CHAPTER 4

RESULTS AND ANALYSIS

In this chapter results are given analysis has been done. An electronic nose system having two different sensor arrays has been developed and simulated for two different applications using two different classification techniques RBFN and ANFIS for both the applications. Then results have compared for both the techniques for the two applications. In Table 4.1 names of toxic chemicals and household items are given.

Table 4.1 Toxic chemicals and Household items smells

Smell No.	Environmental Monitoring	Household Items Monitoring
	Name of the Smell	
1.	Ammonia (NH3)	Distilled Water
2.	Sulfur Dioxide	Lighter Fluid
3.	Polybrominated Diphenyl Ethers	Soda Water
4.	Lead	Perfume Jasmine
5.	Nitrogen Oxides (NOx)	Fruit Juice Orange
6.	Carbon Monoxide	Coffee
7.	Polychlorinated Biphenyls	Rose Water
8.	DDT	Glass Cleaner
9.	Nonylphenol	Honey
10.	Copper	Vinegar

11.		Shoe Polish
12.		Correction Fluid
13.		Fresh Milk
14.		Contact Cement

4.1 Simulation Results for Environment Monitoring

For environment monitoring ten (10) toxic chemicals are taken and smell of each chemical is applied to the sensor array of 12 sensors consist of eight different TGS2000 series sensors having two TGS2630, two TGS2602, two TGS2610, two TGS2620, one TGS2201, one TGS2612, one TGS2444, one TGS 2442. For recording the signals each sensor is interfaced with NI11.0 LABVIEW software. Due to each smell, resistance change occurred in each sensor of the array that has been noted down and modeling of some signals is shown using Lorentzian model [107].

4.1.1 Lorentzian Model Responses

Signals from each sensor in an array are taken and set of data are applied on classification technique platform to distinguish the odor. Change in resistance are noted down then almost same signal is generated by using Lorentzian Model to get the idea of the shape of the original signal. Responses of the sensor array for each chemical smell are given in the figures from Figure 4.1 to Figure 4.10.

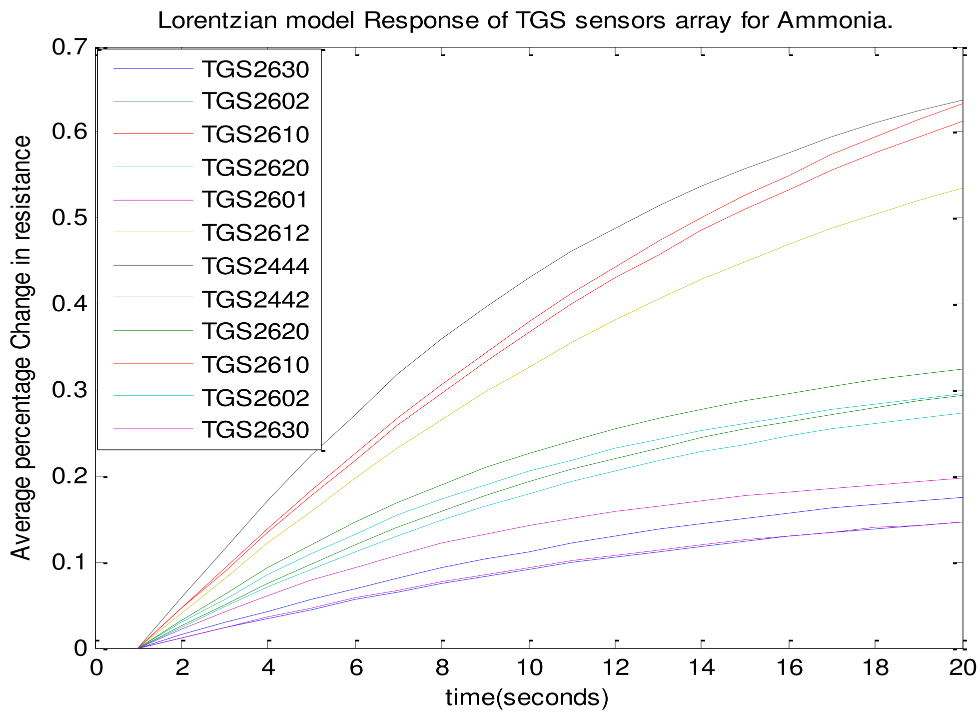

Figure 4.1 Response of Different Sensors in the array for Smell of Ammonia (NH_3)

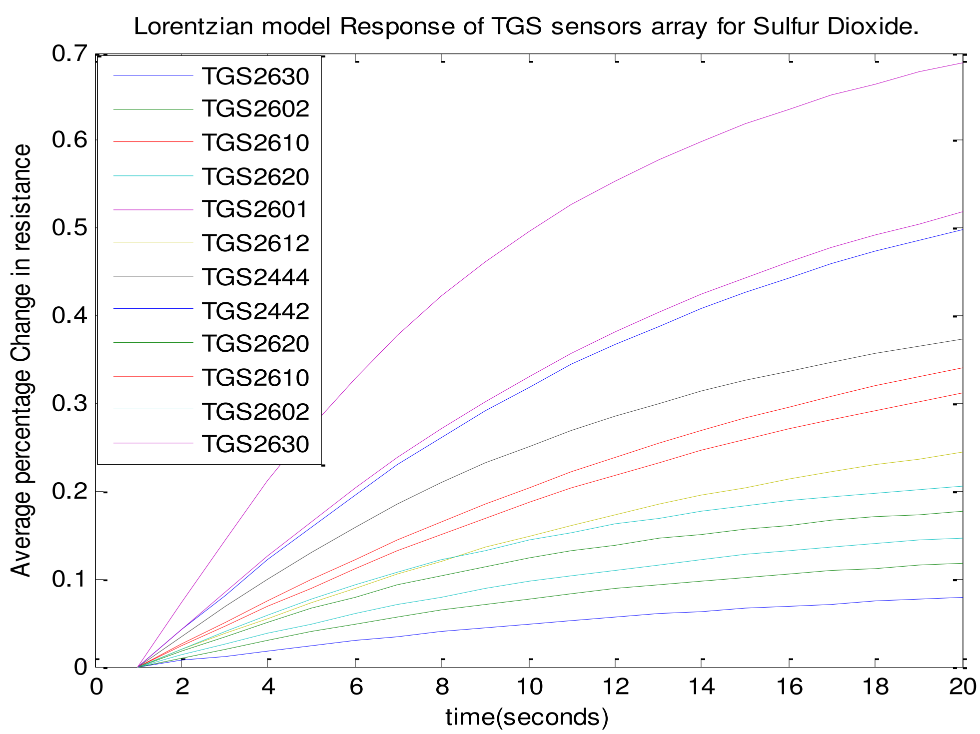

Figure 4.2 Response of Different Sensors in the array for Smell Sulfur Dioxide (SO_2)

