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Fuzzy Adaptive Control of Temperature Support Balanced Mechanical Ventilation System

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Abstract: Room ventilation system is the process of introducing outside air into a space to achieve desired indoor psychrometric conditions. Besides from providing thermal comfort and dehumidification, ventilation is also used to control the indoor air quality (IAQ). Mechanical ventilation system, as opposed to natural ventilation, uses fans to drive and control the flow of air inside a room. Problem with mechanical ventilation is its adaptability to different climate conditions and number of pollutants. In warm and humid climates, positive pressure or pressurization is required while for cold climates and rooms with locally generated pollutants, negative pressure or depressurization is used. To address the problem associated with conventional mechanical ventilation system, this paper presents an adaptive control of room ventilation system using fuzzy logic. Fuzzy logic is an innovative technology and has been proven effective in designing solutions for non-linear control problems and intelligence system applications. Fuzzy rule-based system was used to control and manipulate the speed and direction of the exhaust fan's motor depending on the room temperature. The input to the fuzzy logic control is the error or the deviation of the actual temperature reading and the set point (SP) value. Moreover, the system was capable to display 'Intake' during pressurization and 'Exhaust' during depressurization.

Key Words: exhaust fan; fuzzy logic; microcontroller; temperature control; ventilation

1. INTRODUCTION

Fuzzy logic revolves around the concepts of human perception and cognition which includes rational reasoning and decision–making in an uncertain environment and the capability to function at any given moment without much mathematical computations or measurement needed (Zadeh, 2014). It is fed with incomplete, vague, imprecise information and is designed to accomplish tasks and perform functions given the uncertain inputs. Fuzzy logic, unlike boolean logic, is not limited to absolute truth or falseness but is able to handle inputs that could possibly be of partial truth or falseness. It allows the use of labels like *slightly*, *moderately*, *medium* and *very* so that statements can be made with varying precision degree (Isizoh et al., 2012).

First introduced by Lofti Zadeh in 1965, many researches have unlocked the potential of fuzzy logic in real-life applications such as the braking systems of vehicles, control of subway systems and unmanned vehicles, human face recognition, and air-conditioners to name a few (Singh et al., 2013). Today, studies are still being conducted to further explore its capabilities in nonlinear control systems and artificial intelligence.

Control systems require analytical models that also demand rigorous tasks that consumes too much time, effort and money to obtain accurate results and in most times has failed to do so especially when applied to nonlinear problems (Verma and Gupta, 2012). Implementing fuzzy logic based design control system offers flexibility in system implementation (Isizoh et al., 2012). Its simplicity provide better solutions to problems with numerous, imprecise inputs and its flexibility lets it adjust, add, and/or remove the user-defined rules to suit the needs of the given problem and obtain the most accurate, realistic outputs possible.

In this study, a fuzzy adaptive temperature control of balanced mechanical ventilation system was implemented using a microcontroller. It utilizes a temperature sensor, specifically a thermistor, in order to control the speed and direction of a fan during pressurization and depressurization.

2. FUZZY LOGIC CONTROLLER

A microcontroller-based fuzzy logic control system has a fuzzy inference kernel and a knowledge base as seen in Figure 1. The fuzzy inference kernel is executed periodically to determine system output based on current system input while the knowledge-base contains membership functions and rules. One execution pass through a fuzzy inference kernel generates system output signals in response to current system input conditions (Lipovski, 2004).

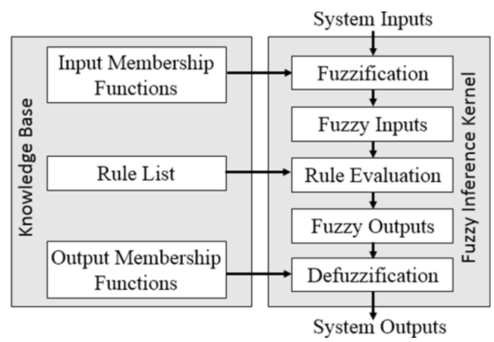

Fig. 1. Knowledge base to fuzzy inference kernel

The structure of the fuzzy inference kernel is similar to conventional control systems where inputs are processed and an output is generated. Also, it is also executed as often as needed to maintain control. However, as illustrated in Figure 1, the process in fuzzy logic is divided into three parts: fuzzification, fuzzy logic processing and defuzzification.

