Sensors and Actuators B: Chemical

Analyzing the Imprecise Electric Properties of Humidity Sensors Data

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Abstract:	The classical statistics cannot be applied adequately when the observations of humidity sensing data are imprecise. In this paper, the analysis of humidity sensing data will be presented using neutrosophic statistics. We present the neutrosophic statistical analysis for electric properties data of humidity sensors. We collected the data and analyzed it using neutrosophic statistics and classical statistics. From the study, we observed the capacitance and resistance variance of humidity sensors with respect to changes in relative humidity. From the comparative study, it is noted that the neutrosophic statistics is more informative, flexible, and adequate in analyzing the imprecise humidity sensors data.

Research Highlights

1. the electric properties of humidity sensors
2. capacitance and resistance of humidity sensors
3. flexible and adequate in the analyzation of capacitance and resistance

Response Letter

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We are thankful to the editor and reviewers for their valuable suggestions to improve the quality and presentation of the paper

Referee: 1

1. In future papers on sensor fusion, the authors should also cite these book series on information fusion:
   F. Smarandache, J. Dezert (editors), Advances and Applications of DSmT for Information Fusion, Collected Works, Vols. 1-4, Amer. Res. Press, 2004-2015, http://fs.unm.edu/DSmT.htm

   Response: **We added and cited the suggested reference in the revised paper.**

Referee: 2

1. The manuscript needs extensive revision for language and grammar
   Response: The language and grammar of manuscript has been revised carefully.

2. The abstract of the manuscript needs to be re-written completely.
   Response: We rewrote the abstract of the paper as suggested.

3. Explain, how authors have collected the data provided in Table 1 and Table 2? Have the authors sought written permission to utilize the experimental data of previously published manuscripts to avoid copyright issues?
   Response: More information about the data has been added in the revised paper before Tables 1-2. We properly cited the papers from where we extracted the data in the revised paper.

4. On various occurring in the manuscript, the authors have falsely claimed to experimentally characterize the humidity sensors themselves, such as Line 17, page 4: All data is measured in interval form…..Line 1, Page 5: After measuring values, we have…… To my understanding the authors have just reviewed the previously published data and analyzed it by statistical means.
   Response: We agree with the reviewer. We updated the revised paper as suggested.

5. Authors seem extremely casual while claiming technical details without giving any scientific reasoning. such as, (1) relative permittivity of humidity is 80% more than the relative permittivity of organic semiconductors …………(2) the values of capacitance has increased with increase in relative humidity but resistance has decreased for all sensors…………(3) This is because at initial there is number of immobile layers of sensing thin films…….. Admittedly, the scientific reasoning is beyond the scope of the present work and is already discussed in detail in previous publications, it is better to avoid discussing such technical details and focus on statistical results in more details. Sections 3.1 and 3.2 may be removed.
   Response: We agree with the reviewer. We updated the revised paper in the light of above suggestions. We removed unnecessary parts from the paper as suggested.

Analyzing the Imprecise Electric Properties of Humidity Sensors Data

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Abstract

The classical statistics cannot be applied adequately when the observations of humidity sensing data are imprecise. In this paper, the analysis of humidity sensing data will be presented using neutrosophic statistics. We present the neutrosophic statistical analysis for electric properties of humidity sensors. We collected the data and analyzed it using neutrosophic statistics and classical statistics. From the study, we observed the capacitance and resistance variance of humidity sensors with respect to changes in relative humidity. From the comparative study, it is noted that the neutrosophic statistics is more informative, flexible, and adequate in analyzing the imprecise humidity sensors data.

Keywords: Humidity; sensors; classical statistics; imprecise data; neutrosophic

1. Introduction

Accurate detection of humidity and humidity control has been gotten importance in the manufacturing of pharmaceuticals, electronics devices, meteorology, and chemical industries (Kiasari, Soltanian, Gholamkhass, & Servati, 2012; Zhang et al., 2005). This thing has increased the importance and use of humidity sensors at the commercial level. Different materials are used in the fabrication of humidity sensors. Nowadays, the use of organic semiconductors in the fabrication of humidity sensors has gotten importance because of their extra-ordinary electric properties like intrinsic property, electrical characterization, and low dielectric permittivity (Karimov et al., 2012; Murtaza et al., 2010). Numerous transduction methods have been used in the fabrication of humidity sensors such as field-effect-transistor, surface-acoustic wave optical, capacitive and resistive transduction with their own performance (Z. Chen & Lu, 2005; Lee & Lee, 2005; Rittersma, 2002; Yao, Chen, Guo, & Wu, 2011). But capacitive transduction in the fabrication of humidity sensors has gotten importance due to its properties like a linear response, low power degeneracy as well as low cost-effective and much more (Saleem et al., 2008). It is estimated that there are about seventy-five percent humidity sensors available in market based on capacitive transduction. Similarly, resistive transduction has been also used in the fabrication of many humidity sensors (Rittersma, 2002). Researchers are working on different organic, inorganic and composite semiconductors materials and using them in the fabrication of humidity sensors. The humidity sensors fabrication with high stability, high sensitivity and sharp response, as well as recovery, is always desirable. Moreover, a good, effective & ideal sensing layer that may be based on single material or composite which should not be peeled or swelled as it absorbs the relative humidity RH, is an essential requirement (Hijikagawa, Miyoshi, Sugihara, & Jinda, 1983). Now let's see some previous works on the fabrication of humidity sensors. (Chani et al., 2012) used aluminum phthalocyanine chloride sensing thin films of 50nm and 100 nm, deposited between aluminum electrodes in the fabrication of a surface-type resistive humidity sensor. Similarly, (Abdulameer, Suhail, Abdullah, & Al-Essa, 2017) used NiPcTs composite organic semi-conductor sensing thin film in the fabrication of surface-type humidity sensors. They characterized its electric properties for both capacitive and resistive transduction. A poly[2-methoxy-5-(2- 3 ethylhexyloxy)-1,4-phenylenevinylene]: polyvinylpyrrolidone (MEH-PPV:

PVP) composite sensing thin film was used by (Azmer, Zafar, Ahmad, & Sulaiman, 2016). They characterized it as surface-type humidity sensors based on capacitive transduction. Also, (Ubaid, Ahmad, Shakoor, & Mohamed, 2018) used PLA sensing film for the fabrication of humidity sensors. They also characterized its electric properties for capacitive transduction.

Generally, it is observed that numerous statistical methods are used to analyze the measured data of humidity sensors. From the best of our literature review, it is found that most researchers have used classical formulas and graphs for these purposes. But such types of analysis only provide information accurately when data is a fix-point value means there is only a single value at a specific value of relative humidity. If there is interval data then all classical methods may mislead the decision-makers. For analyzing such interval data, neutrosophic statistics can be used effectively, see (Florentin Smarandache, 2013). Neutrosophic statistics is more flexible and adequate to analyze the interval data as compared to classical statistics. The use of the neutrosophic statistics for medicine data can be seen in (Ye, 2015), applications in applied sciences can be seen (Christianto, Boyd, & Smarandache, 2020), in astrophysics for studying the variance of wind data (Aslam, 2021) and for analysis of resistance of conductors (Afzal, Alrweili, Ahamd, & Aslam, 2021). (Aslam, 2020a, 2020b) discussed the various applications of neutrosophic statistics. The benefits of the neutrosophic approach over the classical approach can be seen in (Afzal, Ahmad, Zafar, & Aslam, 2021; J. Chen, Ye, & Du, 2017; J. Chen, Ye, Du, & Yong, 2017; F Smarandache, 2014). More applications of DSmT for information fusion can be seen in (Florentin Smarandache & Dezert, 2009).

Recently, (Afzal, Ahmad, et al., 2021) used the neutrosophic method in the analysis of capacitance and resistance data of the humidity sensors as can be seen in our previous work. In this work, we enhanced our previous work by using the capacitance and the resistance of five humidity sensors based on different materials and explain the method of analysis of classical and neutrosophic statistics for data. We will develop an application of material statistics (a study in which material properties data is analyzed through different methods of statistics) for humidity sensors data based on modern statistics methods. It is expected that our work will be more flexible and informative than the analysis based on classical statistics.

2. Experimental

In the following work five humidity sensors have been used which are based on different sensing thin films deposited between different electrodes (shown in Figure 1) i.e. methyl green thin film between aluminum electrodes (Al/MG/Al), methyl red thin film between silver electrodes (Ag/MR/Ag), tetra phenyl porphyrinato nickel (II) thin-film between aluminum electrodes (Al/TPPNi/Al), a composite thin film of copper oxide nanopowder and poly-N-epoxypropylcarbazol between silver electrodes (Ag/ Cu_2O-PEPC/Ag) and a thin film of polydimethylphosphazene between gold electrodes (Au/PDMP/Au).

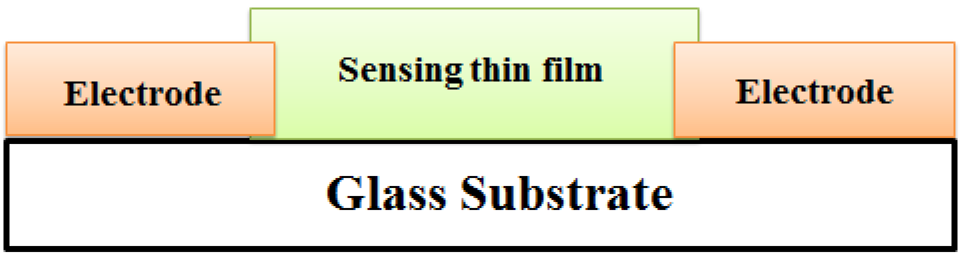

Figure 1: Schematic pic of sensors.

In this work, we have only studied the capacitance and resistance variance with respect to change in relative humidity of said sensors, for the fabrication and other characterizations see the following references (Afzal, Ahmad, et al., 2021; Ahmad, Sayyad, Saleem, Karimov, & Shah, 2008; Akram et al., 2021; Anchisini, Faglia, Gallazzi, Sberveglieri, & Zerbi, 1996; Karimov et al., 2012). According to these references, the capacitance and resistance of sensors have been measured through the LCR meter in a chamber at room temperature by varying relative humidity from 15% to 85% with the help of a humidifier at the room temperature of about 20 ^{o}C with normal atmospheric level. Moreover, the temperature inside the chamber is the same as in the outside atmosphere (We have not measured data experimentally, but by reading the graphs of the above references). The variance of capacitance and resistance of sensors have been studied at 1 kHz with a constant input of 1.0 V as shown in figure 2.

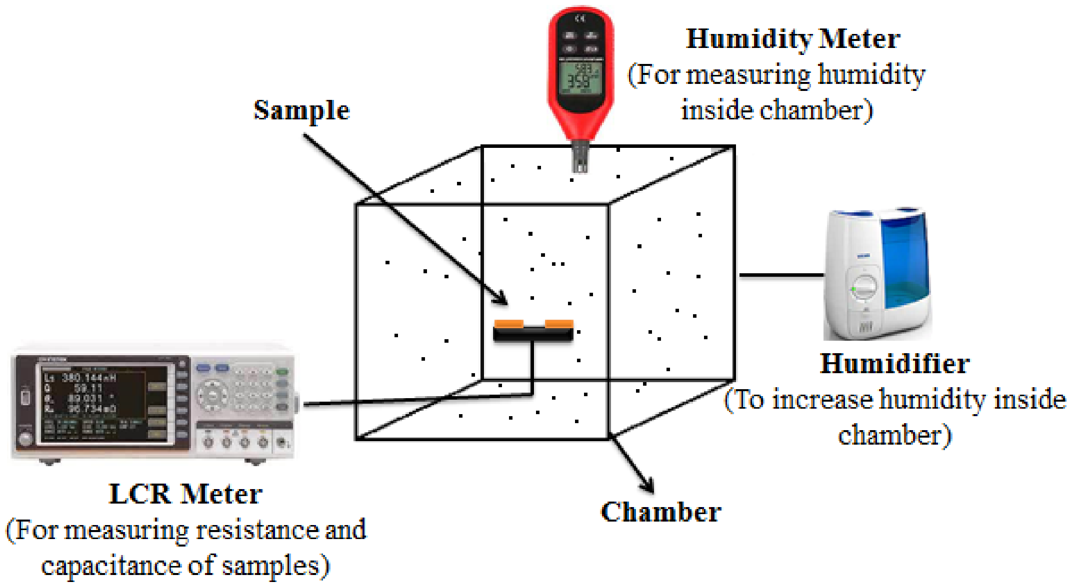

Figure 2: Electrical characterization setup.