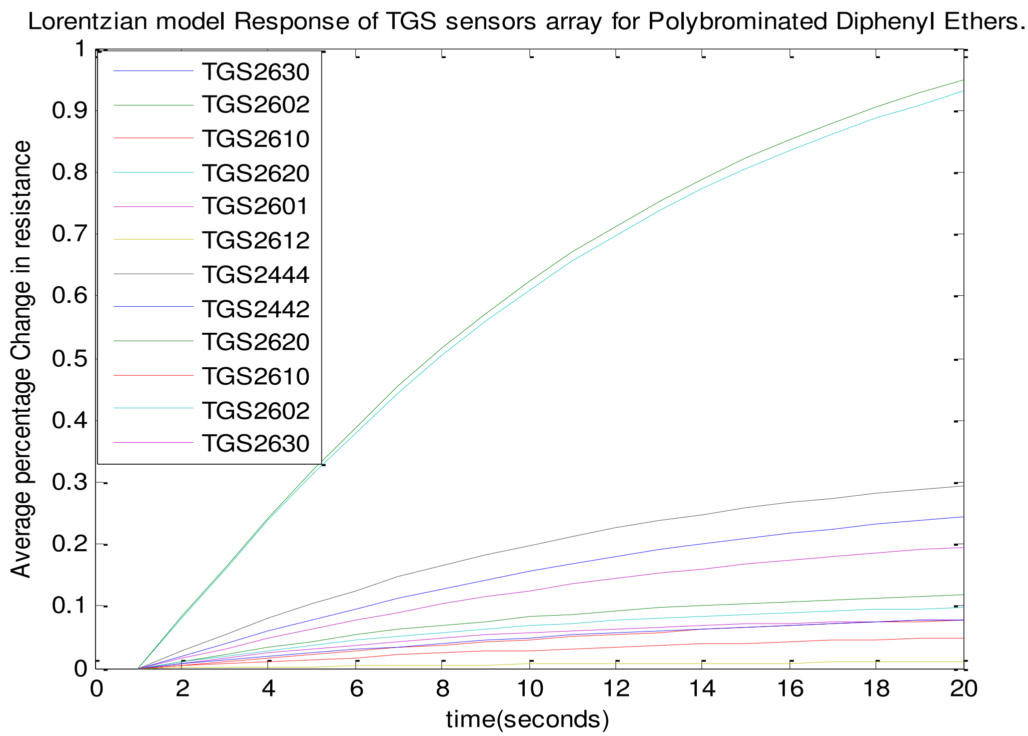

Figure 4.3 Response of Different Sensors in the array for Smell of PBDE

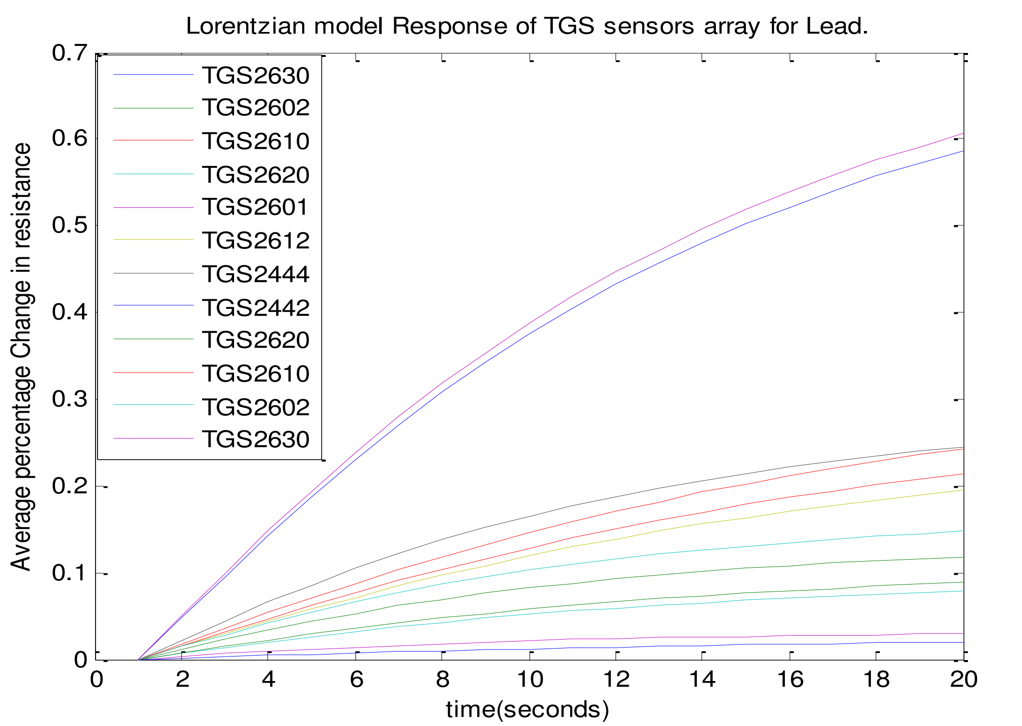

Figure 4.4 Response of Different Sensors in the array for Smell of Lead

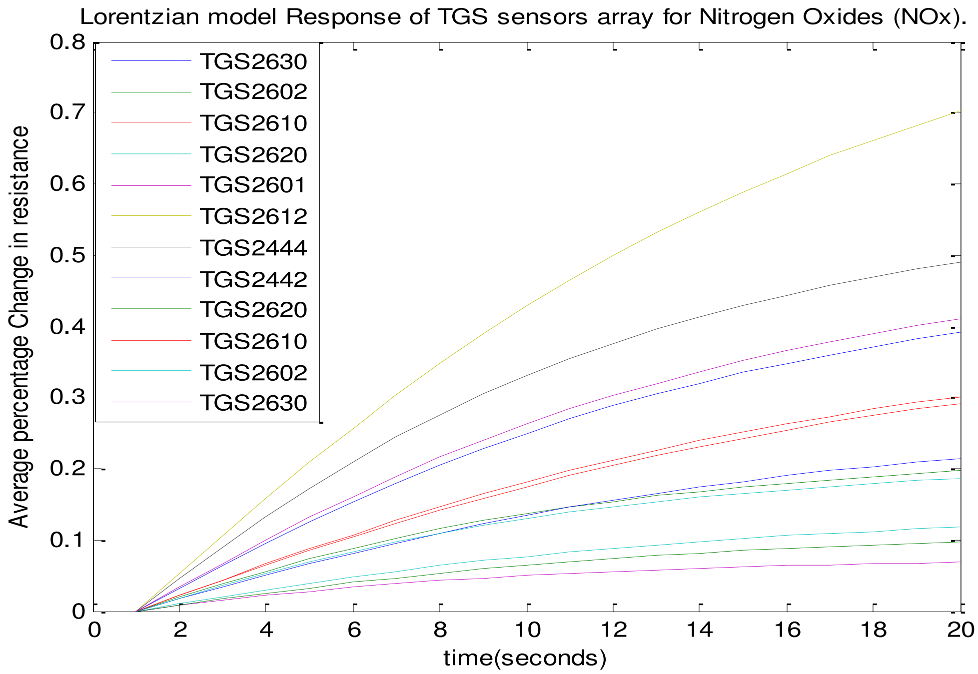

