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Reliability Comparison of a Fabricated Humidity Sensor using Various Artificial Intelligence Techniques

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Abstract

A humidity sensor detects, measures and reports the content of moisture in the air. Using low cost composite materials, a humidity sensor has been fabricated. The characterization has been done using various techniques to prove its surface morphology and working. The fabricated sensor detects relative humidity in the range of 15% to 65%. The life of the sensor has been calculated using different experimental and statistical methods. An expert system has been modeled using different artificial intelligence techniques which predicts failure of the sensor. The Failure prediction of fabricated sensor using Fuzzy Logic, ANN and ANFIS are 81.4%, 97.4% and 98.2% accurate respectively. ANFIS technique proves to be the most accurate technique for prediction of reliability.

Keywords: *humidity sensor; fuzzy logic; artificial neural networks; ANFIS; reliability*

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1. Introduction

The presence of water vapor in the air is called humidity. If humidity exceeds a particular level, it can cause problems to the respiratory system, skin, and eyes. It also enhances the electrostatic discharge from body to conductive surface. The accurate humidity sensor can prevent the products to be corroded and spoiled. There is variety of humidity sensor available in the market. For device fabrication, researchers have shown interest in the materials having high ionic conductivity. In a lattice network, when second insoluble phase is diffused the overall ionic conductivity is increased up to hundred times. The other method to increase ionic conductivity is increase impurity atoms, which will make system amorphous. Rigorous research studies in the past have resulted in a number of high-quality solid electrolyte system, but endeavour to develop new composite material with enhanced properties always persists. In the present paper, we present a solid electrolyte system having high conductivity, where carbon and potash alum acts as a dispersoid. The new composite system acts a humidity sensor [2,3,9,13,14,23].

Accuracy and reliability are two key parameters that are the basis of efficient and desirable product. A product is said to be successful only in the case if it performs the designated operation for designated time without any degradation in performance. Degradation modeling is an effective approach for condition monitoring and health prognostics, using physics of failure or data driven approach [16]. It is the most important issue to target the reliability along with other operational characteristics. If the product or system is not reliable, it will unnecessary sum up the repair cost, degrade the reputation of the product in market. Across the globe, a race has been going on to lure the customers for electronics and electrical items and for that they need to provide better performance, high quality and low cost [20]. Another factor that comes into picture is the Time to market (TTM). As competition is increasing day by day, every sector or industry tries to launch their product as soon as possible because there may be chances that likewise product may get launched and industry may face great loss economically. Another factor that is most important is the “Reliability” of any system. All big brands, big industry with repute

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are moving forward to develop as reliable system as possible to contribute towards customer's safety as well as to maintain the quality. The higher the brand, higher the cost, and higher the reliability.

Ionic transport in silver iodide, including a number of dispersoids (Al_2O_3, AgBr, fly ash, SiO_2), has been reported by Shahi and Wagner [15] and Jow and Wagner [7]. Sachdeva et al. [12] have reported an increase in the conductivity of potash alum when used with fly ash as a dispersoid. Conductivity measurements of carbon black have already been measured by Isaaq et al. [6]. Enhancement of ionic conductivity of gum arabic due to the presence of carbon black as a dispersoid has already been investigated [21].

To utilize carbon black and alum in a better way, a successful effort has been made to fabricate composite based humidity sensor. In the present paper, the reliability of fabricated humidity sensor has been analyzed using accelerated life testing method, which utilizes Arrhenius equation to explore the life of the fabricated sensor. An expert system has been created using different artificial intelligence techniques i.e. artificial neural networks, fuzzy logic and ANFIS. Then, the response obtained using artificial intelligence methods have been compared with reliability calculated by experimental method. The most accurate method has been adopted to create and model intelligent system. Using artificial intelligence techniques, failure prediction and the life of the component have been calculated as a method suggested by Zubaidi et al. [24].

2. Experimental Methodology

2.1 Sample Preparation

Carbon black and potash alum of unknown purity were collected from the local supplier. Then the considerable amount of potash alum and carbon black was weighed, meticulously mixed and pulverized in an agate mortar and pestle for approximately 2 hours. This was followed by pelletization in a nickel-plated steel die at the pressure of 2.5 tons using a hydraulic pelletizer machine. Pellets with a circular contour having area 0.2 cm^2 and 3–5 mm in thickness were obtained [1].