3. Methodology

For the analysis of the data, we have used two statistical methods i.e. classical and neutrosophic methods. The discussion on these methods is as follows:

3.1. Classical Method:

As the classical method deals with fix-point values, so all intervals of capacitance and resistance have to convert into fixed point values by taking the average formula. Let $X_{Ni} \epsilon [X_{Li}, X_{Ui}]$ is an interval then the classical formula can be written as:

$$X_{Ni} = \left(\frac{X_{Li}+X_{Ui}}{2}\right) \quad i = 1, 2, 3, 4....n_N \qquad (1)$$

Classical algorithm for computer programs:

Step 1: Start program

Step 2: Enter all intervals (whether in table form or manually)

Step 3: Start loop from$i = 1 \; to \; i <= n_N$

Step 4: Execute formula: $X_{Ni} = \left(\frac{X_{Li}+X_{Ui}}{2}\right)$ *(for each interval)*

Calculate and draw a graph

Step 5: Increment ++ and go to step 3

Step 6: End internal loop

Step 7: End program

3.2. Neutrosophic Method:

For the neutrosophic method, we have to develop a neutrosophic formula (Afzal, Ahmad, et al., 2021; Afzal, Alrweili, et al., 2021). First, we develop a formula for the capacitance analysis of sensors. Let $C(\%RH)_N$ (as capacitance and resistance depend on the relative humidity) is a neutrosophic variable for capacitance with $C(\%RH)_N \epsilon [C(\%RH)_L, C(\%RH)_U]$ a measured interval of capacitance at specific relative humidity %RH. Here $C(\%RH)_L$ and $C(\%RH)_U$ are the lower and upper values of the interval, respectively. So, the neutrosophic formula for capacitance with indeterminacy $i_N \epsilon [i_L, i_U]$ can be written as:

$$C(\%RH)_N = C(\%RH)_L + C(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U] \quad (2)$$

Basically, the above formula of is $C(\%RH)_N \epsilon [C(\%RH)_L, C(\%RH)_U]$ is an extension of the classical. The equation is containing two parts i.e. $C(\%RH)_L$ determined & $C(\%RH)_U i_N$ indeterminate part. Moreover, $i_N \epsilon [i_L, i_U]$ is known as an indeterminacy interval. For neutrosophic formula $i_L = 0$ and i_U can be found by using$(C(\%RH)_U - C(\%RH)_L) / C(\%RH)_U$. Similarly, for resistance of sensors R(%RH) can be written as:

$$R(\%RH)_N = R(\%RH)_L + R(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U] \quad (3)$$

Neutrosophic algorithm for computer programs:

Step 1: Start program

Step 2: Enter all intervals (whether in table form or manually)

Step 3: Start the main loop from $a = 1\ to\ a <= n_N$

Step 4: Calculate $i_U = \left(\frac{C(\%RH)_U - C(\%RH)_L}{C(\%RH)_U}\right)$ (For capacitance)

Calculate $i_U = \left(\frac{R(\%RH)_U - R(\%RH)_L}{R(\%RH)_U}\right)$ (For resistance)

Step 5: Start internal loop $i_L = 0\ to\ i_L <= i_U$

Step 6: Calculate

$C(\%RH)_N = C(\%RH)_L + C(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U]$ (For capacitance)

$R(\%RH)_N = R(\%RH)_L + R(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U]$ (For resistance)

Step 7: Increment of specific value (for interval loop, here we use 0.05) and go to step 5

Step 8: End internal loop

Step 9: Increment ++ and go to step 3

Step 10: End main loop

Step 11: End program

4. Result and Discussion

In this work, we focused only on the analysis of the electric properties of capacitance and resistance variation with respect to change in the relative humidity. We collected the data from (Afzal, Ahmad, et al., 2021; Ahmad et al., 2008; Akram et al., 2021; Anchisini et al., 1996; Karimov et al., 2012) who used the determinate measurements obtained from the LCR meter. On the other hand, (Afzal, Ahmad, et al., 2021; Afzal, Alrweili, et al., 2021; Lallart, Pruvost, & Guyomar, 2011; Nara, Yasuda, Satake, & Toriumi, 2002; Simić, 2014) aruged that the data obtained from the LCR meter do not have the exact obervations i.e. at a speccific point there a minimum and maximum point for a data variation. The measurement data from LCR meter is exprssed in interval rather than the exact valeus. In such cases, when the actaul meauerements of humidity sensor are in intervals, the use of classical statistics may mislead the decision-makers. We will present the analsysis of the data using the neutrosophic statistics. The humidity sensor imprecise data extrated from (Afzal, Ahmad, et al., 2021; Ahmad et al., 2008; Akram et al., 2021; Anchisini et al., 1996; Karimov et al., 2012) and reported in Tables 1-2.

Table 1: Measured capacitance of all sensors with respect to change in relative humidity

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Capacitance	Capacitance	Capacitance	Capacitance	Capacitance
%RH	pF	pF	pF	pF	pF
15	[146, 166]	[74, 82]	[80, 89]	[0.9, 1.1]	[62, 69]
20	[147, 166]	[81, 90]	[86, 95]	[1.1, 1.2]	[88, 98]
25	[147, 167]	[100, 113]	[91, 102]	[2.7, 3.0]	[110, 123]
30	[149, 168]	[127, 144]	[92, 105]	[2.8, 3.2]	[144, 164]
35	[150, 175]	[160, 182]	[100, 113]	[3.8, 4.2]	[183, 208]

40	[164, 175]	[181, 204]	[107, 120]	[4.7, 5.3]	[214, 242]
45	[168, 176]	[220, 250]	[128, 145]	[5.3, 6.0]	[257, 292]
50	[171, 180]	[252, 290]	[130, 149]	[8.0, 9.2]	[312, 358]
55	[175, 183]	[333, 381]	[149, 170]	[8.7, 9.9]	[369, 422]
60	[216, 224]	[454, 516]	[192, 219]	[11.6, 13.1]	[418, 475]
65	[1116, 1124]	[551, 634]	[298, 343]	[14.2, 16.3]	[463, 532]
70	[1902, 1950]	[631, 726]	[1238, 1424]	[17.0, 19.6]	[497, 572]
75	[2600, 2740]	[757, 871]	[1664, 1915]	[20.2, 23.2]	[515, 592]
80	[3630, 3700]	[863, 893]	[2070, 2382]	[26.5, 28.7]	[527, 607]
85	[6530, 6590]	[963, 990]	[2369, 2725]	[29.8, 32.3]	[579, 667]

Table 2: Measured Resistance of all sensors with respect to change in relative humidity

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Resistance	Resistance	Resistance	Resistance	Resistance
%RH	MΩ	MΩ	MΩ	MΩ	MΩ
15	[1676, 2230]	[35, 47]	[3009, 4015]	[78, 106]	[0.76, 1.01]
20	[1620, 2190]	[34, 45]	[2674, 3572]	[72, 101]	[0.74, 0.99]
25	[1593, 2123]	[33, 44]	[2305, 3091]	[63, 92]	[0.70, 0.94]
30	[1510, 2041]	[32, 43]	[2237, 2997]	[52, 81]	[0.68, 0.91]
35	[1430, 1930]	[32, 41]	[2131, 2741]	[43, 68]	[0.66, 0.84]
40	[1220, 1530]	[31, 40]	[2010, 2580]	[22, 47]	[0.61, 0.78]
45	[1100, 1300]	[30, 38]	[1770, 2276]	[27, 33.8]	[0.57, 0.73]
50	[960, 1050]	[29, 38]	[1574, 2129]	[22, 30]	[0.50, 0.68]
55	[765, 834]	[28, 35]	[1343, 1636]	[15, 21]	[0.49, 0.60]
60	[420, 430]	[27, 34]	[1044, 1250]	[9, 13]	[0.46, 0.55]
65	[123, 125]	[27, 32]	[713, 837]	[5.3, 11.3]	[0.41, 0.48]
70	[100, 102]	[26, 30]	[315, 348]	[2.6, 5.1]	[0.39, 0.43]
75	[85, 87]	[27.3, 27.9]	[288, 295]	[1.9, 3.7]	[0.41, 0.42]
80	[50, 51]	[25.6, 26.2]	[259, 264]	[0.9, 1.7]	[0.39, 0.40]
85	[28.1, 28.5]	[21.5, 21.8]	[259, 263]	[0.2, 0.9]	[0.34, 0.34]

4.1. Analysis of Capacitance and Resistance:

In this section, we discussed the analysis of the data using the neutrosophic statistics and classical statistics. First, we will analyze the data of capacitance and resistance through the classical method as shown in Table 3 and Table 4, then the neutrosophic method as shown in Table 5 and Table 6.

Table 3: Classical analysis of the capacitance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Capacitance	Capacitance	Capacitance	Capacitance	Capacitance
%RH	pF	pF	pF	pF	pF
15	156	78.6	85	1.1	66.0
20	156.5	85.7	91	1.3	93.9
25	157	107.1	97	2.9	117.1
30	158.5	135.7	99	3.0	154.3
35	162.5	171.4	107	4.0	196.1
40	169.5	192.9	114	5.0	228.6
45	172	235.7	137	5.6	275.1
50	175.5	271.4	140	8.6	335.5
55	179	357.1	160	9.3	395.9
60	220	485.7	206	12.4	447.0
65	1120	592.9	321.3	15.2	498.1
70	1926	678.6	1331.1	18.3	535.2
75	2670	814.3	1790.2	21.7	553.8
80	3665	928.6	2226.2	27.6	567.7
85	6560	1035.7	2547.5	31.1	623.5

Table 4: Classical analysis of the capacitance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Resistance	Resistance	Resistance	Resistance	Resistance
%RH	MΩ	MΩ	MΩ	MΩ	MΩ
15	1953	39.3	3512.3	92.5	0.89
20	1905	39.0	3123.2	86.9	0.86
25	1858	38.5	2698.0	77.7	0.82
30	1775.5	38.0	2617.5	66.6	0.79
35	1680	37.2	2436.2	56.4	0.75
40	1375	35.8	2295.3	35.1	0.69

45	1200	34.7	2023.5	21.3	0.64
50	1005	33.8	1852.3	15.2	0.59
55	799.5	32.7	1489.9	11.3	0.54
60	425	31.9	1147.7	10.5	0.50
65	124	30.2	775.2	9.3	0.44
70	101	29.2	332.2	6.5	0.40
75	86	27.6	291.9	3.9	0.41
80	50.5	25.9	261.7	2.9	0.39
85	28.3	21.7	261.7	2.0	0.33