Figure 4.5 Response of Different Sensors in the array for Smell of Nitrogen Oxide (NOx)

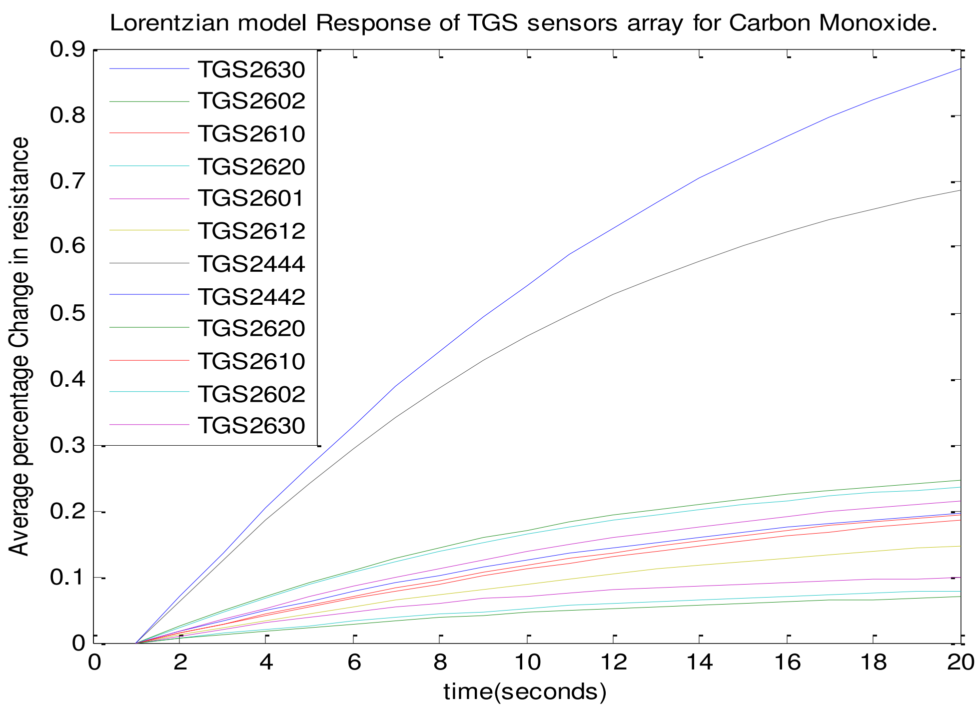

Figure 4.6 Response of Different Sensors in the array for Smell of Carbon Monoxide (CO)

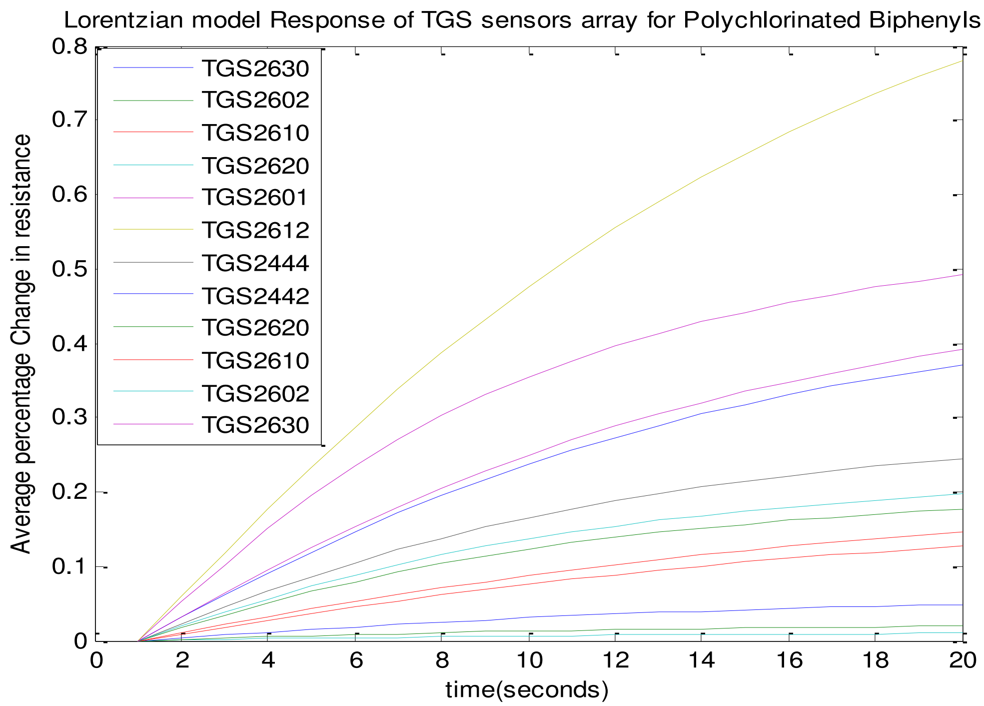

Figure 4.7 Response of Different Sensors in the array for Smell of Polychlorinated Biphenyls