2.1 Fuzzification of Inputs

In fuzzy logic control, the input is not immediately taken as is. The inputs of the system are fuzzified by a fuzzifier that measures the degree of which the data is amongst each category. The data is not heterogeneous in the sense that it belongs to a single category of data, instead it is described as a percentage of relevant categories. As such, because it does not take an exact value but is instead described as how much it is in a category, it is called "fuzzy".

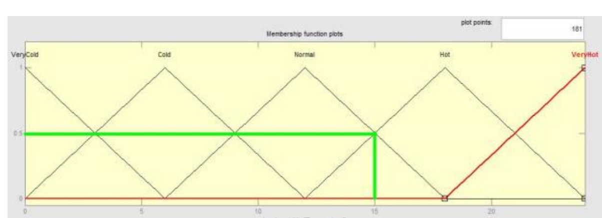

Fig. 2. Fuzzifier with five triangular functions

Input variables in fuzzy control system are mapped by sets of membership functions, known as "fuzzy sets". These are multi-valued characteristic functions that define the fuzzy set to a certain membership grade. It uses shapes, like triangular (Δ), trapezoidal (Π) or Gaussian, to represent a membership (Baldovino and Dadios, 2014).

Fuzzification is the process of connecting a crisp input value to a fuzzy value (Isizoh et al., 2012). During these process, the current input values are compared against stored input membership functions to determine how well the condition of each rule matched that particular input at that instance (Baldovino & Dadios, 2014). Figure 2 illustrates the Δ functions labeled: very cold, cold, normal, hot and very hot that were used in temperature control in this study. In the figure, 15°C isn't described as being either normal or hot; it is 0.50 or 50% normal and 0.50 or 50% hot at the same time.

One thing to note with the use of fuzzy logic is that inputs beyond the extremities (below the minimum and above the maximum) are treated as the extremities themselves. For example: from a range of 0-100, negative values are treated as an input of '0', and values above 100 are treated as 100.

2.2 Fuzzy Logic Processing

Fuzzy logic makes use of rules that determine the relationship between the input and output. It is usually in the form of *if-then* statements, such as "IF temperature is Very Hot THEN Fan is Very Fast", though they may make use of various logical operators depending on user requirements. For each rule, the inference mechanism uses the membership values and according to the condition of the rule comes to a conclusion (Basu, 2012).

1	IF temperature is very cold THEN fanspeed is very slow
2	IF temperature is cold THEN fanspeed is slow
3	IF temperature is normal THEN fanspeed is average
4	IF temperature is hot THEN fanspeed is fast
5	IF temperature is very hot THEN fanspeed is very fast

Fig. 3. Rule evaluation using rule block

Rule evaluation using rule block which makes use of if-then statements was used and is shown in Figure 3. Moreover, relationships between input and output membership functions are shown.

2.3 Defuzzification

The immediate output of fuzzy logic is fuzzy as well, since the input was first converted as such. Fuzzy values are not really useful in the application, as a controller would not be able to understand that the fan should be 50% average and 50% fast. This is why the output must first be converted back to conventional expressions. The defuzzifier does the opposite of the fuzzifier by dissolving multiple degree ambiguous by putting raw fuzzy outputs into a composite numerical output.

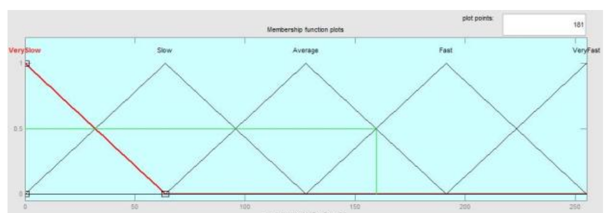

Fig. 4. Rule evaluation using rule block

From Figure 4, the fuzzy output is taken by taking the percentages of the relevant categories, decided by the rules, to the corresponding inputs. Then, this value is found by taking the value that satisfies a given condition.

3. TEMPERATURE CONTROL

Controllers are designed for some intended purpose or control objective. Regulatory control is one of the most common objectives and is implemented to ensure that the measured output is equal to or near the reference output (Abdelhazer et al., 2008). The controller then makes a decision based on the deviation of the measured output from the set point value. This process is called feedback control.

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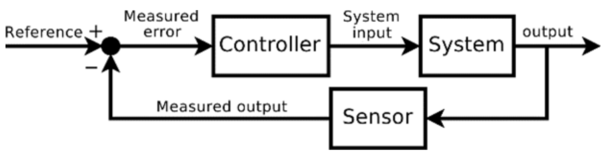

Fig. 5. Feedback control system

The temperature feedback control involves the manipulation of the motor fan speed based on the temperature degree that serves as the system's feedback. Its speed in rpm is based on the surrounding temperature after solving for the measured error.

