SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 10, No. 2, June 2013, 309-318

UDK: 531.754:536.5]:510.6 DOI: 10.2298/SJEE121219006V

Optimum Fuzzy Based Approach to Improve the Instrument's Performance Affected by Environmental Conditions

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Abstract: The performance of instrument has been analyzed, considering the ideal conditions and results which have been obtained when the instrument is subjected to diversified combination of environmental conditions. A peerless analysis has been carried out of these environmental conditions using 'fuzzy set theory' as a mathematical tool. The results showed how the use of fuzzy set theory is adequate to analyze environmental conditions and is able to suggest the optimal operating conditions for performance of the instrument. In this analysis two independent variables temperature and relative humidity have been used, and based on these two independent variables a third dependent variable was defined namely temperature humidity index (THI). Based on THI, a set of fuzzy rules were established considering the influence of both independent variables. The results obtained without fuzzy experimentation according to the specification of instrument and results obtained with fuzzy analysis shown were quite comparable. The results obtained after fuzzification explicitly show that the operating instrument's accuracy can be predicted by comparing with the THI zone and at the same time this research gives an insight for selection of nearest optimal operating condition for normal working of the instrument. It can be summarized that the abrupt variation in independent variables can make the instrument unstable and the fuzzy based approach is helpful in improving the overall instrument performance.

Keywords: Relative Humidity (RH), Temperature Humidity Index (THI), Psychomotor, Fuzzy logic, Environmental condition, Temperature, Humidity, Instrument.

1 Introduction

The instrument performance and industrial productivity largely depend on the environmental operating conditions. Environmental parameters i.e. temperature, humidity, pressure etc., are directly associated with the performance of instruments and components. Out of these different

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environmental parameters, humidity has a greater importance because minute change in its values can significantly affect instrument's performance and it has a cumulative effect on the entire productivity of the industry. Generally humidity can be characterized in terms of absolute humidity, relative humidity and dew point humidity. Out of these, relative humidity has got greater significance in industrial and instruments applications [1]. Relative humidity is closely associated with saturated vapour pressure, so a small change in saturated vapour pressure values shows significant changes in relative humidity parameters. Also, in another way, the relative humidity can be defined as the ratio of water vapour in a mixture of air to the total water vapour, which can be understood in crude sense as the ratio of the partial pressure of water vapour in the mixture of air-water to the saturated vapour pressure of water at some fixed temperature [2]. In studies it has been observed that relative humidity is not only influenced by the temperature but also on the pressure of the system. To analyse the humidity data in order to reach various scientific and engineering conclusions, we generally consider humidity ratio and define it in terms of following parameters depending upon the requirement as pressure, mass and humidity. In terms of pressure, humidity is defined as the ratio of partial pressure of vapour in air to the saturated air pressure. In terms of mass, humidity is defined as the ratio of mass of water vapour present in air to the mass of dry air. In terms of density it is understood as the ratio of density of water vapour available in air to density of dry air. For measurement of relative humidity the following techniques are followed namely Dew point mirror and Psychrometer. In either of the cases a good degree of precision can be achieved, in this paper we have chosen to analyse data obtained from psychrometer [2, 3]. Humidity is one of the most crucial environmental conditions in a large number of processes and industries, however, the accurate measurement of relative humidity is still a tough task. It is of greater cause of concern to track the relative humidity in certain regulated environments. There are various industrial applications which are affected by humidity namely Pharmaceutical industrial applications, Packaging of vegetables and fruits, animals breeding, milk producing industries etc. From the literature it has been leant that many researchers have attempted analyses to know that a change in relative humidity affects the entire output process. Out of the numerous types of quoted effects some unique analysis have been made to prove the effect of relative humidity in different form of engineering application such as; during conversion of solar energy to electrical energy, at the time of production of ozone by corona discharge in oxygen or air, during product production of an industry etc. [4, 5]. Most of the authors have proposed an appropriate controller for controlling the effect of relative humidity. Our research is specifically unique in the sense that here we are not going for a particular controller rather we are optimizing the environmental conditions, i.e., if for a particular value of relative humidity the instrument's performance is degraded, then by selecting proper value of temperature the effect of relative humidity can be annulled. In this paper an alternative strategy to improve instrumental performance has been proposed by managing the control of heat stress which is a function of environmental conditions like temperature and relative humidity. The aim of this paper is also to explore an idea that how the implementation of the fuzzy set theory in relative humidity analysis can be used to adequate the environmental conditions. The mathematical tool will enable the ideal condition for the performance of instrument after analysing the environmental conditions and suggesting the desired changes.

