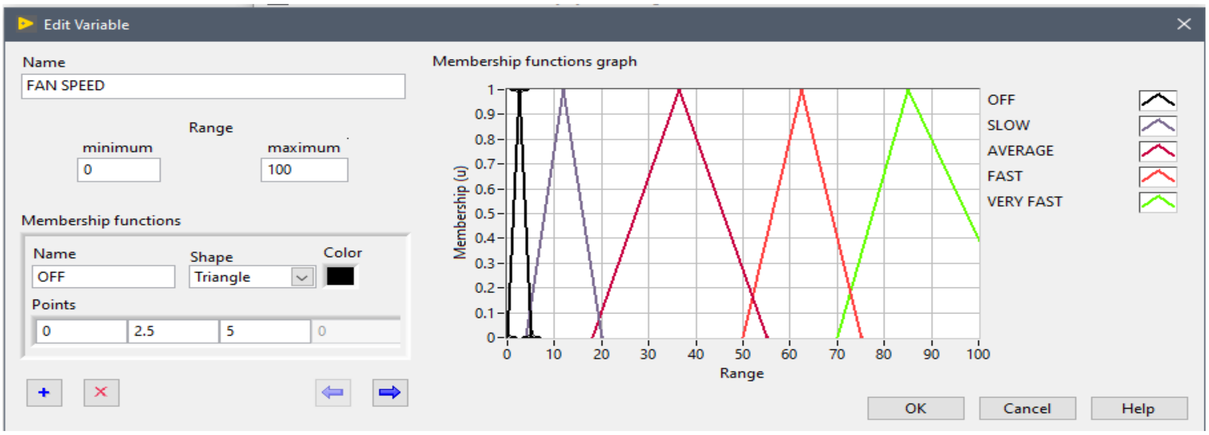


*Fig. 8: Plot of Membership Function of Fan Speed*

### *C. Rule Base*

In designing the heuristic logical fuzzy rules, experience counts. Nevertheless, fuzzy rulesare genericallyIF-THEN logical propositions with a condition and a conclusion.This is logical rules are mapped by the inference engine which uses either the 'AND' or 'OR' operations. In this work, the AND logicaloperator has been used in the system's design.Figure 14 and 15 shows the LabVIEW implementation of the system fuzzy rules, while Table 4 surmises the logical propositions.

**Table 4: Fuzzy Rules for Industrial and Domestic Modes**

| Rule | Temperature | | Temperature Error | | Fan Speed | |
|---|---|---|---|---|---|---|
| | Industrial | Domestic | Industrial | Domestic | Industrial | Domestic |
| 1 | VERY COLD | VERY COLD | SP | LP | OFF | OFF |
| 2 | COLD | COLD | ZERO | SP | SLOW | SLOW |
| 3 | WARM | COLD | SN | ZERO | AVERAGE | SLOW |
| 4 | HOT | WARM | LN | ZERO | FAST | AVERAGE |
| 5 | - | HOT | - | SN | - | FAST |
| 6 | - | VERY HOT | - | LN | - | VERY FAST |

### *D. Defuzzification*

To determine the control output voltage to control the Fan, a crisp value is required, hence defuzzification using the Centre of Gravity on the output MFs shows the actual speed of the fan in correspondence to the input's value. The LabVIEW automatically shows the behaviour of the system after simulating the process inputs. Figure 9 and 10, shows the result of the fuzzy logic process for both industrialand domestic modes respectively.