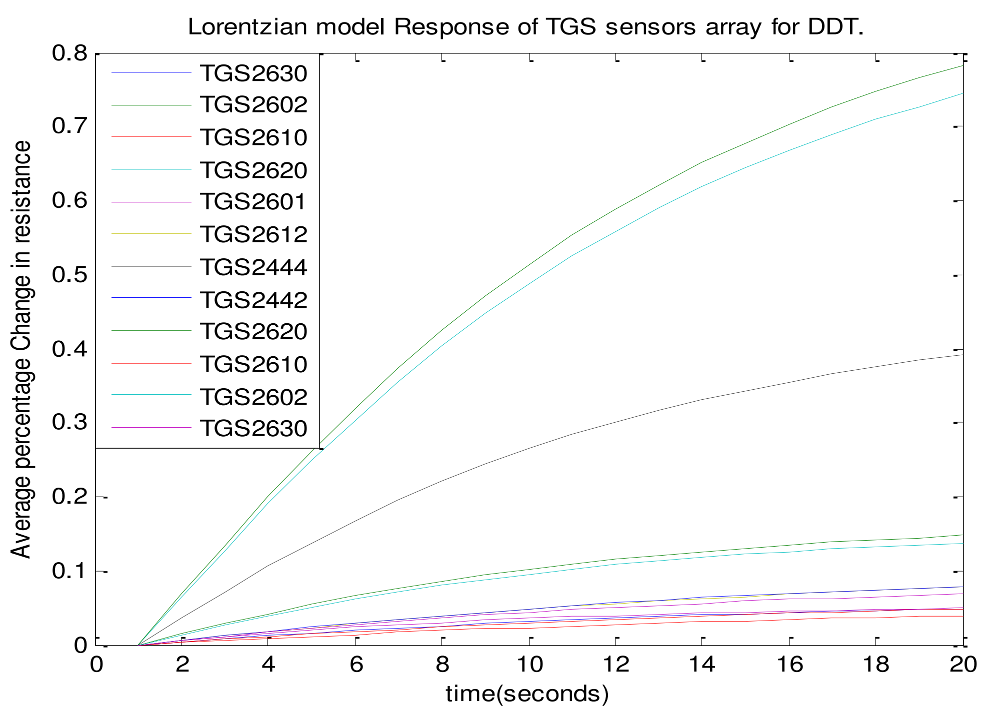

Figure 4.8 Response of Different Sensors in the array for Smell of DDT

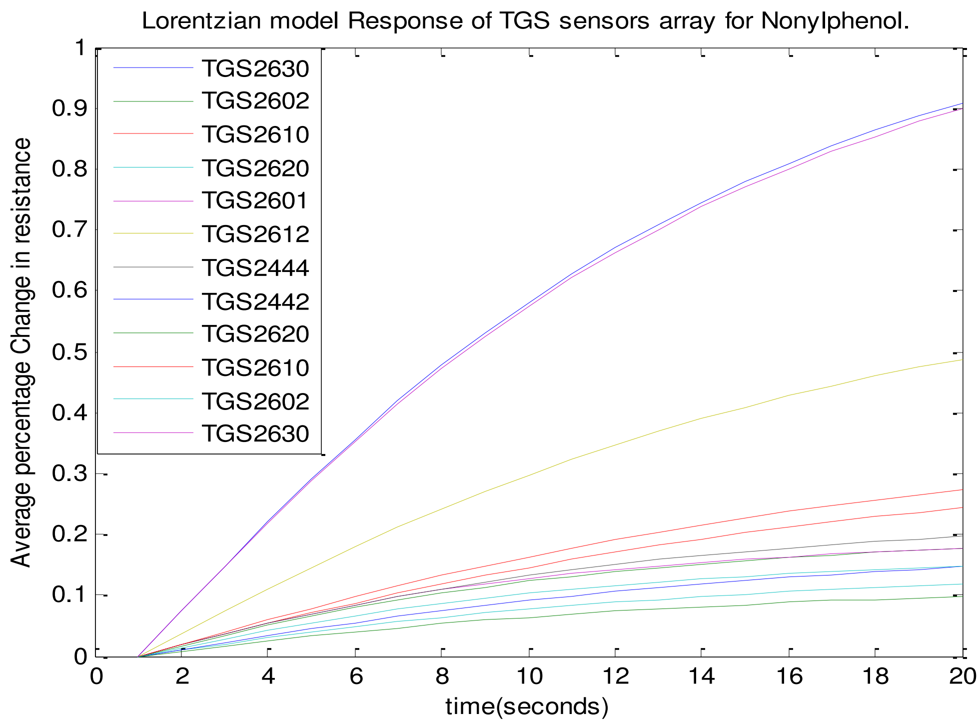

Figure 4.9 Response of Different Sensors in the array for Smell of Nonylphenol

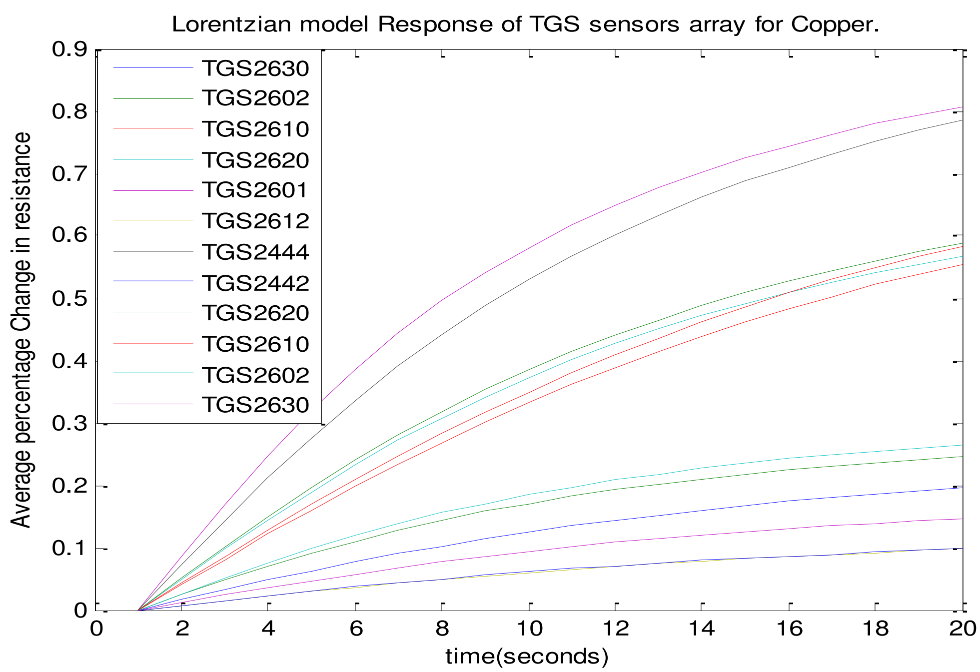

Figure 4.10 Response of Different Sensors in the array for Smell of Copper (Cu)

4.1.2 Smell Finger Prints

From the responses of sensor array modeled by Lorentzian Model, average percentage change in resistance of twelve different sensors of the array are taken and plotted the data using MS-excel as shown in Figure 4.11 to Figure 4.20, to see the