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A Comparison in AC Compressor Control System using Adaptive Neuro Fuzzy Inference System and Artificial Neural Network with specific area based IoT sensor data to measure the lifespan of compressor.

Project Report

Abstract

Variable speed air conditioning system refers to the types of Air Conditioning (AC) compressors which allow it to run at different speeds. Instead of turning on and off between periods, these units vary significantly between different speeds due to changes in input variable. Though electronics-based compressor speed control is quite common, machine learning based speed control provides greater efficiency to the system. We propose a comparative approach for an AC compressor control system using Adaptive Neuro Fuzzy Inference System (ANFIS) and Artificial Neural Network (ANN). A dataset has been built with collected IoT data from temperature and humidity sensors and also added with generated data for better class distribution. The outputs are generated by ANFIS and ANN training procedure to control the compressor speed. Each input and Output datasets have been divided according to the LIKERT-5 scale division procedure. Rather than having compressor speed ranging in some limits, ANN and ANFIS models are trained for regression like Rotation Per minutes (RPM) output. Later, based on the cumulative RPM in the dataset, lifespan of the motor compressor is also calculated for each system.

Keywords: ANN, ANFIS, Likert scale, RPM

Contents

1 Introduction

Air conditioning system automation means the monitoring and control of the system integrated objects intelligently for effective usage. In order to have an intelligent AC monitoring and control system, the whole system should be interconnected as well as providing information for better operation.

Nowadays, air condition system users are increasing significantly. Air conditioning systems are commonly found in home and public enclosed spaces to create a comfortable environment. One reason for their popularity is because air as a resource is safe, flexible, clean and convenient. These machines have evolved into highly reliable pieces of equipment that are almost indispensable in most of the applications they serve. Compressors can come in a wide variety of different types and sizes .Air conditioning has developed to be an integrated industry including environment, energy, machinery, electronics, and automatic control technology, so that it's major trends of development would be on health, environmental protection, energy saving, intelligence and diversity. Air conditioning is not only a name of the product, but by using the ideas and methods of air conditioning to create comfort and natural environment, while at the same time reduce the ravages of nature and achieve the real sense of harmony of human and nature to the maximum extent.

Conventional design methods for air condition controlling systems are developed with mathematical equations. Mathematical models are an abstraction and cannot perfectly represent all possible dynamics of any physical process. Even if a relatively accurate model of a dynamic system can be developed, it is often too complex to use for development of controllers, especially for many conventional design procedures as they require restrictive assumptions for the plant, e.g. Linearity. As opposed to conventional control design, neural network based control focuses on gaining an intuitive understanding of how to best control the process or plant.

This project work provides a new approach for AC compressor control systems using Adaptive Neuro Fuzzy Inference System (ANFIS) and Artificial Neural Networks(ANN).

Inputs are taken from the temperature and humidity sensors and also generated with mathematical models, and the outputs are generated by ANFIS training and ANN training procedure to control the compressor speed. In this project, each input and output datasets is divided according to the LIKERT-5 scale division procedure. Previous analysis was not built on real life sensor data and suggested compressor speed control system was limited with some commanding variable as like as Compressor off, medium and fast but we have worked with Compressor Rotation per Minute (RPM) directly which might be utilized for highest consumption of electricity wastage also.

2 Background study

The first HVAC controllers would be pneumatic since engineers understood fluid control. Thus, mechanical engineers could use their experience with the properties of steam and air to control the flow of heated or cooled air [1].

After the control of air flow and temperature was standardized, the use of electromechanical relays in ladder logic to switch dampers became standardized. Eventually, the relays became electronic switches, as transistors eventually could handle greater current loads.

By the year 2000, computerized controllers were common. Today, some of these controllers can even be accessed by web browsers, which need no longer be in the same building as the HVAC equipment. This allows some economies of scale, as a single operations center can easily monitor multiple buildings.

An article of [6] about the following things Fuzzy logic control appears very useful when linearity and time invariance of the controlled process cannot be assumed, when the process lacks a well posed mathematical model, or when human understanding of the process is very different from its model. Fuzzy logic control provides a formal methodology for representing, manipulating and implementing a human's experience based knowledge about how to control a system [12]. Fuzzy logic uses human knowledge and expertise to deal with uncertainties in the process of control [5].

Besides these, In this paper they decided with a conclusion that the Neuro-fuzzy algorithm is definitely superior to fuzzy logic as it inherits adaptability and learning. It can be concluded from the simulations that neuro-fuzzy control makes the system adaptive to the room environment and weather. Even the control provided by the neuro-fuzzy is much better than fuzzy logic. In comparison to fuzzy algorithms, neuro-fuzzy algorithms makes the air conditioning system energy efficient.

The Adaptive Neuro-Fuzzy Inference (ANFIS) system performed a vital rule for decision making for each data class. Different membership functions were used for the best result. On other hand, ANN is a powerful tool for classification and regression problems.