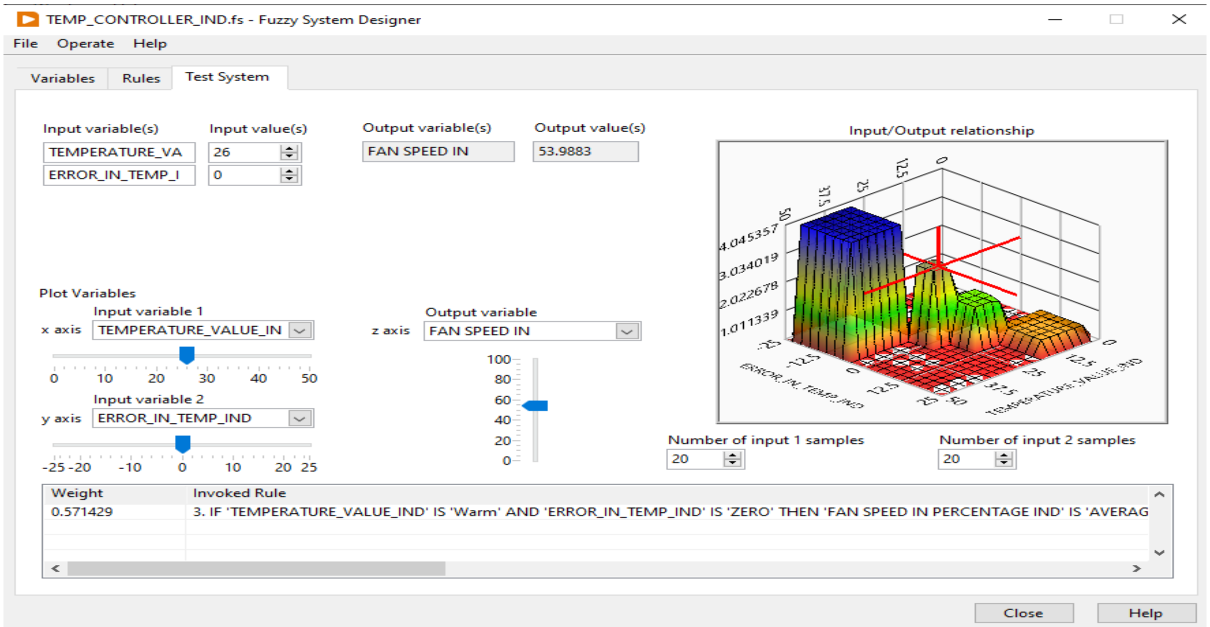


*Fig. 9: Industrial Mode of System Simulation Result*

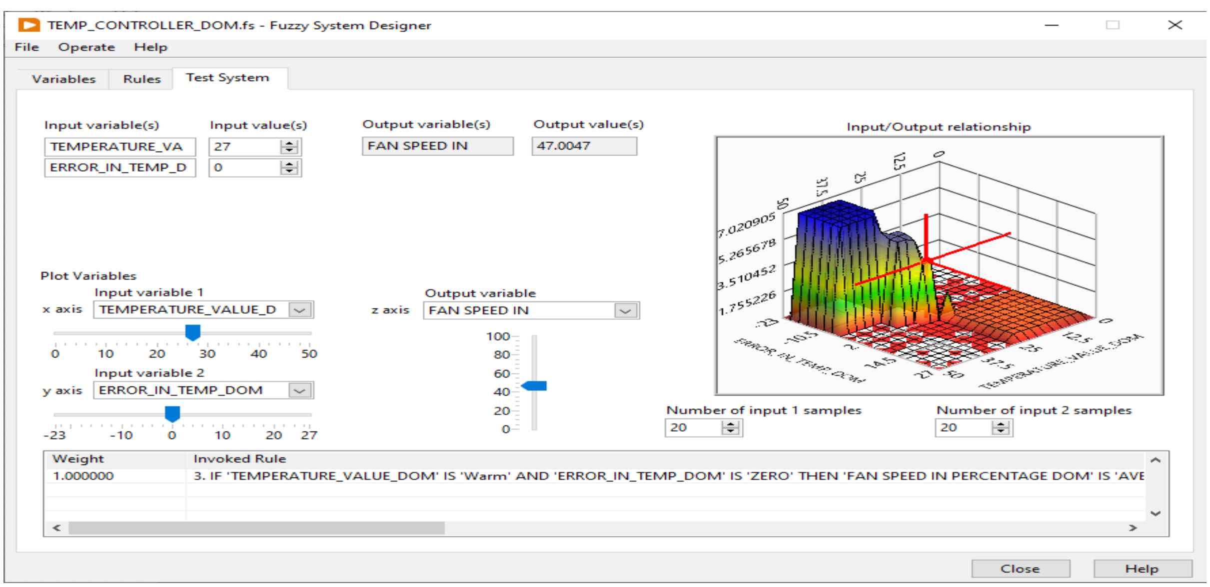


*Fig. 10: Domestic Mode of System Simulation Result*

## 3. Results and Discussion

The result in this section is obtained based on the Fuzzy logic controller setup described in section 2.To demonstrate the effectiveness of the Fuzzy logic controller, the 12V DC Fan is placed in a 37 ℃ closed environment withthe desired temperature set-points at 27 ℃ and 25 ℃ in industrial and domestic modes respectively. Thereafter, the speed of a 12V DC fan is controlled by the Fuzzy logic controller through the DTH11 temperature sensor which provides the input to the fuzzy logic controller and a 12VDC PWM output from the L298N driver. Table 4 shows the response of the system to changes in temperature of the environment for both domestic and industrial mode in tabular form. From the results in Table 5 (i.e. read from top to bottom), the Fuzzy logic controller was able to gradually control the temperature of the room to match the desired set point temperature of 27 ℃ and 25 ℃ within 10s, without any overshoot in both the industrial and domestic modes respectively. Therefore, the environment temperature was controlled by reducing the fan speed as the temperature reduced from 37 ℃ to the desired temperature. Also, once the environmental temperature extremely or slightly falls below the desired/setpoint temperature, the fan automatically turns off or slows down accordingly.