2.2 Characterization Techniques

Both carbon and potash alum were mixed in all possible ratios and conductivity was measured using complex impedance spectroscopy. The sample that possesses highest conductivity has been chosen as composite sample. The conductivity attained maximum of 3.4×10^{-5} S/cm when alum was doped with 40% of Carbon. Then different characterization techniques were implemented on that sample (40% carbon-60% potash alum). Scanning Electron Microscopy (Hitachi S-570) illustrates the topology of pure carbon, pure alum and composite. The SEM result shows that carbon was uniformly mixed with potash alum. FTIR (Perkin Elmer 883) determines the optical property of composite sample. It shows that there was no extra peak in composite sample. XRD Rigaku (D/max-2500) recorded to further investigate the composite nature and structural analysis of the composite electrolyte. It indicates no chemical reaction was taken place between the two components and realization of a perfect composite was achieved.

For electrical measurements, both sides of pellets were coated with silver paste to make it conductive. After silver pasting, we dried them under normal temperature. The Model CHI604D, an electrochemical workstation with a frequency range of 10^{-4} Hz to 10^2 KHz was used, whereas electrodes were made up of pressure-contacted stainless steel.

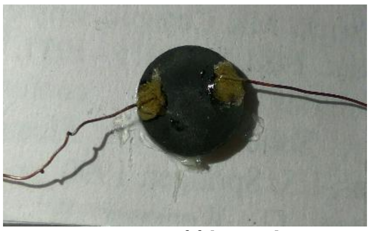

Figure 1. Image of fabricated sensor

Figure 1 shows the image of the sensor which was fabricated using carbon-potash alum composite material. It was observed that the resistance of the composite film decreased by about 10 times, and linearity range expanded from 30% RH to 65% RH.

2.3 Stability Test

The stability of sensor was examined by measuring humidity-resistance property of the sensor at 25°C, in humidity range

10%-90%RH over 30 days in a regular interval of one day, the stability test was monitored at room temperature, the sensor was exposed to air and resistance was measured as %RH in between range of 10%-90%RH for 30 days. The sensor is stable for at least 30 days. The result of stability, in terms of RH Versus Resistance has been analyzed on a daily basis and summarized as day1, day15 and day31 in Table1.

Table1 Relative humidity versus Resistance

Relative Humidity (RH)%	Resistance K-ohms (Day1)	Resistance K-ohms (Day15)	Resistance K-ohms (Day31)
10	400	396	392
15	320	316	312
20	270	263	255
25	200	189	180
30	175	162	149
35	150	134	125
40	115	97	90
45	100	81	75
50	75	67	60
60	65	54	50
70	55	49	45
80	50	47	43
90	48	43	40

The Figure 2 illustrates the graphical representation the change in relative humidity with respect to resistance.

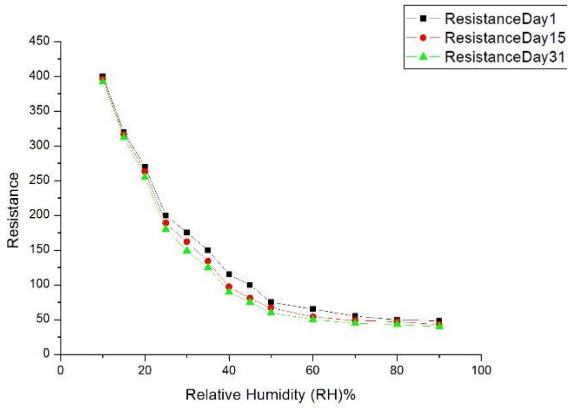

Figure 2. stability graph day1 vs day31

The detection limit of the fabricated sensor has been illustrated as Figure 3.