Table 5: Neutrosophic analysis of the capacitance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Capacitance	Capacitance	Capacitance	Capacitance	Capacitance
%RH	pF	pF	pF	pF	pF
15	$146+166I_N$; $I_N \epsilon [0, 0.120]$	$74+82I_N$; $I_N \epsilon [0, 0.101]$	$80+89I_N$; $I_N \epsilon [0, 0.101]$	$0.9+1.1I_N$; $I_N \epsilon [0, 0.101]$	$62+69I_N$; $I_N \epsilon [0, 0.101]$
20	$147+166I_N$; $I_N \epsilon [0, 0.114]$	$81+90I_N$; $I_N \epsilon [0, 0.099]$	$86+95I_N$; $I_N \epsilon [0, 0.099]$	$1.1+1.2I_N$; $I_N \epsilon [0, 0.099]$	$88+98I_N$; $I_N \epsilon [0, 0.099]$
25	$147+167I_N$; $I_N \epsilon [0, 0.120]$	$100+113I_N$; $I_N \epsilon [0, 0.110]$	$91+102I_N$; $I_N \epsilon [0, 0.120]$	$2.7+3.0I_N$; $I_N \epsilon [0, 0.110]$	$110+123I_N$; $I_N \epsilon [0, 0.120]$
30	$149+168I_N$; $I_N \epsilon [0, 0.113]$	$127+144I_N$; $I_N \epsilon [0, 0.118]$	$92+105I_N$; $I_N \epsilon [0, 0.118]$	$2.8+3.2I_N$; $I_N \epsilon [0, 0.118]$	$144+164I_N$; $I_N \epsilon [0, 0.118]$
35	$150+175I_N$; $I_N \epsilon [0, 143]$	$160+182I_N$; $I_N \epsilon [0, 0.117]$	$100+113I_N$; $I_N \epsilon [0, 0.117]$	$3.8+4.2I_N$; $I_N \epsilon [0, 0.116]$	$183+208I_N$; $I_N \epsilon [0, 0.117]$
40	$164+175I_N$; $I_N \epsilon [0, 0.063]$	$181+204I_N$; $I_N \epsilon [0, 0.113]$	$107+120I_N$; $I_N \epsilon [0, 0.113]$	$4.7+5.3I_N$; $I_N \epsilon [0, 0.112]$	$214+242I_N$; $I_N \epsilon [0, 0.113]$
45	$168+176I_N$; $I_N \epsilon [0, 0.45]$	$220+250I_N$; $I_N \epsilon [0, 0.120]$	$128+145I_N$; $I_N \epsilon [0, 0.120]$	$5.3+6.0I_N$; $I_N \epsilon [0, 0.77]$	$257+292I_N$; $I_N \epsilon [0, 0.120]$
50	$171+180I_N$; $I_N \epsilon [0, 0.050]$	$252+290I_N$; $I_N \epsilon [0, 0.128]$	$130+149I_N$; $I_N \epsilon [0, 0.128]$	$8.0+9.2I_N$; $I_N \epsilon [0, 0.077]$	$312+358I_N$; $I_N \epsilon [0, 0.128]$
55	$175+183I_N$; $I_N \epsilon [0, 0.044]$	$333+381I_N$; $I_N \epsilon [0, 0.095]$	$149+170I_N$; $I_N \epsilon [0, 0.126]$	$8.7+9.9I_N$; $I_N \epsilon [0, 0.039]$	$369+42I_N$; $I_N \epsilon [0, 0.126]$
60	$216+224I_N$;	$454+516I_N$;	$192+219I_N$;	$11.6+13.1I_N$;	$418+475I_N$;

	$I_N\epsilon[0, 0.0.36]$	$I_N\epsilon[0, 0.120]$	$I_N\epsilon[0, 0.120]$	$I_N\epsilon[0, 0.039]$	$I_N\epsilon[0, 0.120]$
65	$1116+ 1124I_N$; $I_N\epsilon[0, 0.007]$	$551+ 634I_N$; $I_N\epsilon[0, 0.058]$	$298+ 343I_N$; $I_N\epsilon[0, 0.131]$	$14.2+ 16.3I_N$; $I_N\epsilon[0, 0.020]$	$463+ 532I_N$; $I_N\epsilon[0, 0.095]$
70	$1902+ 1950I_N$; $I_N\epsilon[0, 0.025]$	$631+ 726I_N$; $I_N\epsilon[0, 0.077]$	$1238+ 1424I_N$; $I_N\epsilon[0, 0.131]$	$17.0+ 19.6I_N$; $I_N\epsilon[0, 0.039]$	$497+ 572I_N$; $I_N\epsilon[0, 0.095]$
75	$2600+ 2740I_N$; $I_N\epsilon[0, 0.051]$	$757+ 871I_N$; $I_N\epsilon[0, 0.039]$	$1664+ 1915I_N$; $I_N\epsilon[0, 0.131]$	$20.2+ 23.2I_N$; $I_N\epsilon[0, 0.058]$	$515+ 592I_N$; $I_N\epsilon[0, 0.095]$
80	$3630+ 3700I_N$; $I_N\epsilon[0, 0.019]$	$863+ 893I_N$; $I_N\epsilon[0, 0.039]$	$2070+ 2382I_N$; $I_N\epsilon[0, 0.131]$	$26.5+ 28.7I_N$; $I_N\epsilon[0, 0.39]$	$527+ 607I_N$; $I_N\epsilon[0, 0.077]$
85	$6530+ 6590I_N$; $I_N\epsilon[0, 0.009]$	$963+ 990I_N$; $I_N\epsilon[0, 0.020]$	$2369+ 2725I_N$; $I_N\epsilon[0, 0.131]$	$29.8+ 32.3I_N$; $I_N\epsilon[0, 0.058]$	$579+ 667I_N$; $I_N\epsilon[0, 0.058]$

Table 6: Neutrosophic analysis of the resistance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Resistance	Resistance	Resistance	Resistance	Resistance
%RH	MΩ	MΩ	MΩ	MΩ	MΩ
15	$1676+ 2230I_N$; $I_N\epsilon[0, 0.248]$	$35+ 47I_N$; $I_N\epsilon[0, 0.251]$	$3009+ 4015I_N$; $I_N\epsilon[0, 0.251]$	$78+ 106I_N$; $I_N\epsilon[0, 0.286]$	$0.76+ 1.01I_N$; $I_N\epsilon[0, 251]$
20	$1620+ 2190I_N$; $I_N\epsilon[0, 0.260]$	$34+ 45I_N$; $I_N\epsilon[0, 0.251]$	$2674+ 3572I_N$; $I_N\epsilon[0, 0.251]$	$72+ 101I_N$; $I_N\epsilon[0, 0.284]$	$0.74+ 0.99I_N$; $I_N\epsilon[0, 0.251]$
25	$1593+ 2123I_N$; $I_N\epsilon[0, 0.250]$	$33+ 44I_N$; $I_N\epsilon[0, 0.254]$	$2305+ 3091I_N$; $I_N\epsilon[0,0.245]$	$63+ 92I_N$; $I_N\epsilon[0, 0.316]$	$0.70+ 0.94I_N$; $I_N\epsilon[0, 0.254]$
30	$1510+ 2041I_N$; $I_N\epsilon[0,0.260]$	$32+ 43I_N$; $I_N\epsilon[0, 0.254]$	$2237+ 2997I_N$; $I_N\epsilon[0, 0.245]$	$52+ 81I_N$; $I_N\epsilon[0, 0.358]$	$0.68+ 0.91I_N$; $I_N\epsilon[0, 0.254]$
35	$1430+ 1930I_N$; $I_N\epsilon[0, 0.259]$	$32+ 41I_N$; $I_N\epsilon[0, 0.222]$	$2131+ 2741I_N$; $I_N\epsilon[0, 0.222]$	$43+ 68I_N$; $I_N\epsilon[0, 0.363]$	$0.66+ 0.84I_N$; $I_N\epsilon[0, 0.222]$
40	$1220+ 1530I_N$; $I_N\epsilon[0, 0.203]$	$31+ 40I_N$; $I_N\epsilon[0, 0.221]$	$2010+ 2580I_N$; $I_N\epsilon[0, 0.221]$	$22+ 47I_N$; $I_N\epsilon[0, 0.522]$	$0.61+ 0.78I_N$; $I_N\epsilon[0, 0.221]$
45	$1100+ 1300I_N$; $I_N\epsilon[0, 0.154]$	$30+ 38 I_N$; $I_N\epsilon[0, 0.223]$	$1770+ 2276I_N$; $I_N\epsilon[0, 0.223]$	$27+ 33.8I_N$; $I_N\epsilon[0, 0.740]$	$0.57+ 0.73I_N$; $I_N\epsilon[0, 0.223]$
50	$960+ 1050I_N$; $I_N\epsilon[0, 0.086]$	$29+ 38I_N$; $I_N\epsilon[0, 0.261]$	$1574+ 2129I_N$; $I_N\epsilon[0, 0.261]$	$22+ 30I_N$; $I_N\epsilon[0, 0.991]$	$0.50+ 0.68I_N$; $I_N\epsilon[0, 0.261]$
55	$765+ 834I_N$; $I_N\epsilon[0, 0.083]$	$28+ 35I_N$; $I_N\epsilon[0, 0.179]$	$1343+ 1636I_N$; $I_N\epsilon[0, 0.179]$	$15+ 21I_N$; $I_N\epsilon[0, 0.929]$	$0.49+ 0.60I_N$; $I_N\epsilon[0, 0.179]$

60	$420+ 430I_N$; $I_N\epsilon[0, 0.023]$	$27+ 34I_N$; $I_N\epsilon[0, 0.165]$	$1044+ 1250I_N$; $I_N\epsilon[0, 0.165]$	$9+ 13I_N$; $I_N\epsilon[0, 0.924]$	$0.46+ 0.55I_N$; $I_N\epsilon[0, 0.165]$
65	$123+ 125I_N$; $I_N\epsilon[0, 0.016]$	$27+ 32I_N$; $I_N\epsilon[0, 0.148]$	$713+ 837I_N$; $I_N\epsilon[0, 0.148]$	$5.3+ 11.3I_N$; $I_N\epsilon[0, 0.924]$	$0.41+ 0.48I_N$; $I_N\epsilon[0, 0.148]$
70	$100+ 102I_N$; $I_N\epsilon[0, 0.020]$	$26+ 30I_N$; $I_N\epsilon[0, 0.096]$	$315+ 348I_N$; $I_N\epsilon[0,n0.096]$	$2.6+ 5.1I_N$; $I_N\epsilon[0, 0.876]$	$0.39+ 0.43I_N$; $I_N\epsilon[0, 0.096]$
75	$85+ 87I_N$; $I_N\epsilon[0, 0.023]$	$27.3+ 27.9I_N$; $I_N\epsilon[0, 0.023]$	$288+ 295I_N$; $I_N\epsilon[0, 0.024]$	$1.9+ 3.7I_N$; $I_N\epsilon[0, 0.472]$	$0.41+ 0.42I_N$; $I_N\epsilon[0, 0.024]$
80	$50+ 51I_N$; $I_N\epsilon[0, 0.020]$	$25.6+ 26.2I_N$; $I_N\epsilon[0, 0.020]$	$259+ 264I_N$; $I_N\epsilon[0, 0.020]$	$0.9+ 1.7I_N$; $I_N\epsilon[0, 0.500]$	$0.39+ 0.40I_N$; $I_N\epsilon[0, 0.020]$
85	$28.1+ 28.5I_N$; $I_N\epsilon[0, 0.014]$	$21.5+ 21.8I_N$; $I_N\epsilon[0, 0.014]$	$259+ 263I_N$; $I_N\epsilon[0, 0.014]$	$0.2+ 0.9I_N$; $I_N\epsilon[0, 0.523]$	$0.34+ 0.34I_N$; $I_N\epsilon[0, 0.014]$

Table 3 and Table 4 are expressing the classical analysis of the capacitance and resistance data of the sensors by applying the classical formula of the mean. From the tables, it is seen that classical analysis has converted all intervals into fi- point, which are not defining the variance of the interval from minimum to a maximum value. We have gotten only a single value of capacitance and resistance against specific relative humidity. This is showing that classical analysis is not reliable in making decisions and in concluding the solution to the problem. Similarly, Table 5 and Table 6 are expressing the neutrosophic analysis of the capacitance and resistance of sensors. From these tables, it is seen that neutrosophic analysis is a more reliable analysis as it uses indeterminacy and gives the whole information about the variance of capacitance and resistance at a specific value of the relative humidity. For example, at 15 %RH the classical value of the capacitance of Al/MG/Al is 156 pF (a single or fix-point value) i.e. $C_{(15\%RH)}$ = 156pF. But the other hand neutrosophic analysis gives an equation $C_{(15\%RH)} = 146+ 166I_N$ with the indeterminacy interval $I_N\epsilon[0, 0.120]$. According to neutrosophic analysis, the value of capacitance lies between 146 and 166 by put indeterminacy values.