2 Methodology

In industries relative humidity is measured with the help of psychrometer, the working principle of measurement involves two parallel thermometers, one is kept open in surrounding but shielded from moisture and radiation; it is used to measure the dry bulb temperature. The other thermometer is covered with water sleeve; it is used to measure the wet bulb temperature. Because of the evaporation taking place from the surface of water sleeve, the latent heat is librated to the surroundings and as a result of this wet bulb temperature decreases. The difference between dry bulb and wet bulb temperature is measured. This difference is used to calculate the relative humidity. A continuous stream of air is blown around the wet bulb which further decreases the temperature of wet bulb because of evaporation taking place from the surface. After sometime an equilibrium is established between heat moving from surroundings to the wet bulb and latent heat librated. The equation written below is derived from Assmann type psychrometer which is also called as Sprung's psychrometric formula.

$$e = e_w - \frac{A}{755} p(t - t_w) , \tag{1}$$

where $A/755$ is the psychrometer constant (the value of A varies with the state of wet bulb, it is 0.50 and 0.45 respectively for the wet bulb when it is not frozen and frozen), e, e_w, p are vapour pressure, saturation vapour pressure and atmospheric pressure in [kPa], respectively, and t, t_w are dry bulb temperature and wet bulb temperature, respectively.

The relative humidity is calculated [2] by as:

$$RH = (e - e_w) \cdot 100 \ [\%] . \tag{2}$$

As shown below, **Table 1** of Relative Humidity Index (RHI) has been prepared from the experimental data collected from the instrument when subjected to wide range values of temperature and humidity with varying percentage of instrument's accuracy. In **Table 1** (THI) the dependent variable temperature humidity index (THI) is obtained through independent variables temperature and relative humidity by using the formula written below. For deriving this equation which is a constituent of many traditional independent variables, a good quantity of regression analysis was performed on the data from Steadman's table and lastly it is converted to ersatz version to obtained Heat Index equation [6].

$$\begin{aligned}\text{Heat Index (THI)} = &-42.379 + \left(2.04901523 \cdot T\right) + \\ &+ \left(10.14333127 \cdot R\right) - \left(0.22475541 \cdot TR\right) - \\ &- \left(6.83783 \cdot 10^{-3} T^2\right) - \left(5.481717 \cdot 10^{-2} R^2\right) + \\ &- \left(1.22874 \times 10^{-3} \cdot T^2 R\right) + \left(8.5282 \cdot 10^{-4} TR^2\right) - \\ &- \left(1.99 \times 10^{-6} \cdot T^2 R^2\right),\end{aligned} \tag{3}$$

where T is temperature in [°F], R is relative humidity in % [7].

Table 1
Temperature Humidity Index THI.

RH [%] / Temperature [°C]	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
21°C	71.3	74.2	76.2	77	76.9	75.9	73.8	70.8	66.9	61.9
23°C	73.5	75.3	76.5	77.2	77.1	76.5	75.4	73.6	71.1	68.4
25°C	75.9	76.1	77.6	78.2	78.6	78.7	78.7	78.5	78.2	77.6
27°C	78.5	78.9	79.5	80.3	81.3	82.5	83.9	85.5	87.3	89.3
29°C	81.3	81.4	82.2	83.5	85.4	87.8	90.9	94.5	98.7	103.5
31°C	84.1	84.3	85.5	87.6	90.7	94.7	99.6	105.5	112.4	120.2
33°C	87.1	87.8	89.6	92.8	97.3	103.2	111	118.6	128.4	139.4
35°C	90.2	91.5	94.5	99	105.3	113.1	122.6	133.7	146.6	161.1
37°C	93.5	95.7	99.9	107	114	126.6	136.7	150.9	167.2	185.2
39°C	96.8	100.3	106.2	115	125	137.6	152.7	170.2	189	210

For further analysis the tolerance band of instrument has been dissected further as shown in operating zone **Table 2**. According to the tolerance band of instrument this THI was categorized in four groups as: Normal, Alert, Extreme and prohibited as shown in **Table 2**. These categories represent another kind of variables which can be recognized as linguistic variables. These linguistic variables are now used to analyse through the fuzzy set theory. The linguistic variable is tabulated as follows:

Table 2
Operating Zones.