pattern of the resistance change that is called signature pattern or finger prints. In the x-axis sensor number is taken and on y-axis percentage change in resistance is taken. In the array sensor no. 1 and 12 are TGS2630, sensor no. 2 and 11 are TGS2602, sensor no. 3 and 10 are TGS2610, sensor no. 4 and 9 are TGS2620, sensor no. 5 is TGS2201, sensor no.6 is TGS2612, sensor no. 7 is TGS2444 and sensor no. 8 is TGS 2442.

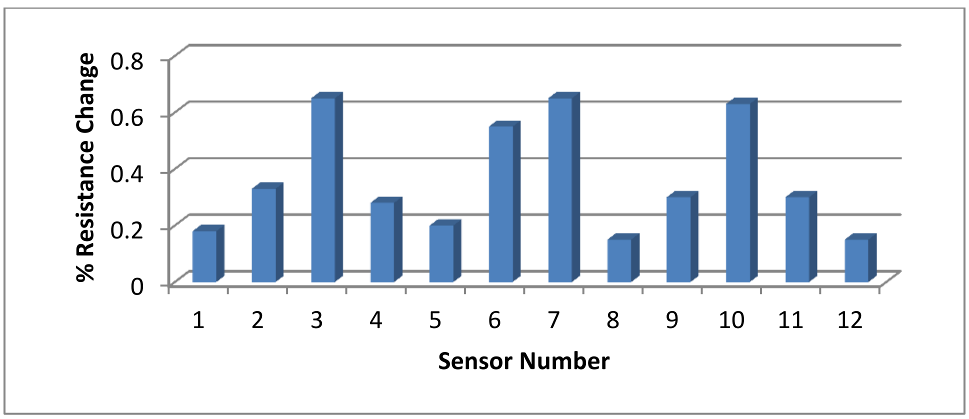

Figure 4.11 Signature pattern for Smell of Ammonia

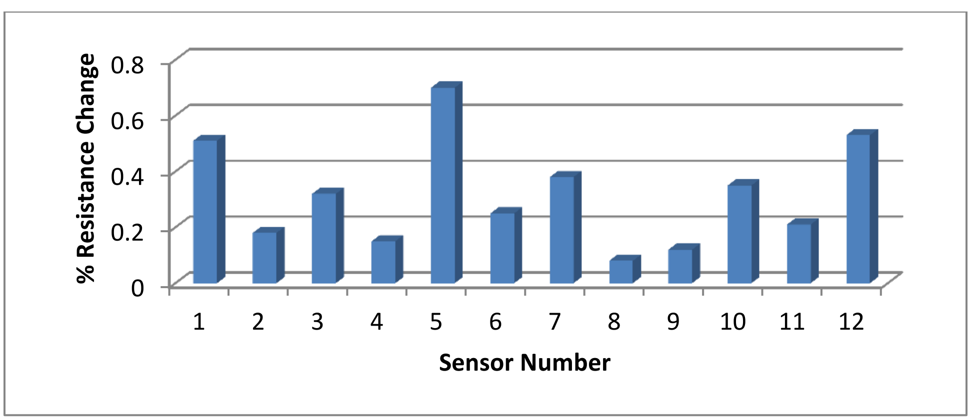

Figure 4.12 Signature pattern for Smell of Sulfur Dioxide (SO_2)