3.4 Graphical Comparison of Neutrosophic and Classical Analysis of Capacitance and Resistance of Humidity Sensors:

The graphical comparison of neutrosophic and classical analysis for capacitance and resistance of Al/MG/Al, Ag/MR/Ag, Al/TPPNi/Al, Ag/ Cu_2O-PEPC/Ag and Au/PDMP/Au are shown in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7.

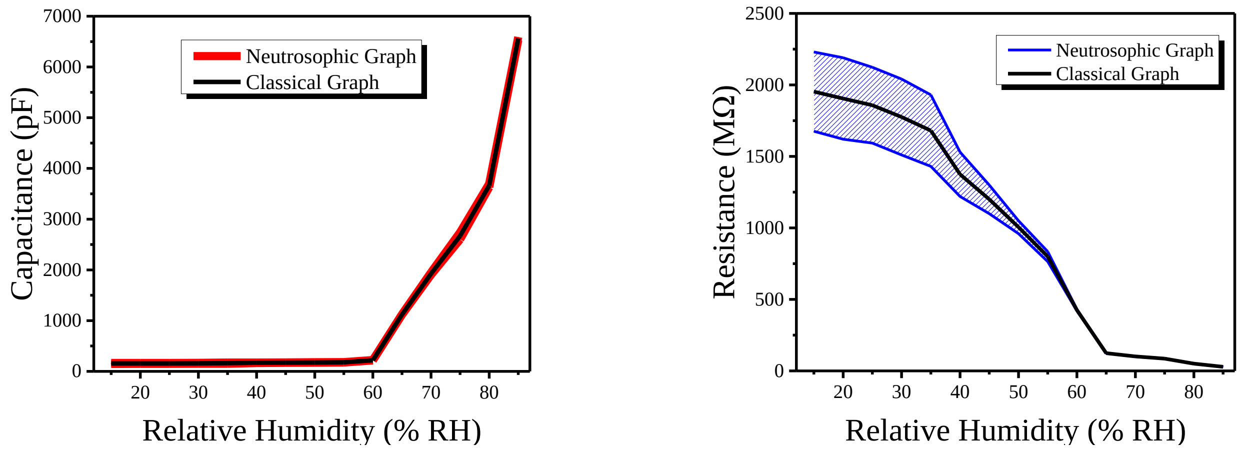

Figure 3: Left side plot is capacitance and right side plot is resistance of Al/MG/Al.

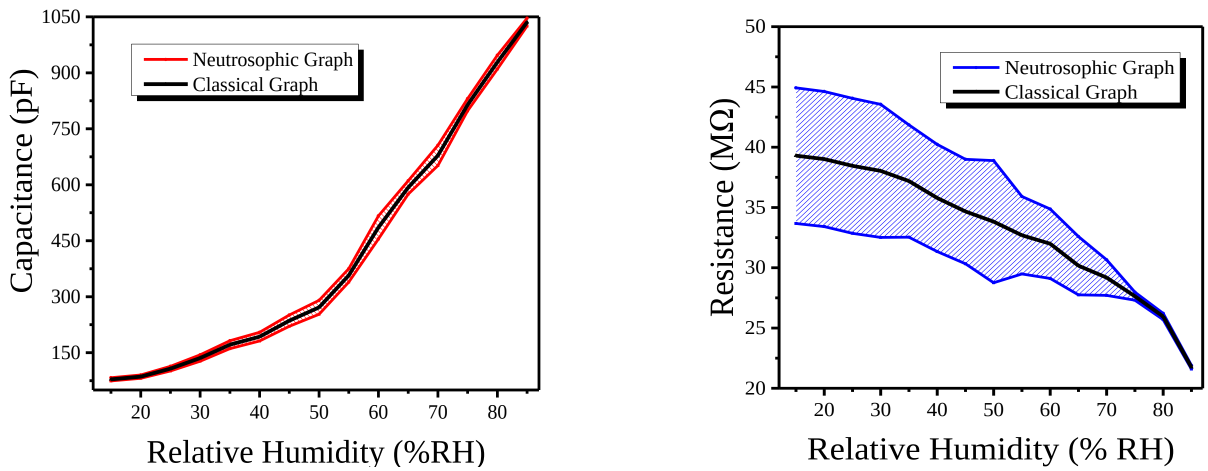

Figure 4: Left side plot is capacitance and right side plot is resistance of Ag/MR/Ag.

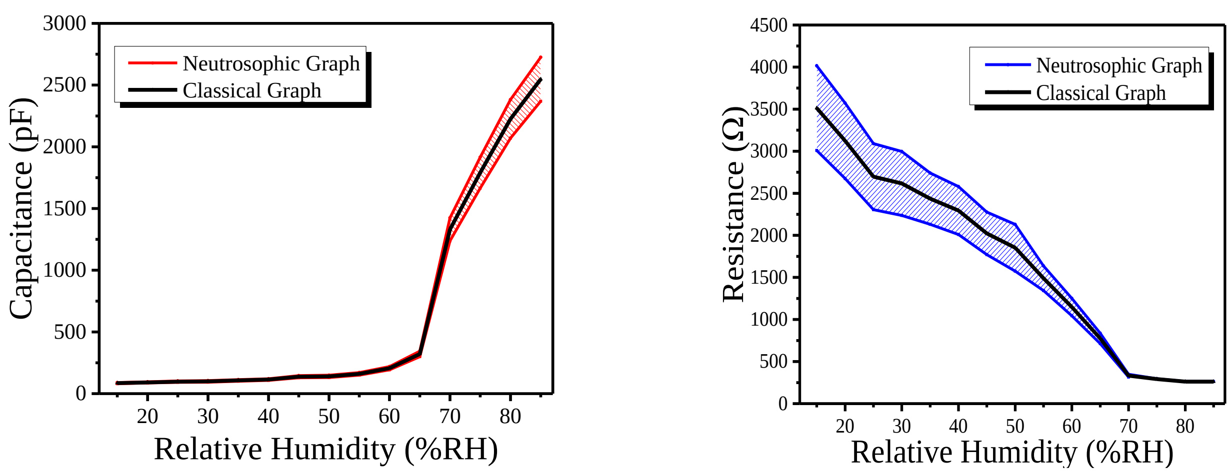

Figure 5: Left side plot is capacitance and right side plot is resistance of Al/TPPNi/Al.

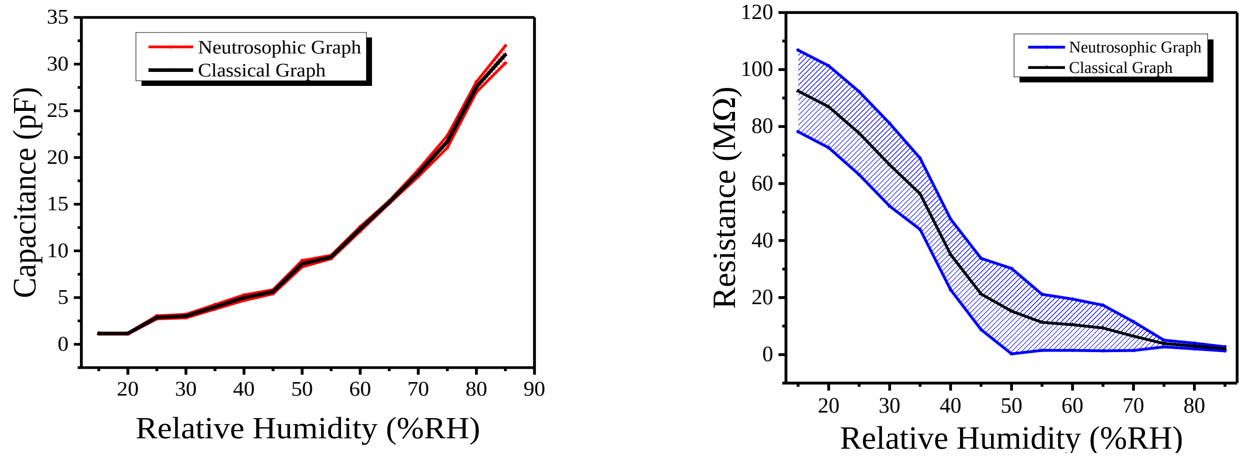

Figure 6: Left side plot is capacitance and right side plot is resistance of Ag/ Cu2O-PEPC/Ag.

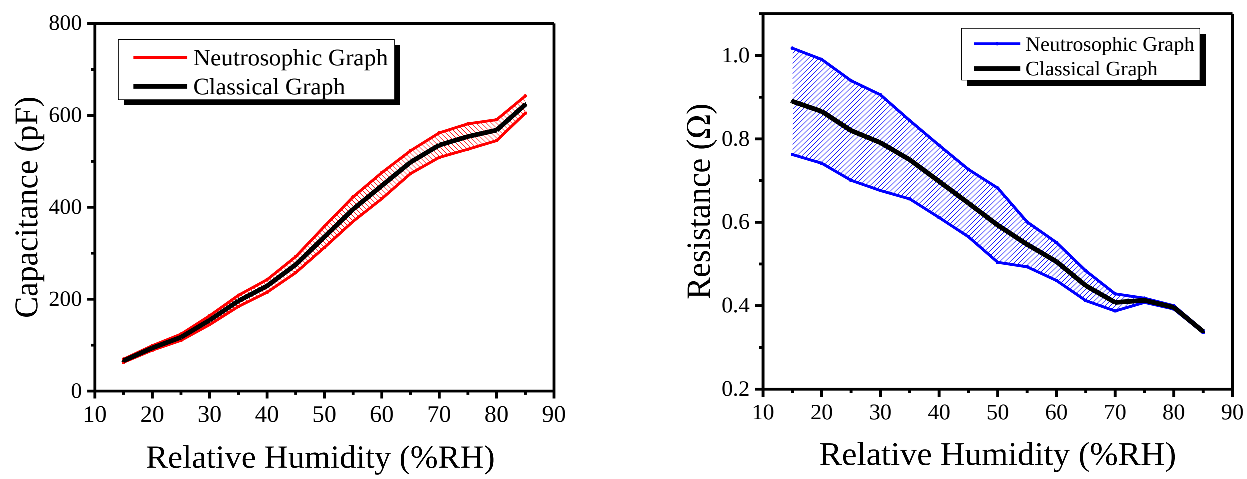

Figure 6: Left side plot is capacitance and right side plot is resistance of Au/PDMP/Au.

The above graphs are showing the comparison between classical and neutrosophic analysis. For capacitance the classical and neutrosophic graphs are looking about the same i.e. having a small plotting difference, this is because there is a small variance of capacitance as compared to the resistance (small variance gives a small interval of indeterminacy). On the other hand, there is a large difference between classical and neutrosophic graphs of resistance. Because there is a large variance of resistance (large variance gives a large interval of indeterminacy). One can easily see that classical graphs are less flexible and informative to explain the capacitance and resistance of sensors as these are drawn on fix-point values. But neutrosophic graphs are enough flexible and informative to explain and conclude the problem. Generally, it is seen that most researchers have used classical graphs in their works either in form of a single line plot or in the form of an error bar graph for expressing the data variation. But statistically, these are not effective plots as the error bar shows the error found in data, not variance. When a researcher uses an error bar it means that he is graphically expressing the data error (which may be due to personal error, sample handling error, or mechanic error) instead of data variance. But the neutrosophic approach is a remarkable approach to analysis the data analysis. That's why we have used the neutrosophic approach for the analysis of the variance of capacitance and resistance of humidity sensors with changes in relative humidity.