Categories	Tolerance Band
Normal(N)	[61,110]
Alert(A)	[111,140]
Extreme(E)	**[**138,158**]**
Prohibited(P)	[155,211]

3 Fuzzy Analysis

The fuzzy logic is a unique tool invented by Zadeh in 1965 at University of London to deal mainly those types of problem**s** where boundaries are not clearly mentioned. As explained in Section 2 (Methodology) that when there are two independent variables and give randomly scattered values. Such peculiar situations often renounce the solution. Fuzzy logic analysis handles such problems in terms of 'degree of matter' which is specified by membership function. MATLAB framework has been used to solve this technical problem because it provides a platform to communicate with fuzzy inference system. Fuzzy logic has good confederation in engineering application for its simple rule features. Its rules are closely associated with the human reasoning and concept formation. It greatly utilizes the concept of human reasoning ability which is based upon approximate values. In this paper we have used various steps of fuzzy analyses like fuzzification of inputs, application of fuzzy operator, implication method, aggregation of all outputs and defuzzification [7 – 9].

Many researchers have proposed different methods for various parameters of analysis through fuzzy. For instances trapezoidal, triangular, Gaussian, sigmoidal etc where as various type of defuzzification methods are given by Adaptive integration, Center of area, Center of gravity, Fuzzy clustering Defuzzification, First of maximum, Last of maximum, Mean of maxima, Semi-linear Defuzzification, Quality method, Middle of maximum etc. As temperature and humidity control belongs to nonlinear systems so it is suitable to choose Gaussian shape, but if Gaussian shape is chosen, the distribution fuzzy variable operation will become quite complex and the calculated speed will slow down. For the computation to be relatively simple, in this research triangular shape which is similar to Gaussian shape has been used [10 – 14].

In this analysis two input variables are defined as temperature and relative humidity and output is temperature humidity index. Fuzzy logic has been used as the main operational platform for this analysis. The number of membership function taken in temperature variable is 9 whereas for second variable relative humidity (RH) 10 membership functions were defined as given in **Table 3** and **Table 4** respectively. **Table 3** shows the temperature index in which the classification of temperature is given in correspondence with their values in the interval column. Fig. 1 shown below gives recitation of **Table 3** index. This is an input2 for the fuzzy system and clearly indicates the data in fuzzy pattern.

Similarly the **Table 4** shows the Relative-Humidity Index in which the classification of RH is given in correspondence with their values. Fig. 2 shown below gives recitation of **Table 4** index. This is an input1 for the fuzzy system and clearly indicates the data in fuzzy pattern. The Figs. 1 and 2 give the fuzzy input format for two independent variables.

Table 3
Temperature Index.

Interval	Term
[21,24]	T1
[22,26]	T2
[24,28]	T3
[26,30]	T4
[28,32]	T5
[30,34]	T6
[32,36]	T7
[34,38]	T8
[36,40]	T9

Table 4
Relative-Humidity RH *Index.*

Interval	Term
[0,12]	RH1
[10,22]	RH2
[20,32]	RH3
[30,42]	RH4
[40,52]	RH5
[50,62]	RH6
[60,72]	RH7
[70,82]	RH8
[80,92]	RH9
[90,100]	RH10