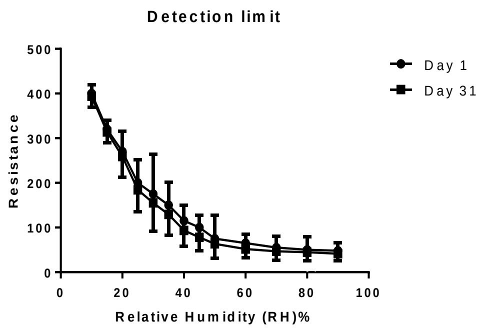

Figure 3. Detection limit day1 vs day31

2.4 Applications

To illustrate the application of the composite sample, the maximum ionic conducting composition was selected and used to fabricate a humidity sensor in our lab. The Silver paste along with attached copper wires was used to investigate its sensing behaviour.

AC mode was used to measure humidity sensor. The Experimental Method has been shown in Figure 4 and Circuit diagram in Figure 5. Response of humidity sensor has been measured in our lab as designed by Srivastava and Chandra [17]. We placed different salt solutions within the chamber to obtain different humidity values as suggested by Sweetman [19].

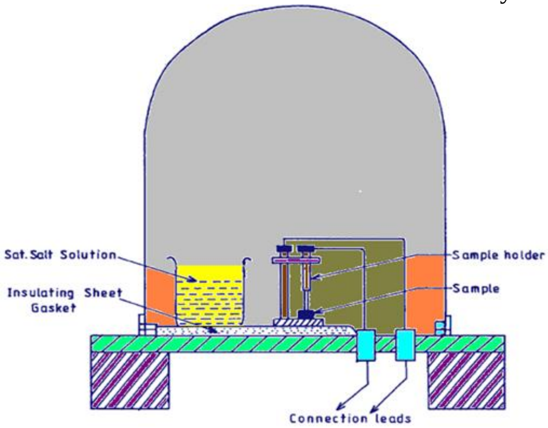

Figure 4. Experimental setup to measure humidity

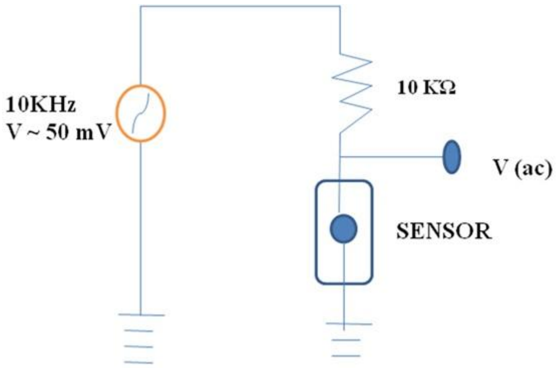

Figure 5. Circuit diagram to record response of sensor

The Response of the sensor (Voltage versus Humidity) was measured. The developed sensor shows an exponential decrease in voltage with an increase in humidity level [8,11,22].

Table 2 Humidity versus voltage

Humidity	40	45	50	55	60	65	70	75	80
Voltage	1.44	0.63	0.29	0.28	0.25	0.24	0.21	0.17	0.15

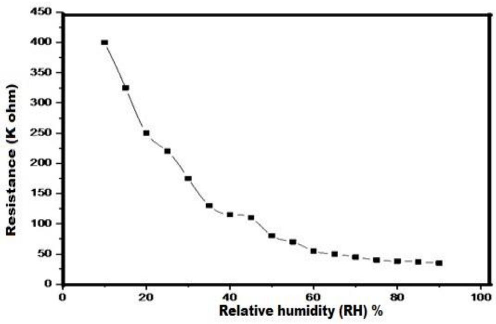

Figure 6. Variation of resistance with relative humidity for maximum conducting sample

The variation of sensor response time and recovery time with temperature was measured**.** The recorded response and recovery time was 47 sec and 318 sec. [4,5,18]

3. Failure Prediction of the sensor

Reliability is one of the major challenges that a sensor technology faces. To predict failure of a sensor before time can save the entire system. The failure can be predicted using FIT (failure in time) and MTBF (mean time between failures). Using artificial intelligence methods, an expert system can predict the failure before the end of life so that replacement of the faulty product can be done well before time.