5. Concluding Remarks

This study belongs to the material statistics as we have used the statistics to analyze the imprecise data of electric properties belongs to humidity sensors based on different materials. For this purpose, we have used the neutrosophic method to analyze the capacitance and resistance of humidity sensors. Al/MG/Al, Ag/MR/Ag, Al/TPPNi/Al, Ag/ Cu_2O-PEPC/Ag and Au/PDMP/Au humidity sensors are used in this work, whose data of capacitance and resistance has been collected from previous published papers with some assumptions (like data is intervals). We have applied classical as well as neutrosophic formulas on the collected data and draw the graphs of the output. We have compared the methods as well as output graphs and find which is more reliable for analysis of sensing data. As a result, it is observed that classical analysis is not effective in explaining the variation of capacitance and resistance with respect to change in relative humidity as data loss its indeterminacy. But the neutrosophic analysis is more effective. It is concluded that neutrosophic statistics is more effective, reliable and much informative in taking decisions as well as classical statistics.

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Declarations

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Analyzing the Imprecise Electric Properties of Humidity Sensors Data

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Abstract

The classical statistics cannot be applied adequately when the observations of humidity sensing data are imprecise. In this paper, the analysis of humidity sensing data will be presented using neutrosophic statistics. We present the neutrosophic statistical analysis for electric properties data of humidity sensors. We collected the data and analyzed it using neutrosophic statistics and classical statistics. From the study, we observed the capacitance and resistance variance of humidity sensors with respect to changes in relative humidity. From the comparative study, it is noted that the neutrosophic statistics is more informative, flexible, and adequate in analyzing the imprecise humidity sensors data.

Keywords: Humidity; sensors; classical statistics; imprecise data; neutrosophic

1. Introduction

Accurate detection of humidity and humidity control has been gotten importance in the manufacturing of pharmaceuticals, electronics devices, meteorology, and chemical industries (Kiasari, Soltanian, Gholamkhass, & Servati, 2012; Zhang et al., 2005). This thing has increased the importance and use of humidity sensors at the commercial level. Different materials are used in the fabrication of humidity sensors. Nowadays, the use of organic semiconductors in the fabrication of humidity sensors has gotten importance because of their extra-ordinary electric properties like intrinsic property, electrical characterization, and low dielectric permittivity (Karimov et al., 2012; Murtaza et al., 2010). Numerous transduction methods have been used in the fabrication of humidity sensors such as field-effect-transistor, surface-acoustic wave optical, capacitive and resistive transduction with their own performance (Z. Chen & Lu, 2005; Lee & Lee, 2005; Rittersma, 2002; Yao, Chen, Guo, & Wu, 2011). But capacitive transduction in the fabrication of humidity sensors has gotten importance due to its properties like a linear response, low power degeneracy as well as low cost-effective and much more (Saleem et al., 2008). It is estimated that there are about seventy-five percent humidity sensors available in market based on capacitive transduction. Similarly, resistive transduction has been also used in the fabrication of many humidity sensors (Rittersma, 2002). Researchers are working on different organic, inorganic and composite semiconductors materials and using them in the fabrication of humidity sensors. The humidity sensors fabrication with high stability, high sensitivity and sharp response, as well as recovery, is always desirable. Moreover, a good, effective & ideal sensing layer that may be based on single material or composite which should not be peeled or swelled as it absorbs the relative humidity RH, is an essential requirement (Hijikagawa, Miyoshi, Sugihara, & Jinda, 1983). Now let's see some previous works on the fabrication of humidity sensors. (Chani et al., 2012) used aluminum phthalocyanine chloride sensing thin films of 50nm and 100 nm, deposited between aluminum electrodes in the fabrication of a surface-type resistive humidity sensor. Similarly, (Abdulameer, Suhail, Abdullah, & Al-Essa, 2017) used NiPcTs composite organic semi-conductor sensing thin film in the fabrication of surface-type humidity sensors. They characterized its electric properties for both capacitive and resistive transduction. A poly[2-methoxy-5-(2- 3 ethylhexyloxy)-1,4-phenylenevinylene]: polyvinylpyrrolidone (MEH-PPV:

PVP) composite sensing thin film was used by (Azmer, Zafar, Ahmad, & Sulaiman, 2016). They characterized it as surface-type humidity sensors based on capacitive transduction. Also, (Ubaid, Ahmad, Shakoor, & Mohamed, 2018) used PLA sensing film for the fabrication of humidity sensors. They also characterized its electric properties for capacitive transduction.

Generally, it is observed that numerous statistical methods are used to analyze the measured data of humidity sensors. From the best of our literature review, it is found that most researchers have used classical formulas and graphs for these purposes. But such types of analysis only provide information accurately when data is a fix-point value means there is only a single value at a specific value of relative humidity. If there is interval data then all classical methods may mislead the decision-makers. For analyzing such interval data, neutrosophic statistics can be used effectively, see (Florentin Smarandache, 2013). Neutrosophic statistics is more flexible and adequate to analyze the interval data as compared to classical statistics. The use of the neutrosophic statistics for medicine data can be seen in (Ye, 2015), applications in applied sciences can be seen (Christianto, Boyd, & Smarandache, 2020), in astrophysics for studying the variance of wind data (Aslam, 2021) and for analysis of resistance of conductors (Afzal, Alrweili, Ahamd, & Aslam, 2021). (Aslam, 2020a, 2020b) discussed the various applications of neutrosophic statistics. The benefits of the neutrosophic approach over the classical approach can be seen in (Afzal, Ahmad, Zafar, & Aslam, 2021; J. Chen, Ye, & Du, 2017; J. Chen, Ye, Du, & Yong, 2017; F Smarandache, 2014). More applications of DSmT for information fusion can be seen in (Florentin Smarandache & Dezert, 2009).

Recently, (Afzal, Ahmad, et al., 2021) used the neutrosophic method in the analysis of capacitance and resistance data of the humidity sensors as can be seen in our previous work. In this work, we enhanced our previous work by using the capacitance and the resistance of five humidity sensors based on different materials and explain the method of analysis of classical and neutrosophic statistics for data. We will develop an application of material statistics (a study in which material properties data is analyzed through different methods of statistics) for humidity sensors data based on modern statistics methods. It is expected that our work will be more flexible and informative than the analysis based on classical statistics.

2. Experimental

In the following work five humidity sensors have been used which are based on different sensing thin films deposited between different electrodes (shown in Figure 1) i.e. methyl green thin film between aluminum electrodes (Al/MG/Al), methyl red thin film between silver electrodes (Ag/MR/Ag), tetra phenyl porphyrinato nickel (II) thin-film between aluminum electrodes (Al/TPPNi/Al), a composite thin film of copper oxide nanopowder and poly-N-epoxypropylcarbazol between silver electrodes (Ag/ Cu_2O-PEPC/Ag) and a thin film of polydimethylphosphazene between gold electrodes (Au/PDMP/Au).

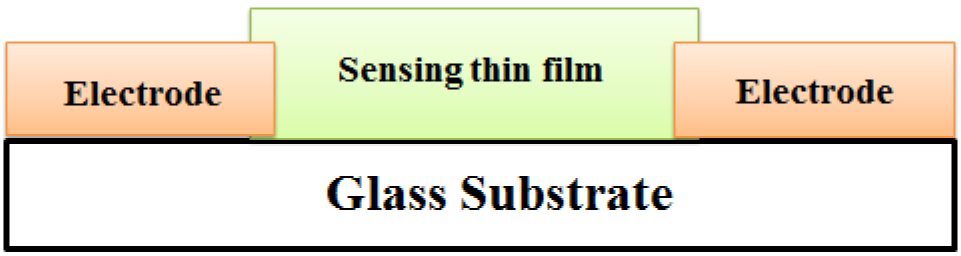

Figure 1: Schematic pic of sensors.

In this work, we have only studied the capacitance and resistance variance with respect to change in relative humidity of said sensors, for the fabrication and other characterizations see the following references (Afzal, Ahmad, et al., 2021; Ahmad, Sayyad, Saleem, Karimov, & Shah, 2008; Akram et al., 2021; Anchisini, Faglia, Gallazzi, Sberveglieri, & Zerbi, 1996; Karimov et al., 2012). According to these references, the capacitance and resistance of sensors have been measured through the LCR meter in a chamber at room temperature by varying relative humidity from 15% to 85% with the help of a humidifier at the room temperature of about 20 ^{o}C with normal atmospheric level. Moreover, the temperature inside the chamber is the same as in the outside atmosphere (We have not measured data experimentally, but by reading the graphs of the above references). The variance of capacitance and resistance of sensors have been studied at 1 kHz with a constant input of 1.0 V as shown in figure 2.

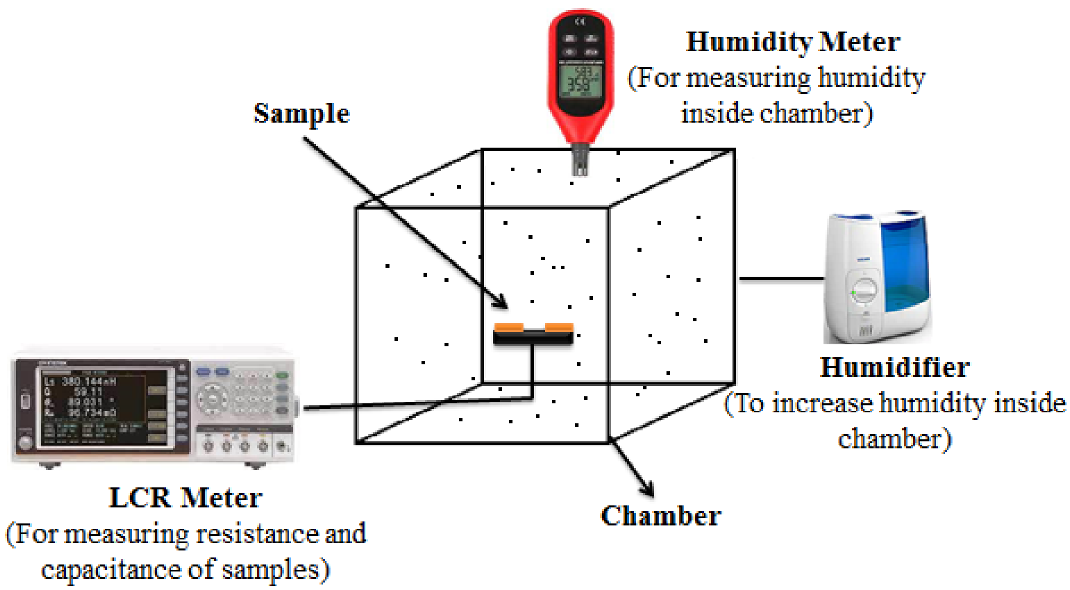

Figure 2: Electrical characterization setup.