3 Preliminaries

This chapter is about the following air conditioning compressor basics with temperature and humidity basics and effects of humidity and temperature in our environment. It also discusses the low humidity and high humidity domain.

3.1 Air Condition

Air conditioning (often referred to as AC, A.C., or A/C) is the process of removing heat from a confined space, thus cooling the air, and removing humidity. Air conditioning can be used in both domestic and commercial environments.

3.1.1 AC Compressor

An air compressor is a device that converts power (using an electric motor, diesel or gasoline engine, etc.) into potential energy stored in pressurized air (i.e., compressed air). By one of several methods, an air compressor forces more and more air into a storage tank, increasing the pressure. When tank pressure reaches its upper limit the air compressor shuts off. The compressed air, then, is held in the tank until called into use. The energy contained in the compressed air can be used for a variety of applications, utilizing the kinetic energy of the air as it is released and the tank depressurizes. When tank pressure reaches its lower limit, the air compressor turns on again and re-pressurizes the tank.

3.2 Humidity and Temperature

Different types of humidity and temperature levels in the home environment is responsible for unhealthy and uncomfortable feelings. This chapter introduces the existing literature of humidity and temperature problems and reducible applications. The study of these approaches will conceptually allow the performance of the proposed approaches to be compared with existing approaches. Such a comparison is particularly valuable since no standard dataset is available for researchers to carry out performance analysis tests, therefore allowing a fair comparison.

Real life data has been collected from a thermal environmental room by installing

DHT22 temperature and humidity sensor. The measurements are taken from different experimental periods. By clustering those data with standard likert scale methods and creating additional data for various range a new solution is provided by classifying clustering those data with standard likert scale methods and creating additional data for various range a new solution is provided we provide a new solution. The proposed technique can save energy by controlling the AC compressor. More specifically home environment is suitable for feeling comfortable at humidity levels between 30-50%. When humidity levels are less than comfort zones or humid and sticky we feel uneasy. By controlling humidity levels, we can get better feelings and reduce maintenance cost as well as energy also [2].

3.3 Data Clustering

The raw data of temperature and humidity sensor device DHT22 is the input device for taking input data. In this section we have discussed part by part in this section.

3.4 Temperature Clustering

Input data are taken from Adafruit server where inputs are taken from the temperature and humidity sensors (DHT22). Then, those data are exported as csv files. Here, the lowest and highest temperatures are 8 and 48 degree Celsius respectively. The temperature data sets are divided into five groups which are: very low, low, average, high and very high.

3.5 Humidity Classification

It is obvious that temperature is not only responsible for unhealthy conditions but also humidity. Air condition control system much more depended on changing humidity. The relative humidity term usually used to define how much water vapor is contained in the air. Relative humidity is the percentage of water vapor in the air at a specific temperature; compared to the amount of water vapor the air is capable of holding at that temperature. Warm air holds more water vapor than cold air. The relative humidity will be 100% if air contains the whole of the water vapor. The relative humidity will be 50% if air contains half of the water vapor at a fixed temperature. In this case, the lowest and highest humidity considered are 7 and 87% respectively. The humidity data sets are divided into five groups which are: Very Dry, Dry, Average, Humid and Sticky.

Based on these aspects the working procedure of our work can be found as follows:

- Device connectivity and circuit setup.
- Set dashboard and feeds in adafruit.io
- Retrieve IoT based sensor data from server into a spreadsheet.
- Data are divided according to likert-5 scaling.
- More data added according to likert-5 scaling.
- ANFIS and ANN model creation for compressor speed prediction.
- Result and performance analysis.

4 Hardware and Software

4.1 Hardware

4.1.1 NodeMCU

NodeMCU is an open-source firmware and development kit that helps to prototype or build IoT product. It includes firmware which runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module. MCU stands for MicroController Unit - which really means it is a computer on a single chip.

4.1.2 DHT22 Tempture and Humidity Sensor

The DHT22 is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed).

4.1.3 Arduino Uno

Arduino is an open source hardware. Most Arduino boards consist of an Atmel 8-bit AVR microcontroller with varying amounts of flash memory, pins, and features. The boards use single or double-row pins or female headers that facilitate connections for programming and incorporation into other circuits. These may connect with add-on modules termed shields. Most boards include a 5 V linear regulator and a 16 MHz crystal oscillator or ceramic resonator.

4.2 Software

4.2.1 Arduino IDE

The Arduino integrated development environment (IDE) is a cross-platform application (for Windows, macOS, Linux) that is written in the programming language Java. It is used to write and upload programs to Arduino board.

4.2.2 Adafruit Server

Adafruit IO is a system that makes data useful. Its focus is on ease of use, and allowing simple data connections with little programming required and to show the data in feeds.

4.2.3 Spyder

Spyder is a powerful scientific environment written in Python, for Python, and designed by and for scientists, engineers and data analysts. It features a unique combination of the advanced editing, analysis, debugging, and profiling functionality of a comprehensive development tool with the data exploration, interactive execution, deep inspection, and beautiful visualization capabilities of a scientific package.