3.1 Analytical method for failure rate

Twenty-five units of the maximum ionic conducting samples were prepared, which acted as a good humidity sensor. To predict their failure and remaining useful life, these 25 units were kept under different temperature conditions for 240 hours. Few units could not bear high temperature for fixed time. The results of these accelerated life test were recorded. The failure in time (FIT per 10^9 hours) was calculated using Arrhenius equation of acceleration factor

$$FIT(\lambda)= F/D.T.A_F \tag{1}$$

Where
F=Number of failures
D=Number of devices tested
T=Test hours
A_F=Acceleration factor= e $^{Ea/k(1/T_{use}-1/T_{test})}$
Ea=Activation energy (ev)
K=Boltzmann constant
T_{use}=use temperature, T_{test}=test temperature

After calculating failure rate, the mean time between failures, MTBF corresponding to failure rate (FIT) was calculated as

MTBF (hours) = $(1/\lambda)*10^9$ hours
MTBF (years) =MTBF (hours)/ (24)*(365)

The failure rate and corresponding MTBF data have been concluded in table 3. It reflects the inverse relationship between reliability and temperature.

3.2 Failure prediction using artificial intelligence techniques

The three different artificial intelligence techniques i.e. artificial neural networks, fuzzy logic and ANFIS were deployed to predict the failure time of the fabricated sensor. Then the predicted failure time was compared with the failure time that was calculated by analytical method. The technique with the least error was chosen as best technique to model the expert system.

3.2.1 Artificial neural networks technique

The application of artificial neural networks has been used to conduct the failure analysis of the developed sensor. For this purpose, an artificial neural network model with feed forward backpropagation algorithm was developed, using neural network Simulink tool for prediction and validation of data. The temperature and conductivity were imported as input and the output was mean time between the failures, MTBF. The 2-10-1 model was selected, where hidden layers are 10, as shown in Figure 6.

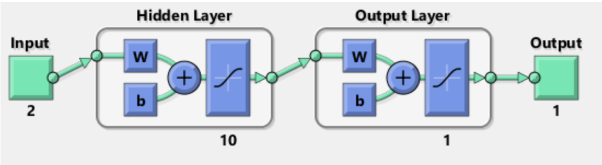

Figure 7. Model of artificial neural networks (2-10-1)

Total 36 data set were recorded, out of which 26 data set were used as training set and 10 data set for testing purpose. The validation of data has been shown in Figure 7.

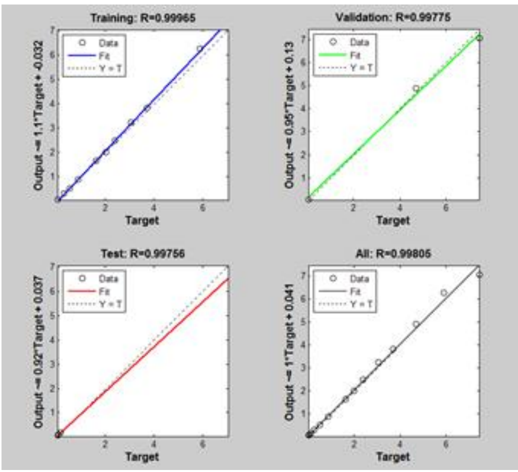

Figure 8. Training and testing of expert system

3.2.2 Fuzzy Logic Approach

The fuzzy logic approach is an interactive way to predict reliability [10]. The fuzzy logic method was used to predict failure time using Mamdani method, where temperature and conductivity were taken as input parameters and life of the sensor was taken as output parameter.

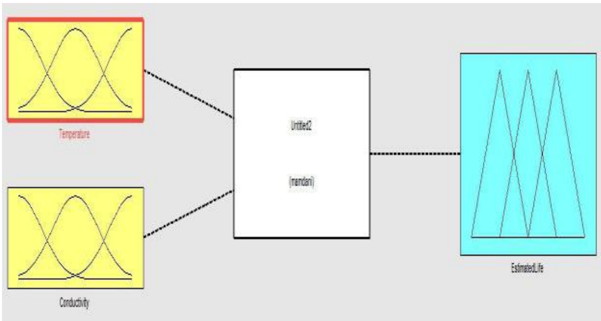

Figure 9. Mamdani based fuzzy system

Different rules were created using fuzzy logic for input and output parameters. The response was measured as per Figure 10.