3. Methodology

For the analysis of the data, we have used two statistical methods i.e. classical and neutrosophic methods. The discussion on these methods is as follows:

3.1. Classical Method:

As the classical method deals with fix-point values, so all intervals of capacitance and resistance have to convert into fixed point values by taking the average formula. Let $X_{Ni} \epsilon [X_{Li}, X_{Ui}]$ is an interval then the classical formula can be written as:

$$X_{Ni} = \left(\frac{X_{Li}+X_{Ui}}{2}\right) \quad i = 1, 2, 3, 4....n_N \qquad (1)$$

Classical algorithm for computer programs:

Step 1: Start program

Step 2: Enter all intervals (whether in table form or manually)

Step 3: Start loop from$i = 1 \; to \; i <= n_N$

Step 4: Execute formula: $X_{Ni} = \left(\frac{X_{Li}+X_{Ui}}{2}\right)$ *(for each interval)*

Calculate and draw a graph

Step 5: Increment ++ and go to step 3

Step 6: End internal loop

Step 7: End program

3.2. Neutrosophic Method:

For the neutrosophic method, we have to develop a neutrosophic formula (Afzal, Ahmad, et al., 2021; Afzal, Alrweili, et al., 2021). First, we develop a formula for the capacitance analysis of sensors. Let $C(\%RH)_N$ (as capacitance and resistance depend on the relative humidity) is a neutrosophic variable for capacitance with $C(\%RH)_N \epsilon [C(\%RH)_L, C(\%RH)_U]$ a measured interval of capacitance at specific relative humidity %RH. Here $C(\%RH)_L$ and $C(\%RH)_U$ are the lower and upper values of the interval, respectively. So, the neutrosophic formula for capacitance with indeterminacy $i_N \epsilon [i_L, i_U]$ can be written as:

$$C(\%RH)_N = C(\%RH)_L + C(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U] \quad (2)$$

Basically, the above formula of is $C(\%RH)_N \epsilon [C(\%RH)_L, C(\%RH)_U]$ is an extension of the classical. The equation is containing two parts i.e. $C(\%RH)_L$ determined & $C(\%RH)_U i_N$ indeterminate part. Moreover, $i_N \epsilon [i_L, i_U]$ is known as an indeterminacy interval. For neutrosophic formula $i_L = 0$ and i_U can be found by using$(C(\%RH)_U - C(\%RH)_L) / C(\%RH)_U$. Similarly, for resistance of sensors R(%RH) can be written as:

$$R(\%RH)_N = R(\%RH)_L + R(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U] \quad (3)$$

Neutrosophic algorithm for computer programs:

Step 1: Start program

Step 2: Enter all intervals (whether in table form or manually)

Step 3: Start the main loop from $a = 1\ to\ a <= n_N$

Step 4: Calculate $i_U = \left(\frac{C(\%RH)_U - C(\%RH)_L}{C(\%RH)_U}\right)$ (For capacitance)

Calculate $i_U = \left(\frac{R(\%RH)_U - R(\%RH)_L}{R(\%RH)_U}\right)$ (For resistance)

Step 5: Start internal loop $i_L = 0\ to\ i_L <= i_U$

Step 6: Calculate

$C(\%RH)_N = C(\%RH)_L + C(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U]$ (For capacitance)

$R(\%RH)_N = R(\%RH)_L + R(\%RH)_U i_N;\ i_N \epsilon [i_L, i_U]$ (For resistance)

Step 7: Increment of specific value (for interval loop, here we use 0.05) and go to step 5

Step 8: End internal loop

Step 9: Increment ++ and go to step 3

Step 10: End main loop

Step 11: End program

4. Result and Discussion

In this work, we focused only on the analysis of the electric properties of capacitance and resistance variation with respect to change in the relative humidity. We collected the data from (Afzal, Ahmad, et al., 2021; Ahmad et al., 2008; Akram et al., 2021; Anchisini et al., 1996; Karimov et al., 2012) who used the determinate measurements obtained from the LCR meter. On the other hand, (Afzal, Ahmad, et al., 2021; Afzal, Alrweili, et al., 2021; Lallart, Pruvost, & Guyomar, 2011; Nara, Yasuda, Satake, & Toriumi, 2002; Simić, 2014) aruged that the data obtained from the LCR meter do not have the exact obervations i.e. at a speccific point there a minimum and maximum point for a data variation. The measurement data from LCR meter is exprssed in interval rather than the exact valeus. In such cases, when the actaul meauerements of humidity sensor are in intervals, the use of classical statistics may mislead the decision-makers. We will present the analsysis of the data using the neutrosophic statistics. The humidity sensor imprecise data extrated from (Afzal, Ahmad, et al., 2021; Ahmad et al., 2008; Akram et al., 2021; Anchisini et al., 1996; Karimov et al., 2012) and reported in Tables 1-2.

Table 1: Measured capacitance of all sensors with respect to change in relative humidity

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Capacitance	Capacitance	Capacitance	Capacitance	Capacitance
%RH	pF	pF	pF	pF	pF
15	[146, 166]	[74, 82]	[80, 89]	[0.9, 1.1]	[62, 69]
20	[147, 166]	[81, 90]	[86, 95]	[1.1, 1.2]	[88, 98]
25	[147, 167]	[100, 113]	[91, 102]	[2.7, 3.0]	[110, 123]
30	[149, 168]	[127, 144]	[92, 105]	[2.8, 3.2]	[144, 164]
35	[150, 175]	[160, 182]	[100, 113]	[3.8, 4.2]	[183, 208]

40	[164, 175]	[181, 204]	[107, 120]	[4.7, 5.3]	[214, 242]
45	[168, 176]	[220, 250]	[128, 145]	[5.3, 6.0]	[257, 292]
50	[171, 180]	[252, 290]	[130, 149]	[8.0, 9.2]	[312, 358]
55	[175, 183]	[333, 381]	[149, 170]	[8.7, 9.9]	[369, 422]
60	[216, 224]	[454, 516]	[192, 219]	[11.6, 13.1]	[418, 475]
65	[1116, 1124]	[551, 634]	[298, 343]	[14.2, 16.3]	[463, 532]
70	[1902, 1950]	[631, 726]	[1238, 1424]	[17.0, 19.6]	[497, 572]
75	[2600, 2740]	[757, 871]	[1664, 1915]	[20.2, 23.2]	[515, 592]
80	[3630, 3700]	[863, 893]	[2070, 2382]	[26.5, 28.7]	[527, 607]
85	[6530, 6590]	[963, 990]	[2369, 2725]	[29.8, 32.3]	[579, 667]

Table 2: Measured Resistance of all sensors with respect to change in relative humidity

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Resistance	Resistance	Resistance	Resistance	Resistance
%RH	MΩ	MΩ	MΩ	MΩ	MΩ
15	[1676, 2230]	[35, 47]	[3009, 4015]	[78, 106]	[0.76, 1.01]
20	[1620, 2190]	[34, 45]	[2674, 3572]	[72, 101]	[0.74, 0.99]
25	[1593, 2123]	[33, 44]	[2305, 3091]	[63, 92]	[0.70, 0.94]
30	[1510, 2041]	[32, 43]	[2237, 2997]	[52, 81]	[0.68, 0.91]
35	[1430, 1930]	[32, 41]	[2131, 2741]	[43, 68]	[0.66, 0.84]
40	[1220, 1530]	[31, 40]	[2010, 2580]	[22, 47]	[0.61, 0.78]
45	[1100, 1300]	[30, 38]	[1770, 2276]	[27, 33.8]	[0.57, 0.73]
50	[960, 1050]	[29, 38]	[1574, 2129]	[22, 30]	[0.50, 0.68]
55	[765, 834]	[28, 35]	[1343, 1636]	[15, 21]	[0.49, 0.60]
60	[420, 430]	[27, 34]	[1044, 1250]	[9, 13]	[0.46, 0.55]
65	[123, 125]	[27, 32]	[713, 837]	[5.3, 11.3]	[0.41, 0.48]
70	[100, 102]	[26, 30]	[315, 348]	[2.6, 5.1]	[0.39, 0.43]
75	[85, 87]	[27.3, 27.9]	[288, 295]	[1.9, 3.7]	[0.41, 0.42]
80	[50, 51]	[25.6, 26.2]	[259, 264]	[0.9, 1.7]	[0.39, 0.40]
85	[28.1, 28.5]	[21.5, 21.8]	[259, 263]	[0.2, 0.9]	[0.34, 0.34]

4.1. Analysis of Capacitance and Resistance:

In this section, we discussed the analysis of the data using the neutrosophic statistics and classical statistics. First, we will analyze the data of capacitance and resistance through the classical method as shown in Table 3 and Table 4, then the neutrosophic method as shown in Table 5 and Table 6.

Table 3: Classical analysis of the capacitance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Capacitance	Capacitance	Capacitance	Capacitance	Capacitance
%RH	pF	pF	pF	pF	pF
15	156	78.6	85	1.1	66.0
20	156.5	85.7	91	1.3	93.9
25	157	107.1	97	2.9	117.1
30	158.5	135.7	99	3.0	154.3
35	162.5	171.4	107	4.0	196.1
40	169.5	192.9	114	5.0	228.6
45	172	235.7	137	5.6	275.1
50	175.5	271.4	140	8.6	335.5
55	179	357.1	160	9.3	395.9
60	220	485.7	206	12.4	447.0
65	1120	592.9	321.3	15.2	498.1
70	1926	678.6	1331.1	18.3	535.2
75	2670	814.3	1790.2	21.7	553.8
80	3665	928.6	2226.2	27.6	567.7
85	6560	1035.7	2547.5	31.1	623.5

Table 4: Classical analysis of the capacitance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Resistance	Resistance	Resistance	Resistance	Resistance
%RH	MΩ	MΩ	MΩ	MΩ	MΩ
15	1953	39.3	3512.3	92.5	0.89
20	1905	39.0	3123.2	86.9	0.86
25	1858	38.5	2698.0	77.7	0.82
30	1775.5	38.0	2617.5	66.6	0.79
35	1680	37.2	2436.2	56.4	0.75
40	1375	35.8	2295.3	35.1	0.69

45	1200	34.7	2023.5	21.3	0.64
50	1005	33.8	1852.3	15.2	0.59
55	799.5	32.7	1489.9	11.3	0.54
60	425	31.9	1147.7	10.5	0.50
65	124	30.2	775.2	9.3	0.44
70	101	29.2	332.2	6.5	0.40
75	86	27.6	291.9	3.9	0.41
80	50.5	25.9	261.7	2.9	0.39
85	28.3	21.7	261.7	2.0	0.33

Table 5: Neutrosophic analysis of the capacitance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Capacitance	Capacitance	Capacitance	Capacitance	Capacitance
%RH	pF	pF	pF	pF	pF
15	$146+ 166I_N$; $I_N \epsilon [0, 0.120]$	$74+ 82I_N$; $I_N \epsilon [0, 0.101]$	$80+ 89I_N$; $I_N \epsilon [0, 0.101]$	$0.9+ 1.1I_N$; $I_N \epsilon [0, 0.101]$	$62+ 69I_N$; $I_N \epsilon [0, 0.101]$
20	$147+ 166I_N$; $I_N \epsilon [0, 0.114]$	$81+ 90I_N$; $I_N \epsilon [0, 0.099]$	$86+ 95I_N$; $I_N \epsilon [0, 0.099]$	$1.1+ 1.2I_N$; $I_N \epsilon [0, 0.099]$	$88+ 98I_N$; $I_N \epsilon [0, 0.099]$
25	$147+ 167I_N$; $I_N \epsilon [0, 0.120]$	$100+ 113I_N$; $I_N \epsilon [0, 0.110]$	$91+ 102I_N$; $I_N \epsilon [0, 0.120]$	$2.7+ 3.0I_N$; $I_N \epsilon [0, 0.110]$	$110+ 123I_N$; $I_N \epsilon [0, 0.120]$
30	$149+ 168I_N$; $I_N \epsilon [0, 0.113]$	$127+ 144I_N$; $I_N \epsilon [0, 0.118]$	$92+ 105I_N$; $I_N \epsilon [0, 0.118]$	$2.8+ 3.2I_N$; $I_N \epsilon [0, 0.118]$	$144+ 164I_N$; $I_N \epsilon [0, 0.118]$
35	$150+ 175I_N$; $I_N \epsilon [0, 143]$	$160+ 182I_N$; $I_N \epsilon [0, 0.117]$	$100+ 113I_N$; $I_N \epsilon [0, 0.117]$	$3.8+ 4.2I_N$; $I_N \epsilon [0, 0.116]$	$183+ 208I_N$; $I_N \epsilon [0, 0.117]$
40	$164+ 175I_N$; $I_N \epsilon [0, 0.063]$	$181+ 204I_N$; $I_N \epsilon [0, 0.113]$	$107+ 120I_N$; $I_N \epsilon [0, 0.113]$	$4.7+ 5.3I_N$; $I_N \epsilon [0, 0.112]$	$214+ 242I_N$; $I_N \epsilon [0, 0.113]$
45	$168+ 176I_N$; $I_N \epsilon [0, 0.45]$	$220+ 250I_N$; $I_N \epsilon [0, 0.120]$	$128+ 145I_N$; $I_N \epsilon [0, 0.120]$	$5.3+ 6.0I_N$; $I_N \epsilon [0, 0.77]$	$257+ 292I_N$; $I_N \epsilon [0, 0.120]$
50	$171+ 180I_N$; $I_N \epsilon [0, 0.050]$	$252+ 290I_N$; $I_N \epsilon [0, 0.128]$	$130+ 149I_N$; $I_N \epsilon [0, 0.128]$	$8.0+ 9.2I_N$; $I_N \epsilon [0, 0.077]$	$312+ 358I_N$; $I_N \epsilon [0, 0.128]$
55	$175+ 183I_N$; $I_N \epsilon [0, 0.044]$	$333+ 381I_N$; $I_N \epsilon [0, 0.095]$	$149+ 170I_N$; $I_N \epsilon [0, 0.126]$	$8.7+ 9.9I_N$; $I_N \epsilon [0, 0.039]$	$369+ 42I_N$; $I_N \epsilon [0, 0.126]$
60	$216+ 224I_N$;	$454+ 516I_N$;	$192+ 219I_N$;	$11.6+ 13.1I_N$;	$418+ 475I_N$;