5 Clustering of Input and Output Parameters Using Likert Scale

Effective criteria is needed to evaluate the systems. These criteria should be logical and affined, so that the analysis of the row data can be evaluated in an advisable manner. The classification of temperature and humidity is the first and foremost task for our system design. But it is not only the analysis of data but also grouping of data is necessary. There are advantages and disadvantages to every type of grouping methods. The main advantage of Likert Scale questions is that they use a universal method of collecting data, which means it is easy to understand them. Working with quantitative data, it is easy to draw conclusions, reports, results and graphs from the responses. Furthermore, because Likert Scale questions use a scale, people are not forced to express an either-or opinion, rather allowing them to be neutral should they so choose. Once all responses have been received, it is very easy to analyze them [3].

5.1 What is Likert Scale?

Likert scale is a method of ascribing quantitative value to qualitative data, to make it amenable to statistical analysis. A numerical value is assigned to each potential choice and a mean figure for all the responses is computed at the end of the evaluation or survey. Used mainly in training course evaluations and market surveys, Likert scales usually have five potential choices (strongly agree, agree, neutral, disagree, strongly disagree) but sometimes go up to ten or more. The final average score represents the overall level of accomplishment or attitude toward the subject matter [4].

The scale is named after its inventor, psychologist Rensis Likert. Likert distinguished between a scale proper, which emerges from collective responses to a set of items, and the format in which responses are scored along a range [11].

When responding to a Likert item, respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. Thus, the range captures the intensity of their feelings for a given item. A scale can be created as the simple sum of questionnaire responses over the full range of the scale. In so doing, Likert scaling assumes distances between each item are equal [8].

5.2 Usage of Likert Scale

Likert-type scales are useful while measuring latent constructs - that is, characteristics of people such as attitudes, feelings, opinions, etc. Latent constructs are generally thought of as unobservable individual characteristics (meaning that there is no concrete, objective measurement) that are believed to exist and cause variations in behavior (e.g., answer questions on a scale). Usually, Likert-type scales use statements and use 5 or 7-point response scales (most commonly). The response scales use anchors such as 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree, etc. The items should be phrased in a way that only poses one characteristic per item so that it is clear what the person is responding to. For example, "I think politicians are honest and helpful" is not a good item because you are asking about two separate issues (honesty and helpfulness). Also, try to avoid using the word "not" or other negatives directly in these items as it can become confusing about what it means to disagree with a negative [11].

5.3 Types of Likert Scales

Likert scale can be formatted in various ways depending on research methodology [8]. Typically 5 or 7 point Likert scales are used in research. In our research work we used a 5 point Likert scale. Likert-type scales can be scored in a variety of ways [8]. Typically, one would score each item so that higher scores always indicate "more" of some characteristic and then take the mean (average) of all of the items. Remember, the numbers will not have any inherent meaning (e.g., if you are measuring attitudes about politicians, scoring a 3.4 doesn't REALLY mean anything except that, on average, that individual was slightly favorable in his/her attitudes and can then be compared to the distribution of the remaining responses [8].

A Likert item is simply a statement that the respondent is asked to evaluate by giving it a quantitative value on any kind of subjective or objective dimension, with level of agreement/disagreement being the dimension most commonly used. Well-designed Likert items exhibit both "symmetry" and "balance". Symmetry means that they contain equal numbers of positive and negative positions whose respective distances apart are bilaterally symmetric about the "neutral"/zero value (whether or not that value is presented as a candidate). Balance means that the distance between each candidate value is the same, allowing for quantitative comparisons such as averaging to be valid across items containing more than two candidate values. In terms of the other data characteristics, there was very little difference among the scale formats in terms of variation about the mean, skewness or kurtosis (Johns, 2010). The format of a typical five-level Likert item, for example, could be [15].

5.4 Temperature Classification

In our country the lowest temperature is assumed as less than fifteen. That's why the temperature ranges from between 8 to 14 is assigned as a 'Very Low' class. From 15 degrees Celsius to 20 degrees Celsius is assigned as a 'Low' class. The temperature ranges from between 21 to 30 is assigned as an 'Average' class. The remaining two classes are 'High' and 'Very High', where high class temperature is between 31 to 39 degrees Celsius. Finally, the remaining data are defined as Very high class where data are defined from 40 degrees to 48 degrees Celsius.

Those data are clustered using 5 scales Likert scale. A problem was faced while using Likert scale to group. Traditional grouping system is in 4 scales, but the constructed Likert scale for collecting data is 5-point scale. Therefore, we have to convert the traditional 4 scale classification system into 5 scale to get the more effective output. The following table 1 shows the traditional 4 scale system.

Table 1: 4 scale classification system for temperature

Temperature	Compressor speed
Very Low	Off
Low	Off
High	On
Very high	On

Before predicting the compressor speed control we assigned different temperatures in different classes. This following table 2 shows our system into a 5 scale Likert method.

One thing may be asked why the lowest temperature is 8 degrees Celsius and why the highest temperature is only 48 degrees Celsius.