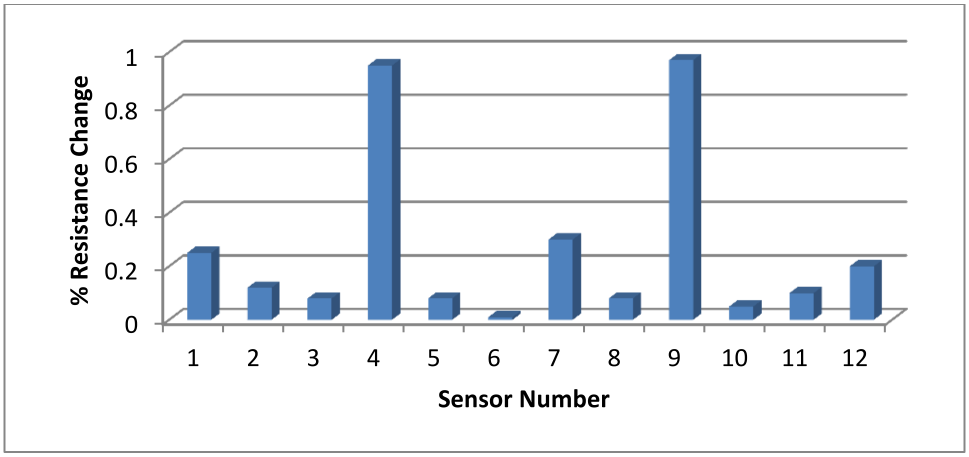

Figure 4.13 Signature pattern for Smell of Polybrominated Diphenyl Ethers

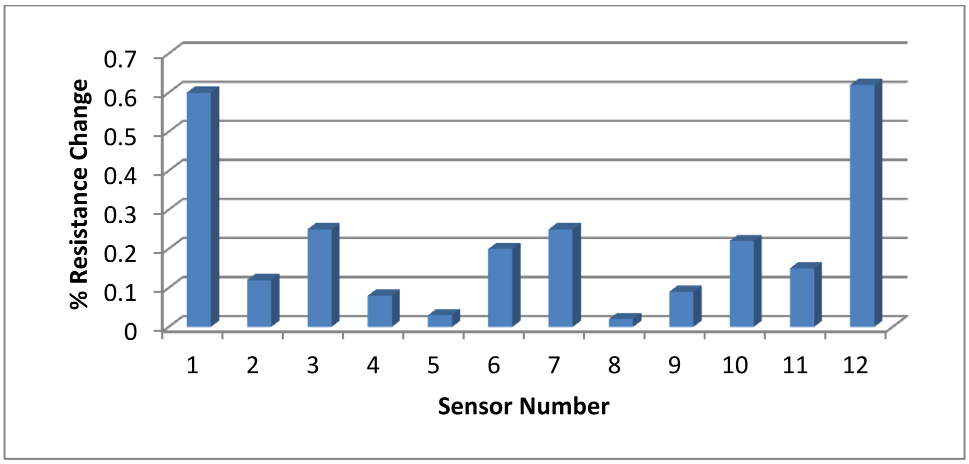

Figure 4.14 Signature pattern for Smell of Lead

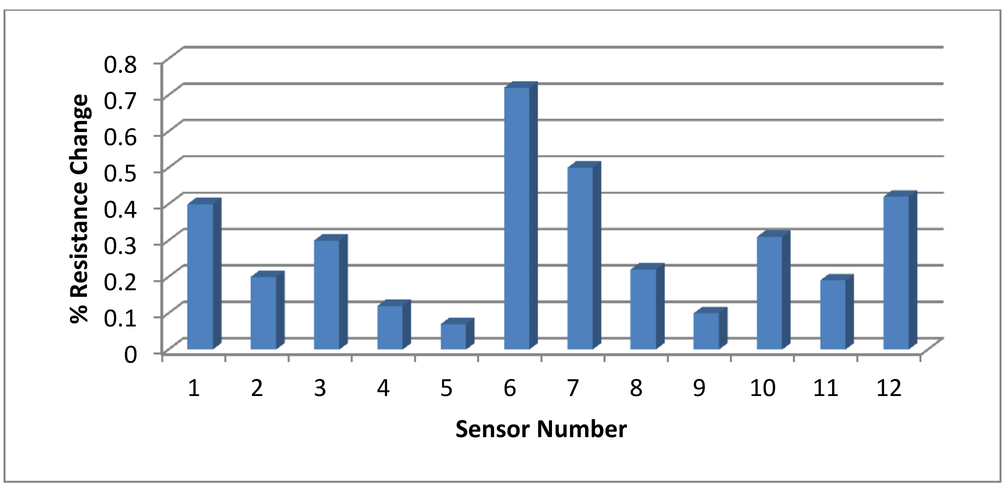

Figure 4.15 Signature pattern for Smell of Nitrogen Oxides (NOx)