	$I_N\epsilon[0, 0.0.36]$	$I_N\epsilon[0, 0.120]$	$I_N\epsilon[0, 0.120]$	$I_N\epsilon[0, 0.039]$	$I_N\epsilon[0, 0.120]$
65	$1116+ 1124I_N$; $I_N\epsilon[0, 0.007]$	$551+ 634I_N$; $I_N\epsilon[0, 0.058]$	$298+ 343I_N$; $I_N\epsilon[0, 0.131]$	$14.2+ 16.3I_N$; $I_N\epsilon[0, 0.020]$	$463+ 532I_N$; $I_N\epsilon[0, 0.095]$
70	$1902+ 1950I_N$; $I_N\epsilon[0, 0.025]$	$631+ 726I_N$; $I_N\epsilon[0, 0.077]$	$1238+ 1424I_N$; $I_N\epsilon[0, 0.131]$	$17.0+ 19.6I_N$; $I_N\epsilon[0, 0.039]$	$497+ 572I_N$; $I_N\epsilon[0, 0.095]$
75	$2600+ 2740I_N$; $I_N\epsilon[0, 0.051]$	$757+ 871I_N$; $I_N\epsilon[0, 0.039]$	$1664+ 1915I_N$; $I_N\epsilon[0, 0.131]$	$20.2+ 23.2I_N$; $I_N\epsilon[0, 0.058]$	$515+ 592I_N$; $I_N\epsilon[0, 0.095]$
80	$3630+ 3700I_N$; $I_N\epsilon[0, 0.019]$	$863+ 893I_N$; $I_N\epsilon[0, 0.039]$	$2070+ 2382I_N$; $I_N\epsilon[0, 0.131]$	$26.5+ 28.7I_N$; $I_N\epsilon[0, 0.39]$	$527+ 607I_N$; $I_N\epsilon[0, 0.077]$
85	$6530+ 6590I_N$; $I_N\epsilon[0, 0.009]$	$963+ 990I_N$; $I_N\epsilon[0, 0.020]$	$2369+ 2725I_N$; $I_N\epsilon[0, 0.131]$	$29.8+ 32.3I_N$; $I_N\epsilon[0, 0.058]$	$579+ 667I_N$; $I_N\epsilon[0, 0.058]$

Table 6: Neutrosophic analysis of the resistance of sensors

Relative Humidity	**Al/MG/Al**	**Ag/MR/AL**	**Al/TPPNi/Al**	**Ag/ Cu_2O-PEPC/Ag**	**Au/PDMP/Au**
	Resistance	Resistance	Resistance	Resistance	Resistance
%RH	MΩ	MΩ	MΩ	MΩ	MΩ
15	$1676+ 2230I_N$; $I_N\epsilon[0, 0.248]$	$35+ 47I_N$; $I_N\epsilon[0, 0.251]$	$3009+ 4015I_N$; $I_N\epsilon[0, 0.251]$	$78+ 106I_N$; $I_N\epsilon[0, 0.286]$	$0.76+ 1.01I_N$; $I_N\epsilon[0, 251]$
20	$1620+ 2190I_N$; $I_N\epsilon[0, 0.260]$	$34+ 45I_N$; $I_N\epsilon[0, 0.251]$	$2674+ 3572I_N$; $I_N\epsilon[0, 0.251]$	$72+ 101I_N$; $I_N\epsilon[0, 0.284]$	$0.74+ 0.99I_N$; $I_N\epsilon[0, 0.251]$
25	$1593+ 2123I_N$; $I_N\epsilon[0, 0.250]$	$33+ 44I_N$; $I_N\epsilon[0, 0.254]$	$2305+ 3091I_N$; $I_N\epsilon[0,0.245]$	$63+ 92I_N$; $I_N\epsilon[0, 0.316]$	$0.70+ 0.94I_N$; $I_N\epsilon[0, 0.254]$
30	$1510+ 2041I_N$; $I_N\epsilon[0,0.260]$	$32+ 43I_N$; $I_N\epsilon[0, 0.254]$	$2237+ 2997I_N$; $I_N\epsilon[0, 0.245]$	$52+ 81I_N$; $I_N\epsilon[0, 0.358]$	$0.68+ 0.91I_N$; $I_N\epsilon[0, 0.254]$
35	$1430+ 1930I_N$; $I_N\epsilon[0, 0.259]$	$32+ 41I_N$; $I_N\epsilon[0, 0.222]$	$2131+ 2741I_N$; $I_N\epsilon[0, 0.222]$	$43+ 68I_N$; $I_N\epsilon[0, 0.363]$	$0.66+ 0.84I_N$; $I_N\epsilon[0, 0.222]$
40	$1220+ 1530I_N$; $I_N\epsilon[0, 0.203]$	$31+ 40I_N$; $I_N\epsilon[0, 0.221]$	$2010+ 2580I_N$; $I_N\epsilon[0, 0.221]$	$22+ 47I_N$; $I_N\epsilon[0, 0.522]$	$0.61+ 0.78I_N$; $I_N\epsilon[0, 0.221]$
45	$1100+ 1300I_N$; $I_N\epsilon[0, 0.154]$	$30+ 38 I_N$; $I_N\epsilon[0, 0.223]$	$1770+ 2276I_N$; $I_N\epsilon[0, 0.223]$	$27+ 33.8I_N$; $I_N\epsilon[0, 0.740]$	$0.57+ 0.73I_N$; $I_N\epsilon[0, 0.223]$
50	$960+ 1050I_N$; $I_N\epsilon[0, 0.086]$	$29+ 38I_N$; $I_N\epsilon[0, 0.261]$	$1574+ 2129I_N$; $I_N\epsilon[0, 0.261]$	$22+ 30I_N$; $I_N\epsilon[0, 0.991]$	$0.50+ 0.68I_N$; $I_N\epsilon[0, 0.261]$
55	$765+ 834I_N$; $I_N\epsilon[0, 0.083]$	$28+ 35I_N$; $I_N\epsilon[0, 0.179]$	$1343+ 1636I_N$; $I_N\epsilon[0, 0.179]$	$15+ 21I_N$; $I_N\epsilon[0, 0.929]$	$0.49+ 0.60I_N$; $I_N\epsilon[0, 0.179]$

60	$420+430I_N$; $I_N\epsilon[0, 0.023]$	$27+34I_N$; $I_N\epsilon[0, 0.165]$	$1044+1250I_N$; $I_N\epsilon[0, 0.165]$	$9+13I_N$; $I_N\epsilon[0, 0.924]$	$0.46+0.55I_N$; $I_N\epsilon[0, 0.165]$
65	$123+125I_N$; $I_N\epsilon[0, 0.016]$	$27+32I_N$; $I_N\epsilon[0, 0.148]$	$713+837I_N$; $I_N\epsilon[0, 0.148]$	$5.3+11.3I_N$; $I_N\epsilon[0, 0.924]$	$0.41+0.48I_N$; $I_N\epsilon[0, 0.148]$
70	$100+102I_N$; $I_N\epsilon[0, 0.020]$	$26+30I_N$; $I_N\epsilon[0, 0.096]$	$315+348I_N$; $I_N\epsilon[0,n0.096]$	$2.6+5.1I_N$; $I_N\epsilon[0, 0.876]$	$0.39+0.43I_N$; $I_N\epsilon[0, 0.096]$
75	$85+87I_N$; $I_N\epsilon[0, 0.023]$	$27.3+27.9I_N$; $I_N\epsilon[0, 0.023]$	$288+295I_N$; $I_N\epsilon[0, 0.024]$	$1.9+3.7I_N$; $I_N\epsilon[0, 0.472]$	$0.41+0.42I_N$; $I_N\epsilon[0, 0.024]$
80	$50+51I_N$; $I_N\epsilon[0, 0.020]$	$25.6+26.2I_N$; $I_N\epsilon[0, 0.020]$	$259+264I_N$; $I_N\epsilon[0, 0.020]$	$0.9+1.7I_N$; $I_N\epsilon[0, 0.500]$	$0.39+0.40I_N$; $I_N\epsilon[0, 0.020]$
85	$28.1+28.5I_N$; $I_N\epsilon[0, 0.014]$	$21.5+21.8I_N$; $I_N\epsilon[0, 0.014]$	$259+263I_N$; $I_N\epsilon[0, 0.014]$	$0.2+0.9I_N$; $I_N\epsilon[0, 0.523]$	$0.34+0.34I_N$; $I_N\epsilon[0, 0.014]$

Table 3 and Table 4 are expressing the classical analysis of the capacitance and resistance data of the sensors by applying the classical formula of the mean. From the tables, it is seen that classical analysis has converted all intervals into fi- point, which are not defining the variance of the interval from minimum to a maximum value. We have gotten only a single value of capacitance and resistance against specific relative humidity. This is showing that classical analysis is not reliable in making decisions and in concluding the solution to the problem. Similarly, Table 5 and Table 6 are expressing the neutrosophic analysis of the capacitance and resistance of sensors. From these tables, it is seen that neutrosophic analysis is a more reliable analysis as it uses indeterminacy and gives the whole information about the variance of capacitance and resistance at a specific value of the relative humidity. For example, at 15 %RH the classical value of the capacitance of Al/MG/Al is 156 pF (a single or fix-point value) i.e. $C_{(15\%RH)}$ = 156pF. But the other hand neutrosophic analysis gives an equation $C_{(15\%RH)} = 146+166I_N$ with the indeterminacy interval $I_N\epsilon[0, 0.120]$. According to neutrosophic analysis, the value of capacitance lies between 146 and 166 by put indeterminacy values.

3.4 Graphical Comparison of Neutrosophic and Classical Analysis of Capacitance and Resistance of Humidity Sensors:

The graphical comparison of neutrosophic and classical analysis for capacitance and resistance of Al/MG/Al, Ag/MR/Ag, Al/TPPNi/Al, Ag/ Cu_2O-PEPC/Ag and Au/PDMP/Au are shown in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7.