Table 2: 5 scales Likert method for temperature

Temperatures Parameter	Temperature Ranges (Degrees Celsius)
Very Low	8 – 14
Low	15 – 20
Average	21 – 30
High	31 – 39
Very high	40 – 48

5.5 Humidity Classification

In our country the lowest humidity is assumed as less than ten. That's why the humidity ranges from between 7 to 20 is assigned as 'Very Dry' class. From 21% to 40% is assigned as 'Dry' class. The humidity ranges from between 41 to 55 is assigned as an 'Average' class. The remaining two classes are 'Humid' and 'Sticky'. Both of the humid and sticky classes are tough to survive without an air conditioning system. The humid class humidity is between 56 to 70%. Finally, the remaining data are defined as Sticky classes where data are defined from 71% to 87%.

Those data are clustered using 5 scales Likert scale.. Traditional grouping system is in 4 scales, but constructed Likert scale for collecting data is 5-point scale. Therefore, we have to convert the traditional 4 scale classification system into 5 scale to get the more effective output. The following table 3 shows the traditional 4 scale system.

Table 3: 4 scale classification system for humidity

Humidity	Compressor speed
Dry	Off
Comfortable	Off
Humid	On
Sticky	On

For more realistic data analysis we divided humidity data more specifically. The following table 4 shows our system into a 5 scale Likert method.

Table 4: 5 scale Likert method for humidity

Humidity parameters	Humidity Ranges (Degrees Celsius)
Very Dry	7 – 20
Dry	21 – 40
Average	41 – 55
Humid	56 – 70
Sticky	71 – 87

5.6 Compressor Speed Classification

Nowadays expansive but for better light load efficiency and dehumidification the 1,500-7,200 RPM speed range air conditioning speed motor is used for getting the highest part load efficiency in its class enabling significant electricity wastage consumption. To go through the further evaluation, it is necessary to evaluate the present state of the research. Another main aim of this research is to find out the deficiencies of the fixed values command of an AC compressor. Try to understand why these fixed values are responsible for electricity wastage. Once the deficiencies are excavated, this proposed model can suggest a new way to improve the present states of the research. Once the total model of evaluation is done, the next step is to test it with neural networks. Thus these models can be more dynamic where these models can be implemented using artificial intelligence.

Those decimal numbers will predict the user to run the AC in difference classes as shown in table 5 below:

Table 5: 5 scales Likert method for compressor speed

Compressor Speed	0 RPM	1500-2700 RPM	2701 -3900 RPM	3901-5500 RPM	5501-7200 RPM
Compressor Status	Off	Class A	Class B	Class C	Class D
Cluster Number	0	1	2	3	4

6 Dataset

In the previous chapter we have discussed Likert scales and clustering. Likert scales were used for data classification for the temperature and humidity data. Each humidity and temperature data field are classified into five scales according to Likert scale classification method. In this chapter we are going to discuss the possible outcome for both temperature and humidity.

We have collected data from the server and those data can be mixed. According to two criteria of the two inputs the third prediction is built with compressor speed. Again collected room temperature and humidity data mostly contained in a narrow window of ranges as temperature and humidity does not vary significantly in several days.Very high and low temperature ,humidity data was not available in the dataset. For this reason additional higher and lower end data was added to the dataset according to the Likert scale.

Grouping of the data makes it easy to work with any possible outcome. It is hard and complex to work with each and every individual dataset. It is time consuming too. Among all the dataset there should be a possible single outcome for the same group of data who have the same characteristics. Fig 1 shows the pair plot of the final dataset which represents relation among the variables.

6.1 Clustering of the Dataset

This is not a rule of thumb to predict for each data or for float data without neural networks training procedure. Therefore, one temperature scale may have all possible scales in different environments which may be adapted in the proposed system design. Thus the proposed structure of the model is achieved in a manner where one temperature scale may contain all other scales of the humidity. It's also needed to clarify that each of the AC clusters represent a range of speed for the compressor. For individual temperature and humidity tuples residing in same cluster can have different AC speed. This following figure 2 shows our grouping system:

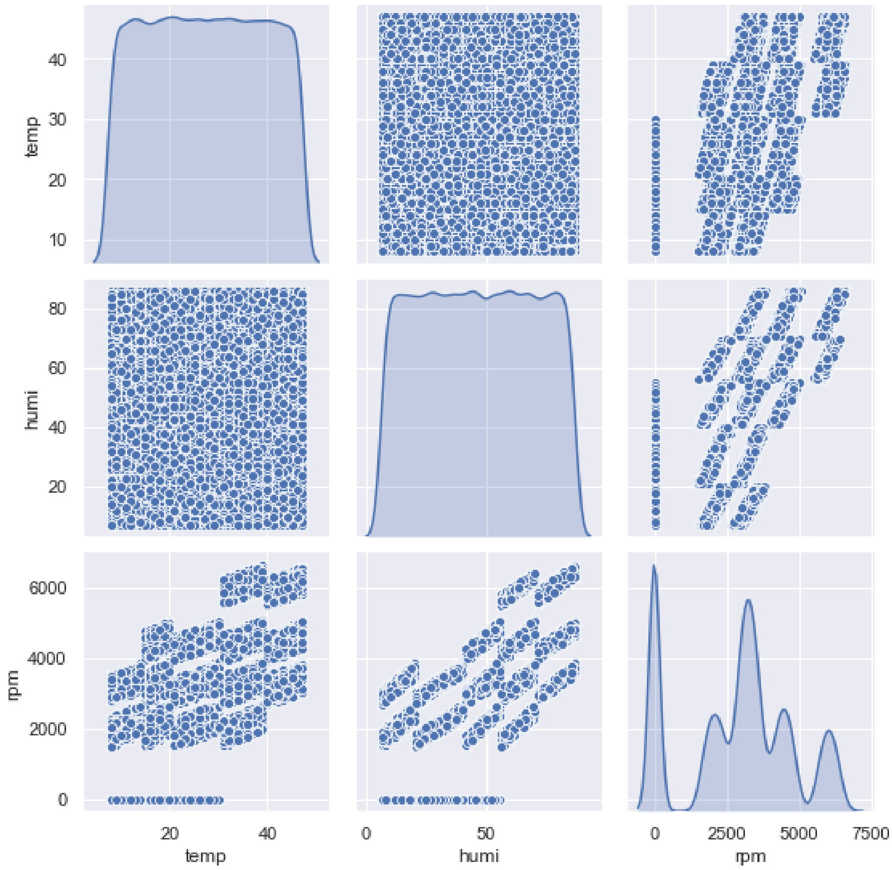

Figure 1: Pair plot of dataset inputs and output

6.2 Working with Data

This research works with 100000 data of humidity and temperature sensors. For the measurement, fixed scale as "OFF" marks or a minimum speed was not used. Some of these data are made from mathematical models. In normal room condition temperature and humidity almost remains constant in time ranges of days. For better evaluation performance of proposed models additional data is required which represent various ranges of input and output classes. Fig 3 shows the uniform distribution of temperature and humidity in the final dataset.

Very simple normalization methods were used for calculations. The proposed system measures the rotation per minute of the compressor for better electricity consumption, no matter if they demand high or low AC speed. The proposed model just compares the needed speed and actual speed of the system.

Data were collected and stored in spreadsheets. Data were checked for missing values.

Temperature(degrees)	Humidity(Percent)	AC speed cluster
Very Low (8-14)	Very Dry (7 – 20)	0
	Dry (21-40)	0
	Comfort (41-55)	0
	Humid (56-70)	1
	Sticky (71-87)	2
Low (15-20)	Very Dry (7 – 20)	0
	Dry (21-40)	0
	Comfort (41-55)	1
	Humid (56-70)	2
	Sticky (71-87)	3
Average (21-30)	Very Dry (7 – 20)	0
	Dry (21-40)	1
	Comfort (41-55)	2
	Humid (56-70)	2
	Sticky (71-87)	3
High (31-39)	Very Dry (7 – 20)	1
	Dry (21-40)	1
	Comfort (41-55)	1
	Humid (56-70)	3
	Sticky (71-87)	4
Very High (40-48)	Very Dry (7 – 20)	2
	Dry (21-40)	2
	Comfort (41-55)	3
	Humid (56-70)	4
	Sticky (71-87)	4

Figure 2: Clustering of Dataset

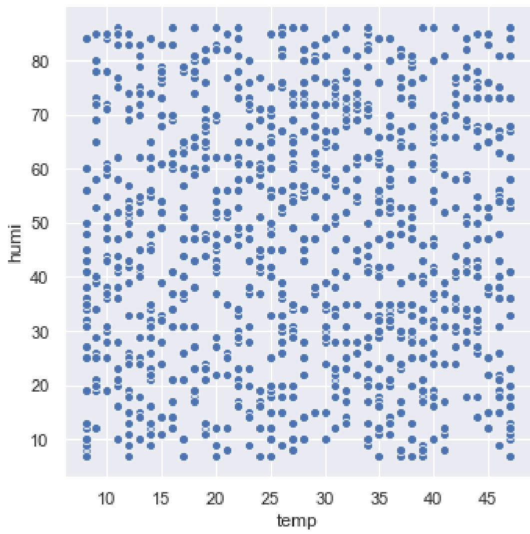

Figure 3: Distribution of first 1000 data in dataset

Mathematical computations were done on a portable Core i5 with Nvidia GPU computing machine with Windows 10 operating system through Python. The calculations were performed using three statistical regression errors : mean squared error, mean squared logarithmic error and mean absolute error.

6.3 The Evaluation Process

The entire evaluation process has two parts, Inputs and Outputs where Inputs that represent humidity and temperature. Those two inputs have greater importance for diction making for variable speed compressors. It is certain that decision should be the prime concern for finding greater benefits. Therefore, in this research, final results have been put greater importance on motor rotation.