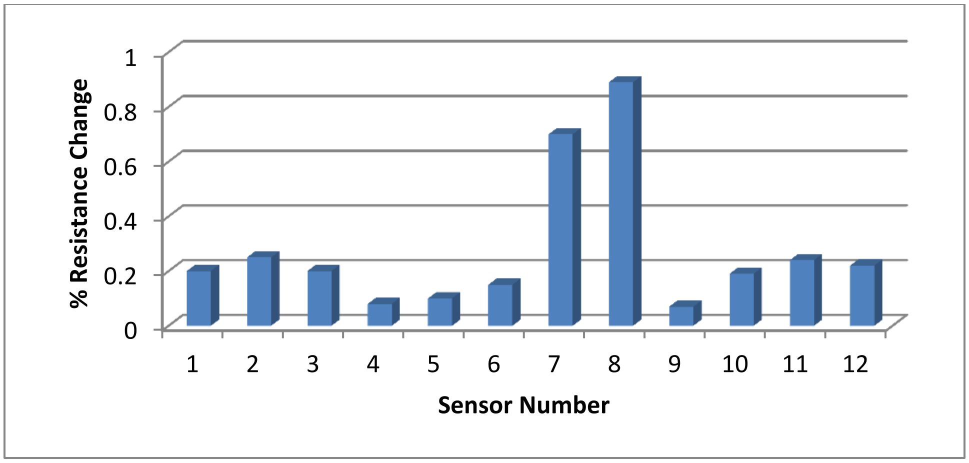

Figure 4.16 Signature pattern for Smell of Carbon Monoxide

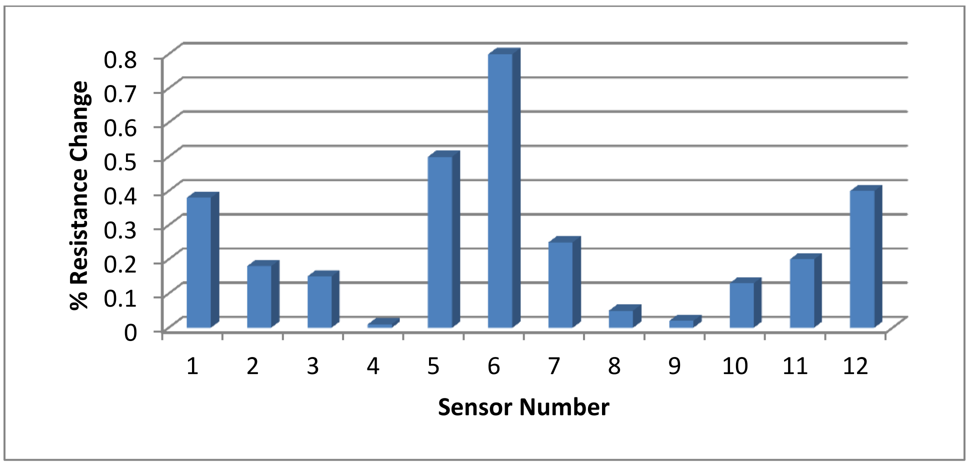

Figure 4.17 Signature pattern for Smell of Polychlorinated Biphenyls

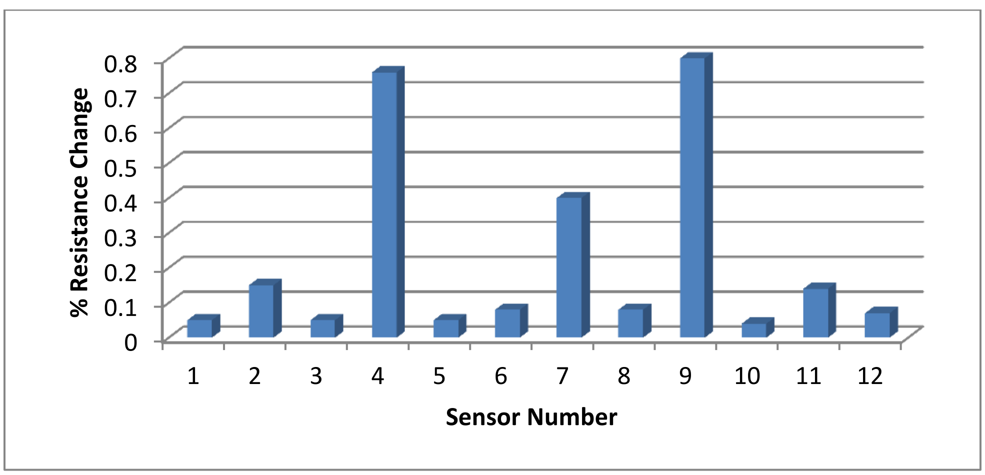

Figure 4.18 Signature pattern for Smell of DDT

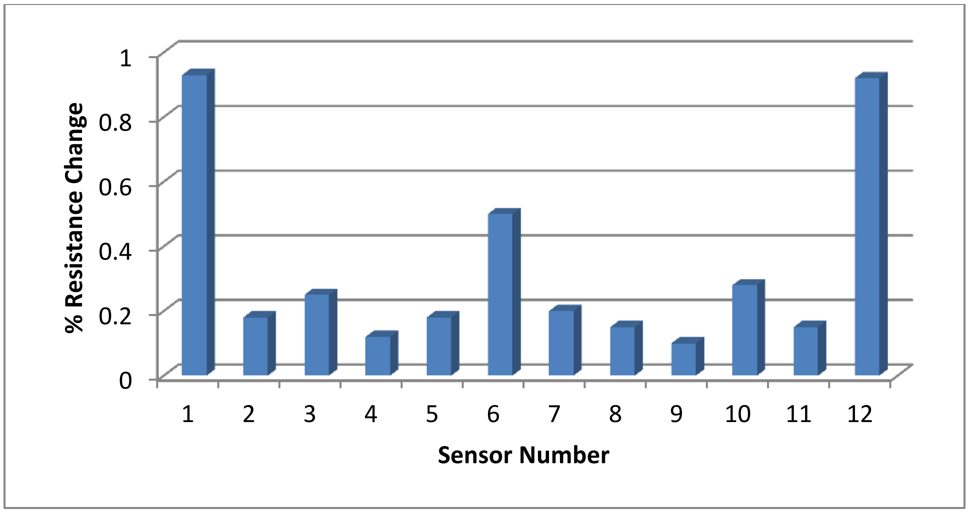

Figure 4.19 Signature pattern for Smell of Nonylphenol

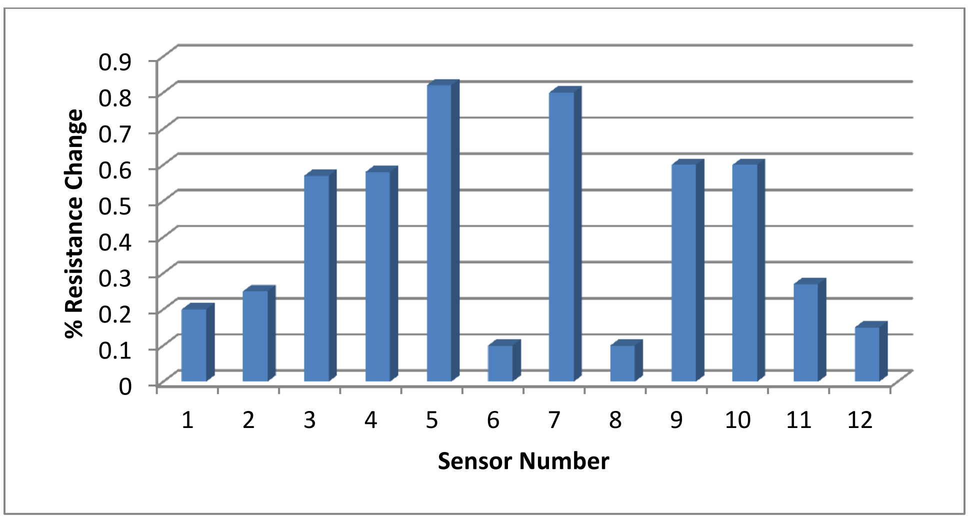

Figure 4.20 Signature pattern for Smell of Copper

4.1.3 RBFN Results

The above signature patterns or smell finger prints are applied in a radial basis function based neural network using MATLAB. For the training of the network the 2/3rd of the total database are used and 1/3rd of the total database used as testing data. On applying the testing data the results are obtained that are shown in Figure 4.21 to Figure 4.30. Figure 4.31 shows training of RBFN network for 10 chemical smells dataset.