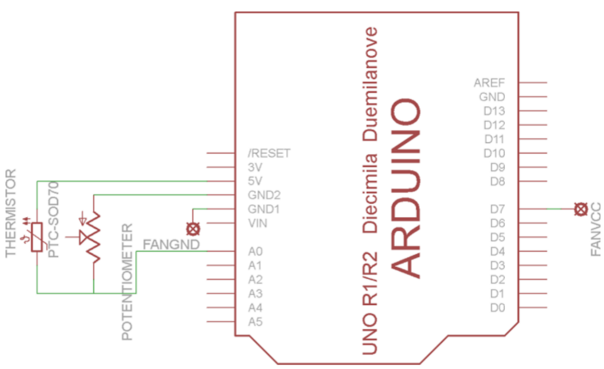

Fig. 6. Schematic layout of actual PCB

3.1 Temperature Sensor

A temperature sensor is sensitive to changes in its surrounding temperature. It can be useful in consumer technology such as refrigerators, air conditioners, etc. and industrial technology such as water temperature control, heat detectors, etc. A contact-type temperature sensor is used in this project due to its low-cost and availability. LM35 is employed in sensing the room temperature. It produces voltage of 10 mV for 10°C rise in the temperature. The sensor output, which is an analog signal, is fed to the input of the analog-to-digital converter (ADC) in order to convert the analog temperature value to its digital equivalent (Nwanko et al., 2014).

3.2 Microcontroller

An Arduino–based microcontroller (see Fig. 6) is used in the simulation due to its characteristic as an open-source platform. Codes, which can perform various task, are available online, thus, program construction is at ease (Badamasi, 2014).

4. METHODOLOGY

The proposed fuzzy temperature controller, as seen in Figure 7, contains one fuzzy input and output. The input based on the reading of the temperature sensor controls the output which in this study is the direction and speed of the motor.

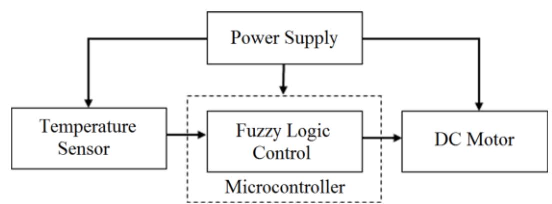

Fig. 6. Proposed fuzzy temperature controller

The input to the fuzzy logic control is the error or the deviation of the actual value or the temperature reading of the thermistor and the set point (SP) value which in this case is 24°C. The initial reading made by the thermistor is in analog therefore, in order to calculate the error, it must first be converted to °C. This value can be obtained using Eq. 1 where *tempin* is the analog reading and *ActualValue* is the reading in °C.

$$ActualValue = tempin * 0.48882825 \qquad (1)$$

The error is then calculated using Eq. 2 and is used as the input to the fuzzy logic control and displayed in the serial monitor in the Arduino integrated development environment (IDE).

$$error = ActualValue - SP \qquad (2)$$

The said process was using the embedded fuzzy logic library (eFLL) downloaded from github through the Arduino IDE.

5. RESULTS

The output, supposedly the speed of a fan, is simulated by a motor. The speed of the motor varies as the difference in voltage set along its poles, where 0 and 255 are the minimum and maximum speeds of the motor, respectively. The direction which the motor spins also depends on the sign of the difference in voltage. This is used to simulate a reverse response when the input becomes negative sign.

While the actual motor speed is difficult to measure the Arduino IDE provides its user with a serial monitor that shows various data within the code. In this case, the serial monitor is used to display the voltage across the motor as the output.

The output did in fact follow a trend in accordance with membership functions created. It also displayed a smooth change in the output as the input changed.

While the speed itself remained unchanged, the direction at which the motor spun did change if the input was negative or, in this case, too cold. Additionally, the serial monitor was programmed to display 'Exhaust' during the mentioned condition, and 'Intake' otherwise.

6. CONCLUSION

This study demonstrated the application of fuzzy logic as an adaptive control system in balanced mechanical ventilation system. Depending on the room temperature, the error or difference of the actual temperature reading and the set point (SP) value can be solved easily. The computation, with the help of the fuzzy system, became a straightforward approach especially in controlling the speed and direction of the fan's motor.

Fuzzy logic proves to be a viable algorithm for systems as it offers more control over the relationship of the inputs and outputs as compared to the common linear systems. It also provides a smoother adjustment of the output as the input changes, thus preventing damage to the equipment due to sudden changes in operation.

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