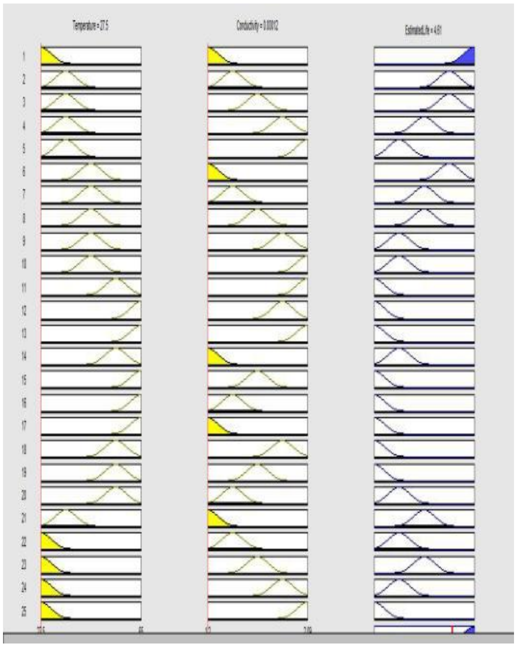

Figure 10. Response using fuzzy logic

The predicted values for recorded and taking analytical failure time as base, the error was calculated.

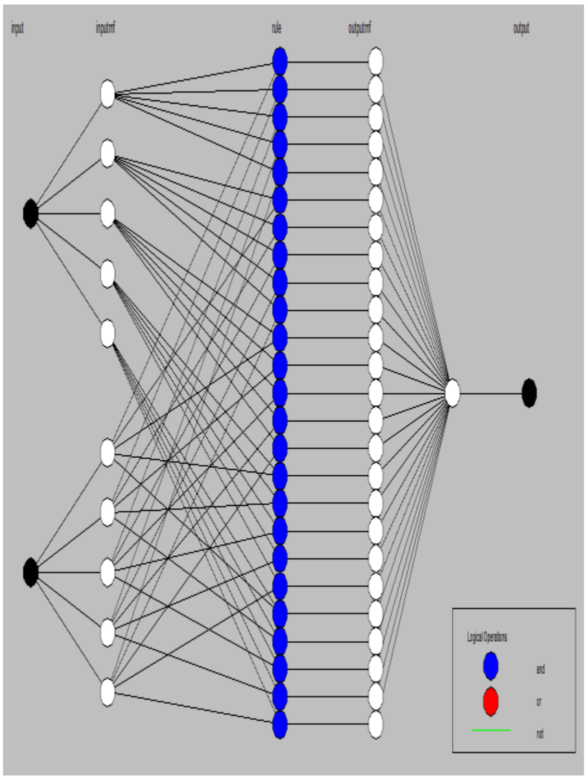

Figure 11. ANFIS approach for train the system

3.2.3 ANFIS approach

ANFIS is also one of the techniques prominently used for Intelligent Modelling. The advantage with ANFIS is that it combined properties of both Fuzzy system and ANN. After applying artificial neural network and fuzzy logic techniques, a hybrid technique known as ANFIS method was also applied. The membership functions were taken and the response was calculated, which is shown as per Figure 12.

Figure 12. Output response using ANFIS technique

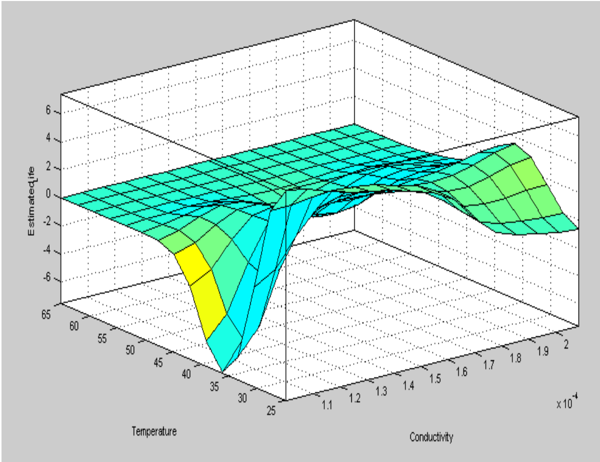

Figure 13. 3D plot using MATLAB Simulink

The data has been loaded in MATLAB ANFIS Simulink, train the system and test it. The plotted graph for Training and Test Data is shown in Figure 14.