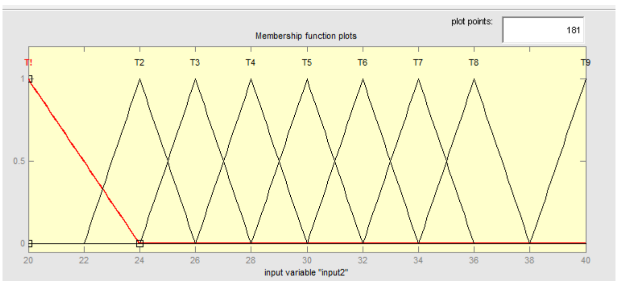

Fig. 1 – *Temperature membership function.*

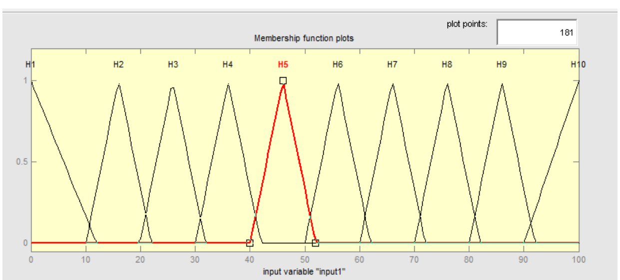

Fig. 2 – *Relative Humidity membership function.*

90 rules have been obtained with the combination of two input variables, temperature and relative humidity having membership functions 9 and 10 respectively. The inputs are mapped depending upon the Rules given as follows:

– If input1 is H1 and input2 is T1 then output is THI1;

– If input1 is H1 and input2 is T2 then output is THI1;

– If input1 is H1 and input2 is T3 then output is THI1;

– If input1 is H2 and input2 is T1 then output is THI1;

– If input1 is H10 and input2 is T9 then output is THI4.

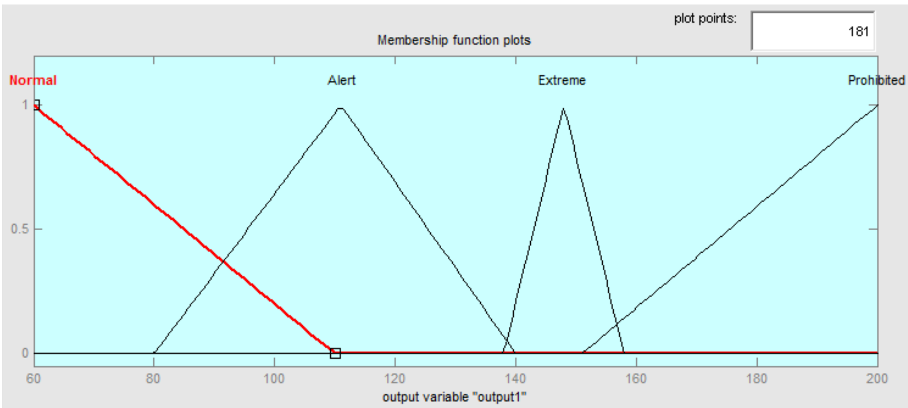

Fig. 3 – THI *Membership Function Plot for Output variable.*

The output results are depicted in Fig. 3. The output THI has been defined by four triangular membership functions which itself acting as deciding parameter for operating zone of the instrument under certain environmental conditions.

4 Results

Fig. 4 shows the 3D surface generated as a function of the fuzzy set theory which summarizes the rules system. This 3D surface shows the stability of fuzzy controller and satisfying the results evaluated in odd circumstances. The 3D surface in Fig. 4 clearly represents that when the two input values are low, the output is also low. The output is gradually increasing in correspondence with the changes in inputs. And an abrupt rise can also be seen when input values are very high. Overall the complete system is minimising and maximising in coherence with the input and output values. So it can be summarised that the system is completely balanced and stable. Rules as shown in **Table 5** are obtained from all the 90 compositions of the variables. The elements of this **Table** $THI_{(i,j)}$ has been interpreted as THI (H_i ,T_j). For example

$THI_{8,8} = THI(H_8, T_8)$, represents the Alert condition through rule “If H is H_8 and T is T_8 then THI is Alert”. Similarly other rules have been implemented in the program.

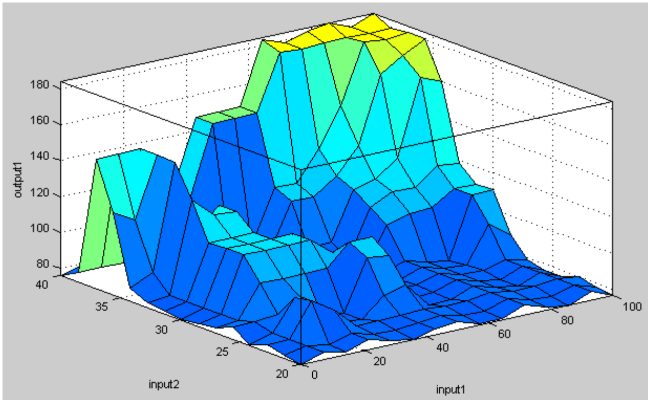

Fig. 4 – 3D *Surface Generated Fuzzy Set*.