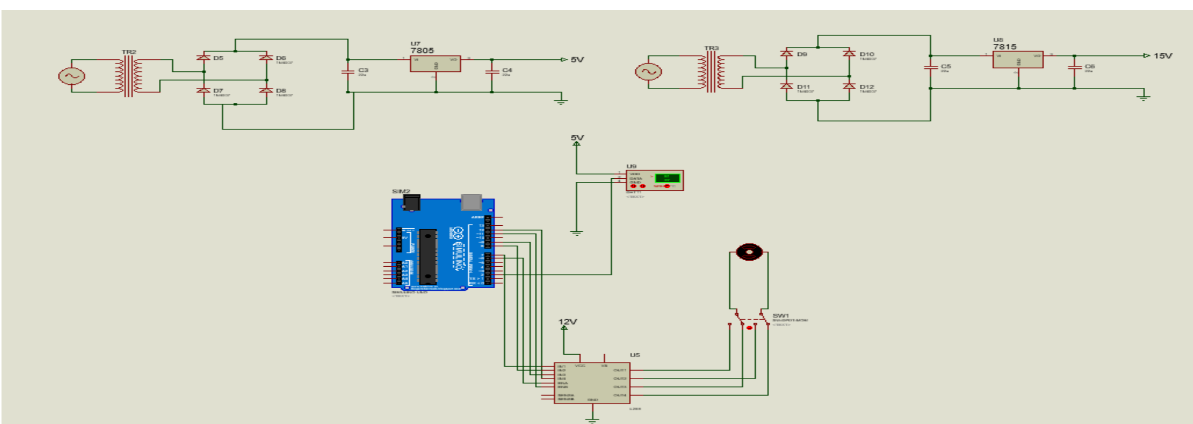


Fig. 11: General Circuit Diagram design using Proteus 8 Software

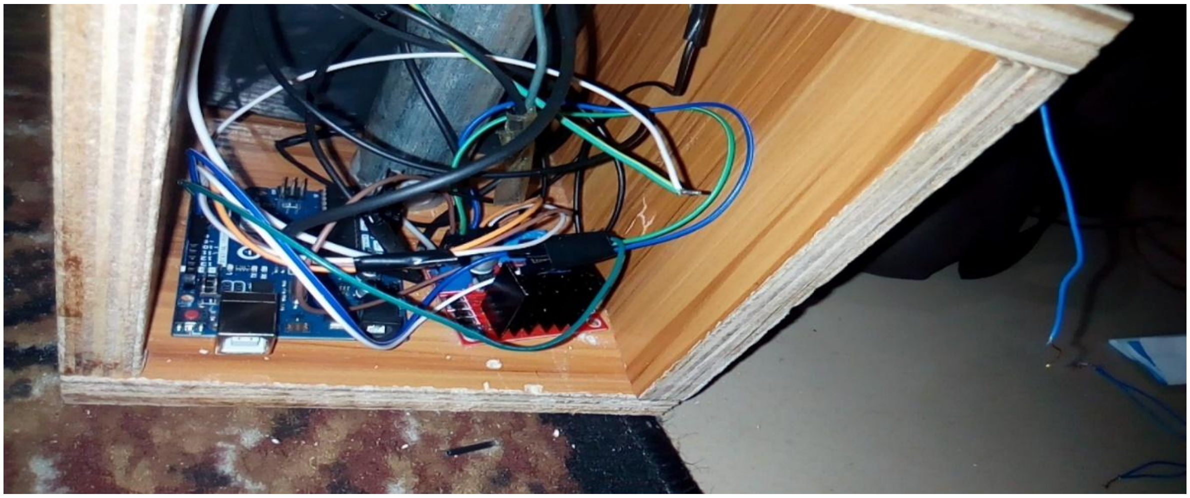

Fig. 12: Implementation of System on Vero board

***Table 5: System Results for Domestic and Industrial Mode***

| SetPoint (℃) | | Fan Speed (%) | | Voltage (V) | | Temperature(℃) | |
|---|---|---|---|---|---|---|---|
| **Industrial** | **Domestic** | **Industrial** | **Domestic** | **Industrial** | **Domestic** | **Industrial** | **Domestic** |
| 25 | 27 | 84 | 87 | 10.08 | 10.44 | 37 | 37 |
| 25 | 27 | 84 | 87 | 10.08 | 10.44 | 36 | 36 |
| 25 | 27 | 84 | 87 | 10.08 | 10.44 | 35 | 35 |
| 25 | 27 | 84 | 70 | 10.08 | 8.4 | 34 | 34 |
| 25 | 27 | 84 | 68 | 10.08 | 8.16 | 33 | 33 |
| 25 | 27 | 84 | 68 | 10.08 | 8.16 | 32 | 32 |
| 25 | 27 | 84 | 68 | 10.08 | 8.16 | 31 | 31 |
| 25 | 27 | 84 | 68 | 10.08 | 8.16 | 30 | 30 |
| 25 | 27 | 55 | 67 | 6.6 | 8.04 | 28 | 29 |
| 25 | 27 | 54 | 48 | 6.48 | 5.76 | 27 | 28 |
| 25 | 27 | 54 | 47 | 6.48 | 5.64 | 25 | 27 |

## Conclusion

The room temperature based electric fan speed controller was designed, tested and implemented using fuzzy logic successfully. The system was implemented using an Arduino Uno board. LAB-VIEW fuzzy logic toolbox was used to simulate the fuzzy logic which had two inputs for both modes: (temperature and deviation temperature in both domestic and industrial modes) and one output (fan speed). The algorithm plan makes the system efficient and absolutely under control. The analysis clearly shows the ease of fuzzy logic in handling problems that are difficult to overcome using analytically and mathematical approaches yet are easily solved intuitively in terms of linguistic variables. The room temperature based electric fan controller was built to control the speed of the fan according to the ambient temperature of the room for both domestic and industrial purposes. Each input and the output iscomprised of different membership functions which increase the performance of the system. The speed of the fan is adjusted automatically according to the variation in temperature of the environment. During implementation, the crisp inputs were taken in fuzzy form and output is defuzzified. The approach of using software design, minimised the cost of the hardware while the prototype design gave maximum comfort with high efficiency.

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