7 ANFIS and ANN

From the previous chapters it is already clear how the data is collected, how the data is analyzed and how the grouping is done. Now it is time to discuss how the data is calculated for the fuzzy training. The data is already grouped into five classes. In this chapter the discussion will be on the implementation of neural networks namely ANFIS and ANN.

7.1 Fuzzy algorithm

Fuzzy logic is another form of many values representation, maybe a logic in which the truth values of variables may be the real number between 0 and 1. By contrast, in Boolean logic, the truth values of variables may only be the integer values 0 or 1. Fuzzy logic has handled the real employee the concept of solidly truth, where the truth value may cover the range between all true and all false. Furthermore, when linguistic variables are used, these degrees may be managed by specific (membership) functions [10].

7.1.1 Membership function

The membership function of a fuzzy set is a generalization of the pointer function in older sets. In fuzzy logic, inference rules represent the degree of truth as its own expression methods. Degrees of real are confused with probabilities, although they are thought distinct, because fuzzy reality represents membership in vaguely recognized sets, of likely condition. Zedeh introduced membership functions at first in 1965. There is a list of various membership functions such as triangular, trapezoidal, piecewise linear, gaussian, singleton etc.

7.2 Adaptive neuro-fuzzy inference system

ANFIS stands for adaptive neuro-fuzzy inference system or (ANFIS). It is a neural-network. An ANFIS is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. ANFIS technique was developed in the 1990s. This system was integrating both neural networks and fuzzy logic principles. That's why the new framework ensures the double benefit in a single space or platform. ANFIS learning capability to design inference system are integrated with IF –THEN rules. ANFIS is considered to be a worldwide estimator. For using the ANFIS in a more efficient and optimal way, one can use the best parameters obtained by genetic algorithms [13].

During the research work python was used to implement ANFIS and ANN. A python package based on scikit fuzzy toolkit [14] of ANFIS is used for basic networks architecture Different membership function is being utilized for ANFIS.The experimental input data produce output according to the train data and also which membership function was used [9]. For ANN tensorflow and keras library is used as basic building block.

7.3 Artificial Neural Network

An Artificial Neural Network is an information retrieval method. It functions much as the way data is interpreted by the human brain. ANN contains a wide number of linked processing units that work together to process information. Typically, the artificial neural network is structured into layers [7]. Layers have been made up of several interconnected nodes which include an activation function. The following layers can include a neural network:

- Input layer: The aim of the input layer is to accept as input the values of the explanatory attributes for each observation. Usually, the amount of input nodes is equivalent to the number of informative variables in an input sheet. Input layer exposes the patterns to the network, which communicates to one or more hidden layers. The nodes of the input layer are inactive, implying they do not alter the info. They receive a single value on their input and copy the value along with their other outputs. From the input layer, it copies each value and sends it to all of the hidden nodes.

- Hidden layer: Hidden layers add the input values within the network to the formulas given. In this, incoming clusters are attached to each node from other hidden nodes or through the input nodes. It connects to output nodes or other concealed nodes with departing arcs. In a hidden layer, the specific processing is achieved through a network of weighted connections.

- Output layer: The secret layers then connect to an output layer. The output layer gets ties from hidden layers or from the input layer. It produces a final output that contributes to the prediction of the dependent variables.

- Batch Normalization layer: A process used to render neural networks quicker and more robust by re-centering and re-scaling of the input layer. Also reduces overfitting and stabilizes the learning process.

  Initially, ANN goes through a process of preparation where it begins to distinguish knowledge patterns, whether visually, aurally, or textually. The network contrasts its real output generated with what it was intended to achieve the desired output during this controlled process. Using backpropagation, the difference between both results is modified. This means that the system works backward, heading from the output unit to the input units to alter the weight of its connections between the units till the error between the measured and desired outcome generates the lowest possible error.

8 Performance Analysis

From the previous chapters it is already clear how the data is collected, how the data is analyzed and how the analyzed data are used for decision making. In this chapter Training of ANFIS, ANN and comparison with existing systems are described sequentially.

8.1 Training Anfis system

The data is inserted into the ANFIS system for training. After training the system we can get the assumption wise result for further query. Training is the best solution for getting more realistic knowledge. Here we train the ANFIS with Neuro fuzzy logic rules for our 100000 temperature and humidity data. In this training procedure we need to discuss some membership function and its possible outcome.

Squared error is utilized for error calculation. Fig 4 shows cumulative error of ANFIS training. Though in this figures showed a very high value of errors, it also need to be mentioned that simple variance of 100 for 100000 data points squared can easily create error over 10 to the power 9 and these are summed up for 50 epochs in the given figure.