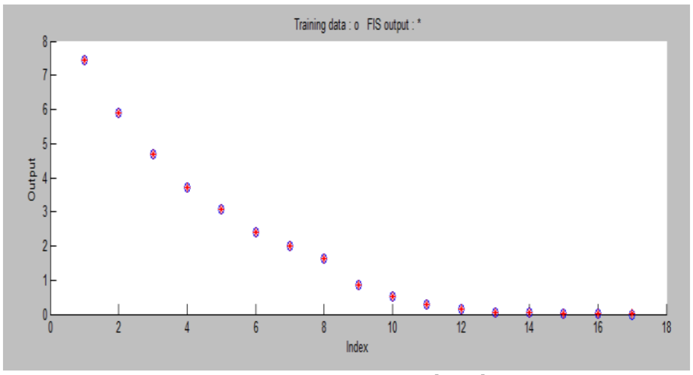

Figure 14. Training vs Test data plot

The accuracy has been measured using analytically calculated output (failure/MTBF) as reference.

3.3 Comparison of predicted data with analytically calculated data

The accuracy of the expert system was analyzed by comparing the predicted values of MTBF with an analytical value of MTBF that was calculated using the analytical method. After comparison, it was observed that the expert system was successfully predicted the MTBF value with 97.8% accuracy with ANFIS technique, as shown in table 3.

Table 3: MTBF calculations and error analysis

Temp	FIT (per 10^9 hours)	MTBF (hours)	MTBF (years), calculated by Arrhenius method,[A]	MTBF(years), predicted by ANN,[B]	MTBF(years), predicted by Fuzzy Logic,[C]	MTBF(years), predicted by ANFIS,[D]	Error (%) =[(A-B)/A]*100	Error (%) =[(A-C)/A]*100	Error (%) =[(A-D)/A]*100
25	13511	74013.7	8.449	8.347	6.22	8.424	1.20	26.38	0.29
30	21158	47263.4	5.395	5.324	4.611	5.345	1.32	14.53	0.92
35	32655	30623.1	3.495	3.451	3.130	3.431	1.28	10.44	1.83
40	49706	20118.3	2.296	2.281	1.971	2.196	0.68	14.15	4.31
45	114651	8722.1	0.995	0.987	0.876	0.978	0.87	11.95	1.70
50	344579	2902.09	0.331	0.329	0.278	0.330	0.69	16.13	0.30
55	1505179	664.372	0.075	0.069	0.067	0.074	9.02	10.66	2.66
60	2778779	359.87	0.041	0.039	0.035	0.040	5.06	14.63	1.33
65	4495173	222.460	0.025	0.024	0.013	0.024	2.40	48.01	2.40

4. Conclusion

A solid composite electrolyte based on doping potash alum with carbon black has been fabricated and studied using various characterization techniques. An accelerated life testing method is used to explore the performance parameters and MTBF of the fabricated humidity sensor. After exploring the failure time of the humidity sensor, an expert model is created which predicts the residual lifetime of sensor using various artificial intelligence techniques.

The reliability and remaining useful lifetime of this sensor has been predicted successfully using Artificial neural networks (ANN), and Fuzzy logic and adaptive neuro fuzzy inference system (ANFIS) technique. The responses of the artificial intelligence techniques have been validated using accelerated life testing method also. A comparison is carried out for both analytical as well as artificial intelligence method to choose the best method for failure prediction of the humidity sensor. The analysis of comparison shows that accuracy of ANN technique comes out to be 97.4%, whereas fuzzy logic accuracy has been calculated as 81.4%. The accuracy using ANFIS technique is 98.2%. So, it concludes that ANFIS technique proves to be the most accurate method to create an expert model for prediction of MTBF and reliability.

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