Table 5

Temperature v/s RH *variable composition.*

RH [%] / Temperature [°C]	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8	RH9	RH10
T1	N	N	N	N	N	N	N	N	N	N
T2	N	N	N	N	N	N	N	N	N	N
T3	N	N	N	N	N	N	N	N	N	N
T4	N	N	A	A	A	N	N	N	N	N
T5	N	A	A	A	N	N	N	N	N	A
T6	N	A	A	N	N	N	N	A	A	A
T7	N	E	E	N	N	N	N	A	A	E
T8	E	E	N	N	N	A	A	E	P	P
T9	N	N	A	A	E	E	P	P	P	P

It becomes necessary to evaluate the defuzzyfied results before reaching the final conclusion. Here the defuzzification has been done, as a deciding element for an appropriate representative value in the final output (crisp value) to find the conclusion. Using this analysis and the obtained defuzzified output in Fig. 5, it is possible to obtain results for different combination of independent variables. It can also be assumed that the centre of gravity of the system is maintained and is placed near the centroid of the system. Depending upon the band in which it lies, we can predict about its accuracy and the variation in the input independent variable can bring the operating condition of the instrument in normal range.

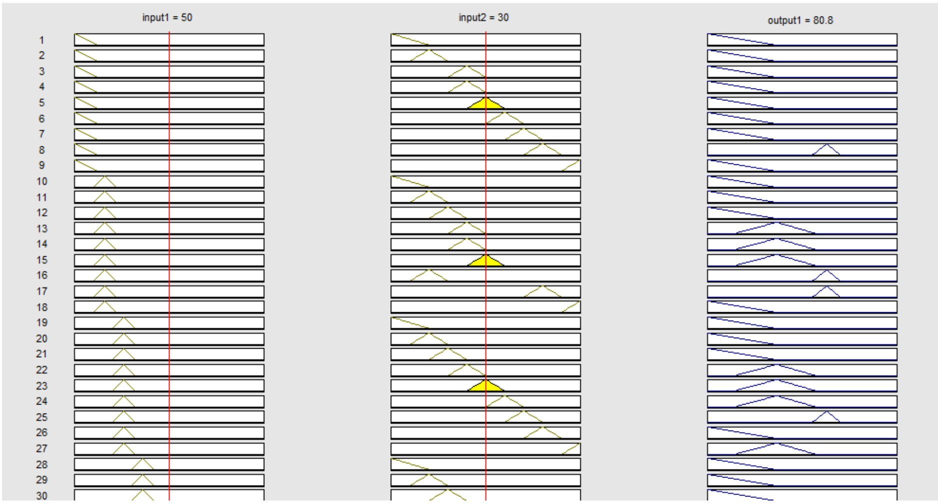

Fig. 5 – *Defuzzyfied output*.

Assume for a particular case if the selected values like $T = 28$°C and RH = 60%, the resulting THI comes under alert zone so depending upon the desired accuracy of instrument. Now if there is a change in either of the variable say the temperature has been varied and new value is $T = 26$°C and RH remains same. Now THI came under normal operating zone to bring the operating condition of the instrument under control. So this way the operating condition and instrument's errors can be rectified automatically and they can be brought back to the normalcy from error environment or abnormality.

5 Conclusion

The result of this research gives an idea that by observing the environmental conditions i.e. relative humidity and temperature we can predict the operating instrument's accuracy by comparing with the THI band and at the same time this research gives an insight for selection of nearest optimal operating condition for normal working of the instrument. With an example we can conclude that for fixed value of RH = 80%, for normal operation and good accuracy the temperature range should be within 30°C, though depending upon the need of accuracy for particular experiment range can be further extended. Advantages of improved technique can be summarized as follows:

1. *Easier implementation*: The improved technique can be easily employed in the industrial environment to improve instrumental performance;
2. *Higher accuracy*: By application of this technique the accuracy as well as overall performance of the working instrument can be significantly enhanced.

6 Acknowledgement

We are highly thankful to the Belz Instruments pvt. Ltd. Faridabad (Haryana) – India for their whole hearted support and for providing us the facility at their workplace to establish experimental study and to procure the experimental data from their instrument named RH generator.

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