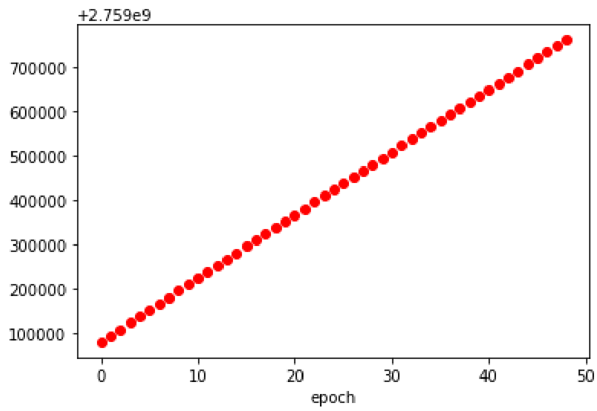

Figure 4: Squared error for ANFIS

8.2 Training ANN

The ANN model comprises one input layer, one output layer, three hidden layers and one batch normalization layer. The complete ANN architecture showed in figure 5. As predicted output varies in range 0 to 7200, by definition compressor speed prediction is a regression problem. For this reason output dense layer does not contain any sigmoid activation instead linear activation is used. 'he-uniform' has also been used as kernel initializer because of the dataset being uniformly distributed. The hidden layer Rectified Linear Unit (ReLU) is used as an activation function. Mean Squared Error (MSE) tends to be the de facto loss function in regression problems. Since output data varies in huge range, and the dataset contains 100000 data, MSE provides a large value for overall loss which hampers network training. For this reason, Mean Squared Logarithmic Error (MSLE) is used as a loss function for proposed ANN. First order gradient-based Adam has been also used as an optimizer. The proposed ANN contains a total 1201 parameters and trained for 1000 epochs with batch size 500. Mean Absolute Error(MAE) is exploited in this network as a metric.

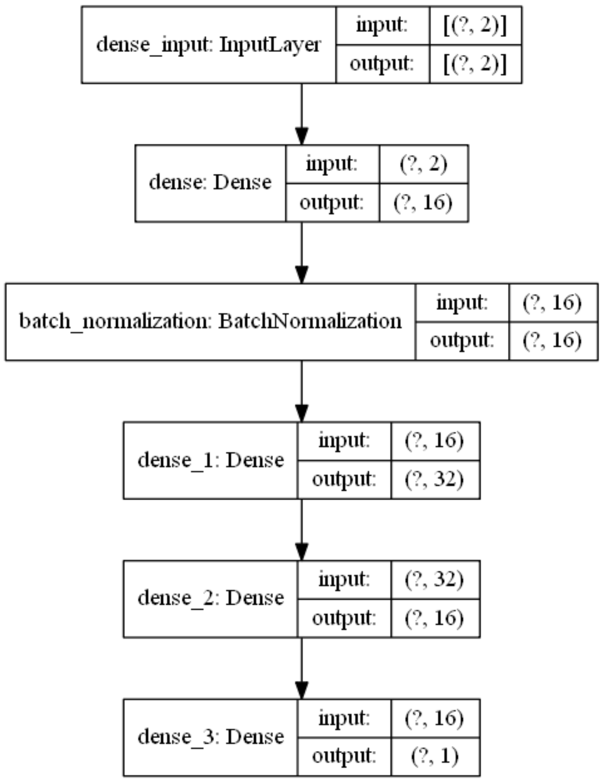

Figure 5: ANN architecture

Then, figure 6 and 7 shows the Loss and MAE of ANN over epochs.

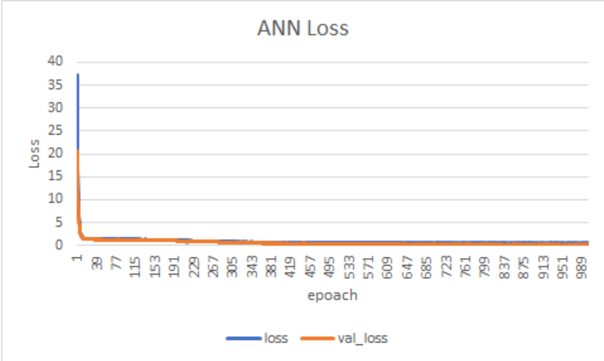

Figure 6: ANN loss

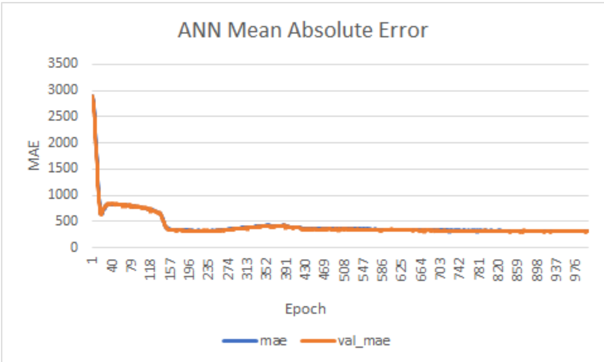

Figure 7: ANN mae

8.3 Predicted Outputs

The following figure says the analytical compressor speed and our predicted compressor speed. We can see that both results are nearly the same. Total prediction vs true class in the dataset cannot be plotted due to the reason of the dataset being very large . Prediction of first 100 data in dataset by ANFIS is shown in figure 8.