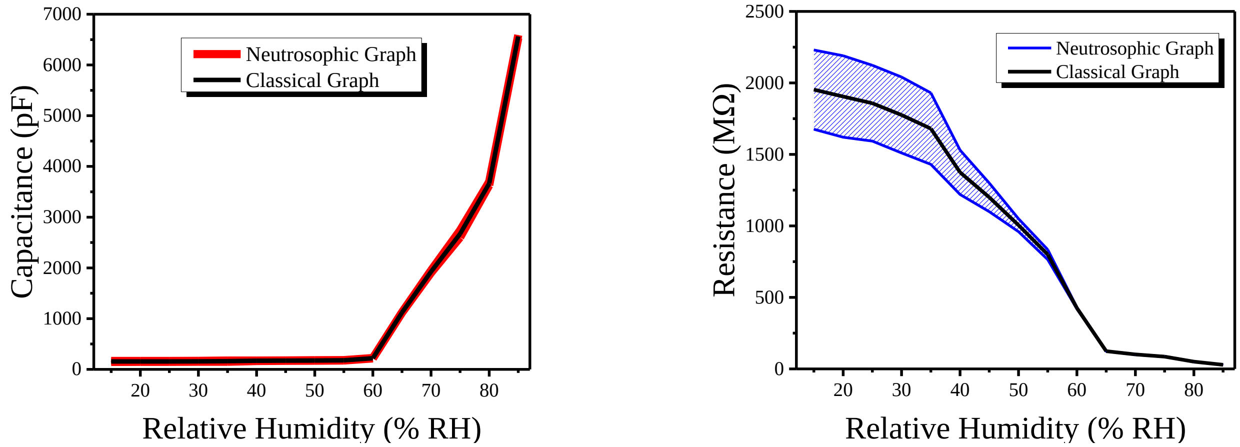

Figure 3: Left side plot is capacitance and right side plot is resistance of Al/MG/Al.

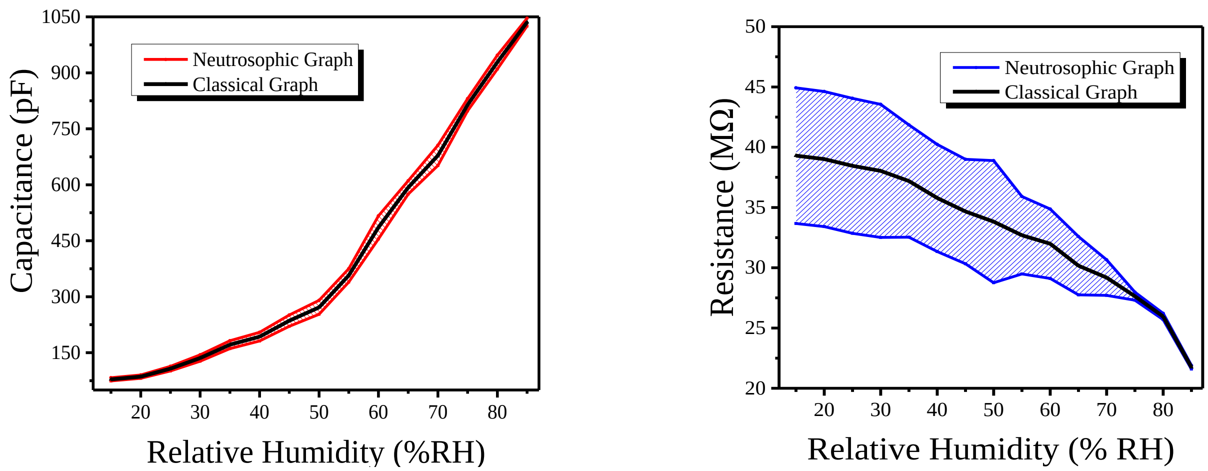

Figure 4: Left side plot is capacitance and right side plot is resistance of Ag/MR/Ag.

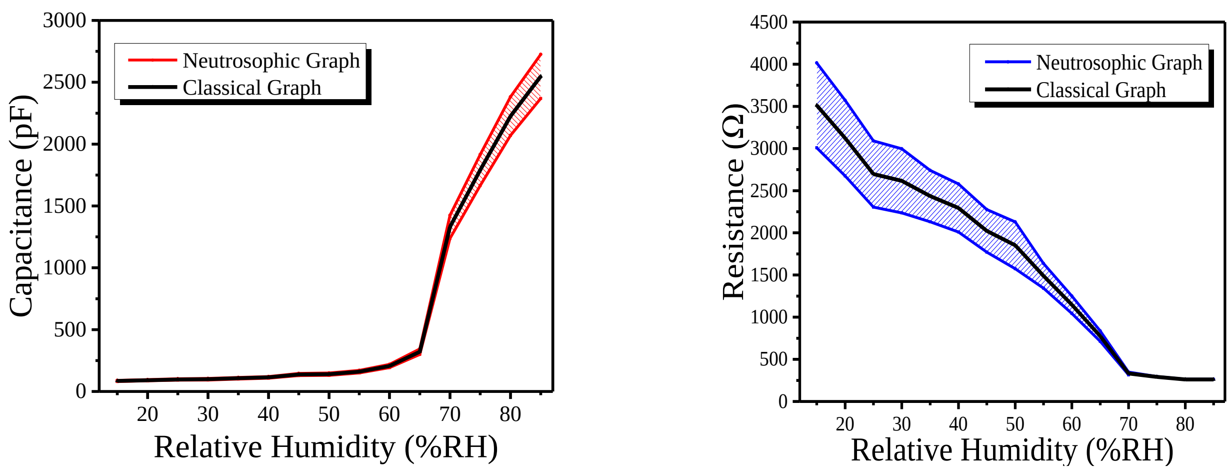

Figure 5: Left side plot is capacitance and right side plot is resistance of Al/TPPNi/Al.

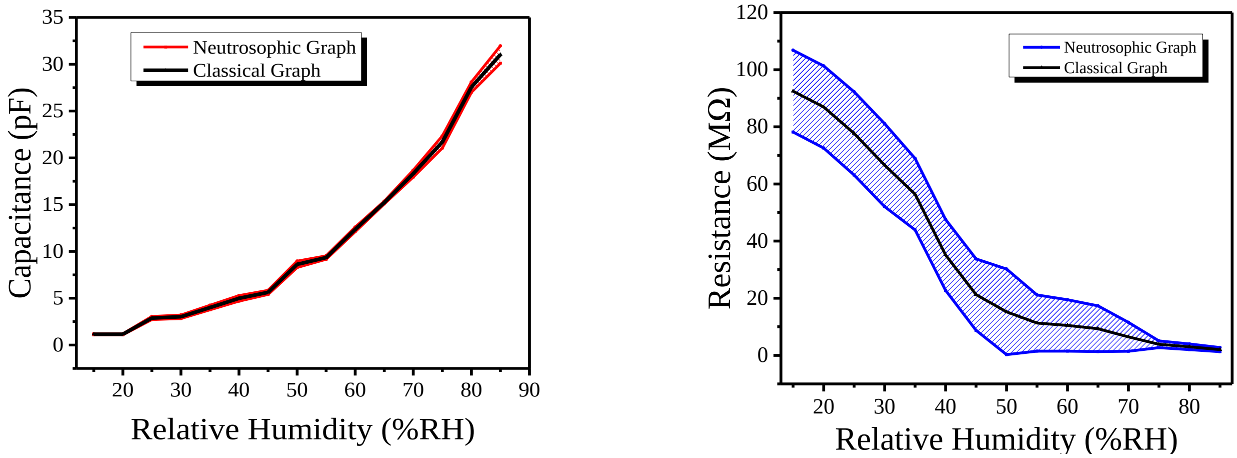

Figure 6: Left side plot is capacitance and right side plot is resistance of Ag/ Cu2O-PEPC/Ag.

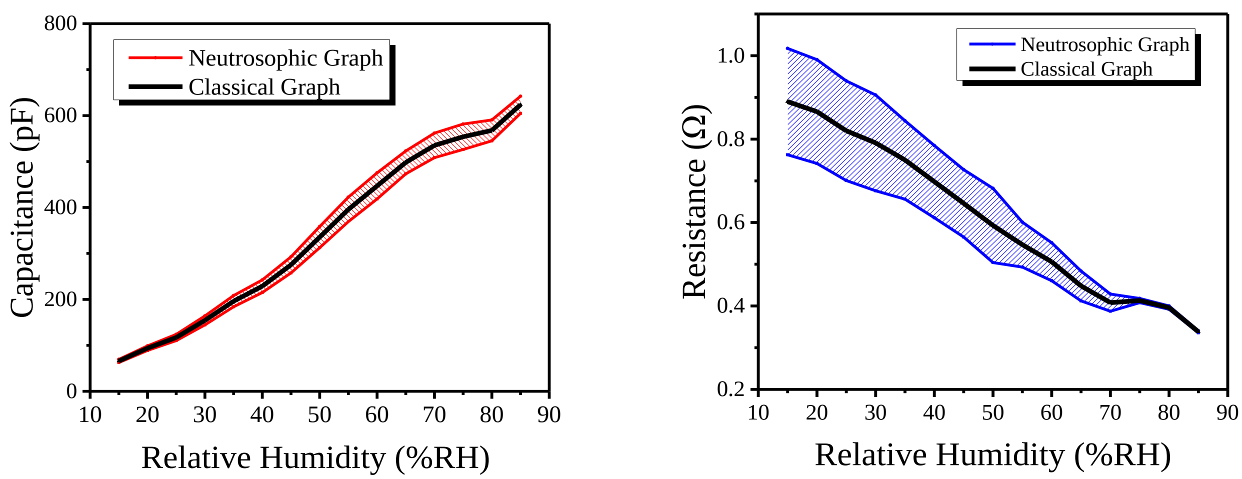

Figure 6: Left side plot is capacitance and right side plot is resistance of Au/PDMP/Au.

The above graphs are showing the comparison between classical and neutrosophic analysis. For capacitance the classical and neutrosophic graphs are looking about the same i.e. having a small plotting difference, this is because there is a small variance of capacitance as compared to the resistance (small variance gives a small interval of indeterminacy). On the other hand, there is a large difference between classical and neutrosophic graphs of resistance. Because there is a large variance of resistance (large variance gives a large interval of indeterminacy). One can easily see that classical graphs are less flexible and informative to explain the capacitance and resistance of sensors as these are drawn on fix-point values. But neutrosophic graphs are enough flexible and informative to explain and conclude the problem. Generally, it is seen that most researchers have used classical graphs in their works either in form of a single line plot or in the form of an error bar graph for expressing the data variation. But statistically, these are not effective plots as the error bar shows the error found in data, not variance. When a researcher uses an error bar it means that he is graphically expressing the data error (which may be due to personal error, sample handling error, or mechanic error) instead of data variance. But the neutrosophic approach is a remarkable approach to analysis the data analysis. That's why we have used the neutrosophic approach for the analysis of the variance of capacitance and resistance of humidity sensors with changes in relative humidity.

5. Concluding Remarks

This study belongs to the material statistics as we have used the statistics to analyze the imprecise data of electric properties belongs to humidity sensors based on different materials. For this purpose, we have used the neutrosophic method to analyze the capacitance and resistance of humidity sensors. Al/MG/Al, Ag/MR/Ag, Al/TPPNi/Al, Ag/ Cu_2O-PEPC/Ag and Au/PDMP/Au humidity sensors are used in this work, whose data of capacitance and resistance has been collected from previous published papers with some assumptions (like data is intervals). We have applied classical as well as neutrosophic formulas on the collected data and draw the graphs of the output. We have compared the methods as well as output graphs and find which is more reliable for analysis of sensing data. As a result, it is observed that classical analysis is not effective in explaining the variation of capacitance and resistance with respect to change in relative humidity as data loss its indeterminacy. But the neutrosophic analysis is more effective. It is concluded that neutrosophic statistics is more effective, reliable and much informative in taking decisions as well as classical statistics.

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