Then prediction of first 100 data in dataset by ANN is shown in figure 9. Average validation loss of all epochs is 0.811935. Average validation MAE of all epochs 427.2073.

8.4 Calculation

In this part we are going to calculate the rotation per minute (rpm) and power consumption.

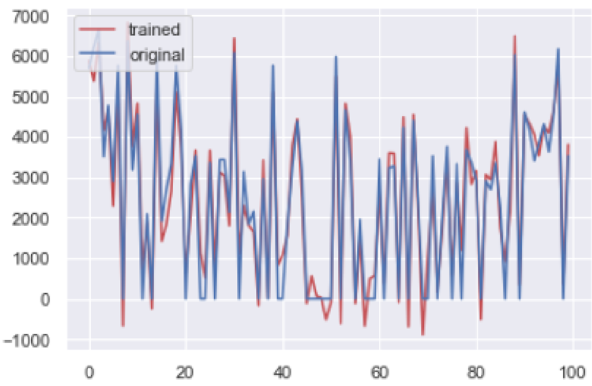

Figure 8: Prediction vs True class for first 100 data by ANFIS

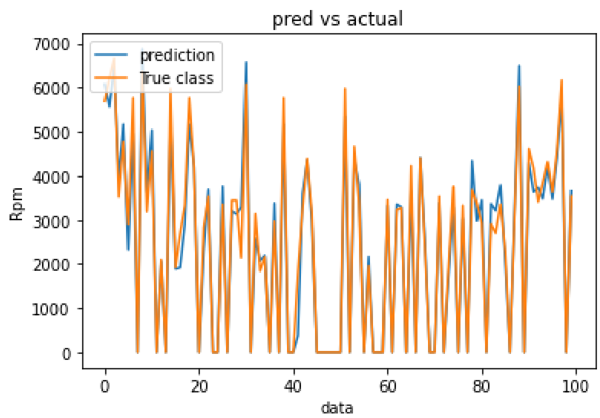

Figure 9: Prediction vs True class for first 100 data by ANN

8.4.1 RPM

$Speed(rpm) = 2 * (FrequencyofACpower * 60)/numberofpoles.$

For example, if your supply is 50 Hz and the motor is using two-pole,

The $synchronousspeed = 2 * (50X60)/2 = 3000rpm$

With a power line frequency of 50 hertz the RPM are:

3000 RPM (for a 2 pole motor)

1500 RPM (for a 4 pole motor)

1000 RPM (for a 6 pole motor)

60Hz is the most common frequency in the US and 50Hz is the most common frequency outside the US

8.4.2 Power Calculation

To find the power consumption of electric motor we have to calculate the total power consumption. Here is some formula for support calculation:

$P = T * W/9.5488;$

where, P = power (watt or KWatt), T= torque, W = angular velocity (Rotation per minute).

For comparison, a 5 step variable speed compressor is referred to as an existing system. Compressor rpm is calculated using a range from likert scale. Mean value of cluster range is taken as output rpm as the existing system. Figure 10 shows the summation of rotation of each method for the dataset. From previous figures 4 and 6 it can be observed that ANN tends to have lower error than ANFIS . Again in figure 10 shows that the total number of rotations in ANN is also lower than ANFIS which tends to lower power consumption. As previously stated if torque of any compressor remains equivalent , power consumption is directly proportional to rotation. On the other hand every compressor is rated for a constant number of rotations in its life span. Thus lower number of rotations tends to crease the lifespan of the compressor.

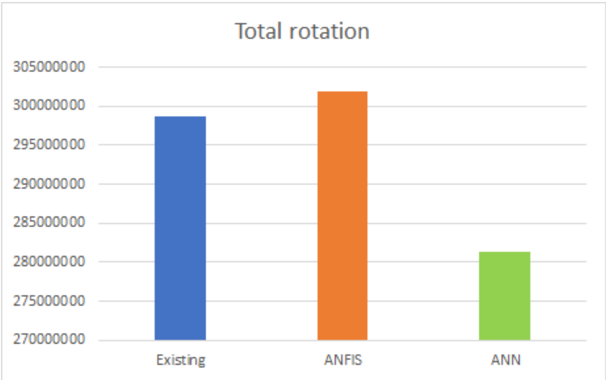

Figure 10: Total rotation of different methods in the given dataset.

9 Conclusion

AC Compressor Speed controller based on ANFIS and ANN was successfully developed in this article with significantly lower validation loss. It has also been shown that predicted output from ANFIS and ANN matches with actual compressor speed for any given discrete value of inputs. The performance also compared with existing five scale variable compressor output. Among ANFIS and ANN, ANN outper performs ANFIS both in less error and less power consumption. It can be concluded from the experimental results that trained ANN makes the system energy efficient and adaptive to change in temperature and humidity then other methods. In future complete ANN powered speed controllers with other variables such as compressor blade design , electricity consumption ,air quality can also be added for further improvement.

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