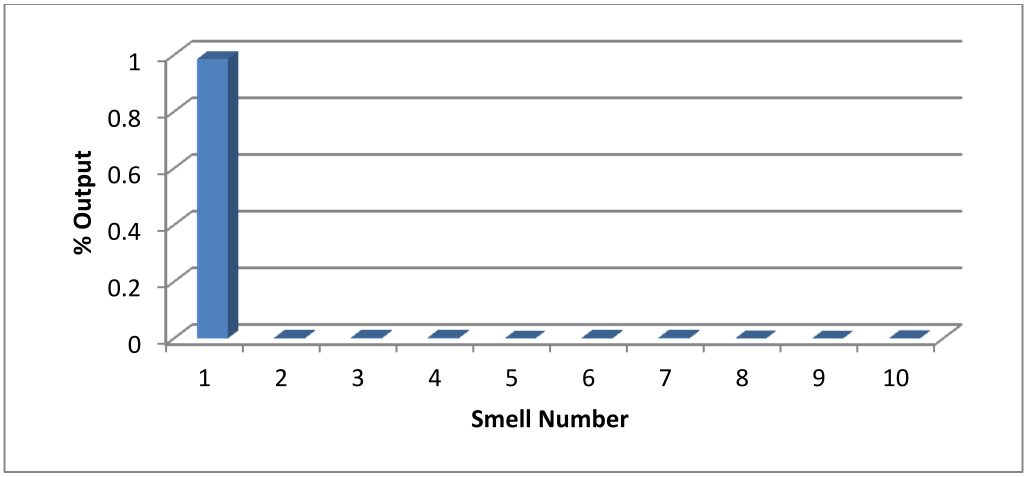

Figure 4.21 Output pattern for Smell No. 1 (Ammonia)

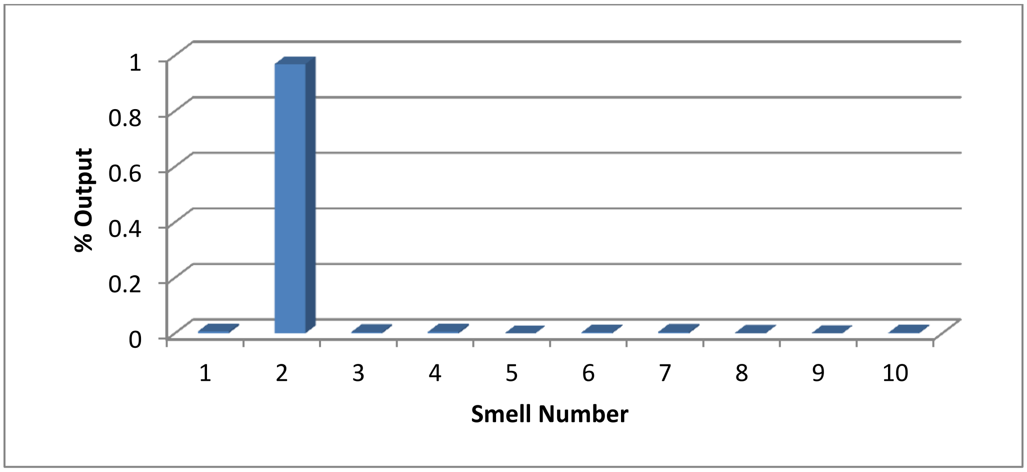

Figure 4.22 Output pattern for Smell No. 2 (Sulfur dioxide)

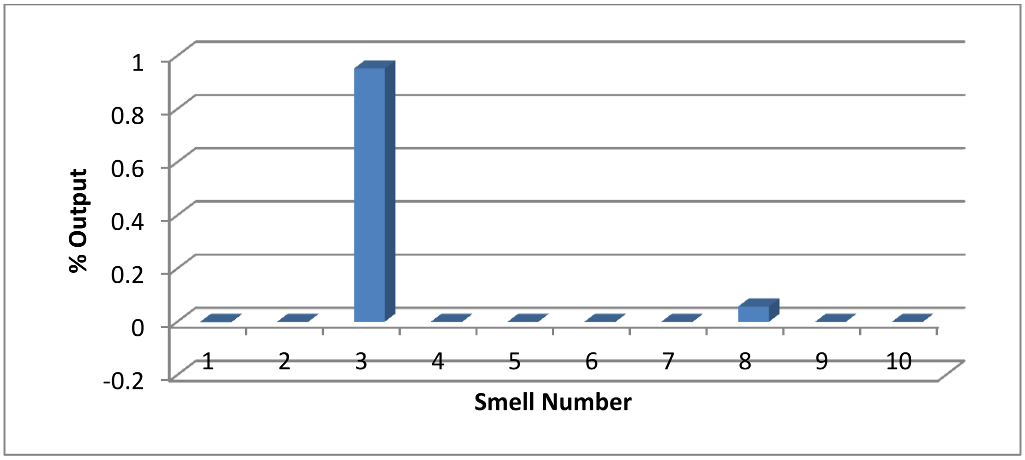

Figure 4.23 Output pattern for Smell No. 3 (Polybrominated Diphenyl Ethers)

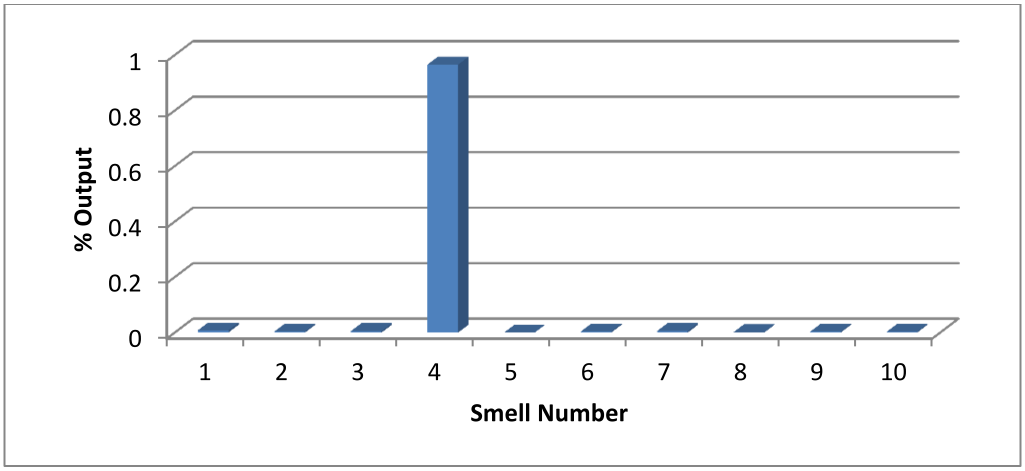

Figure 4.24 Output pattern for Smell No. 4 (Lead)

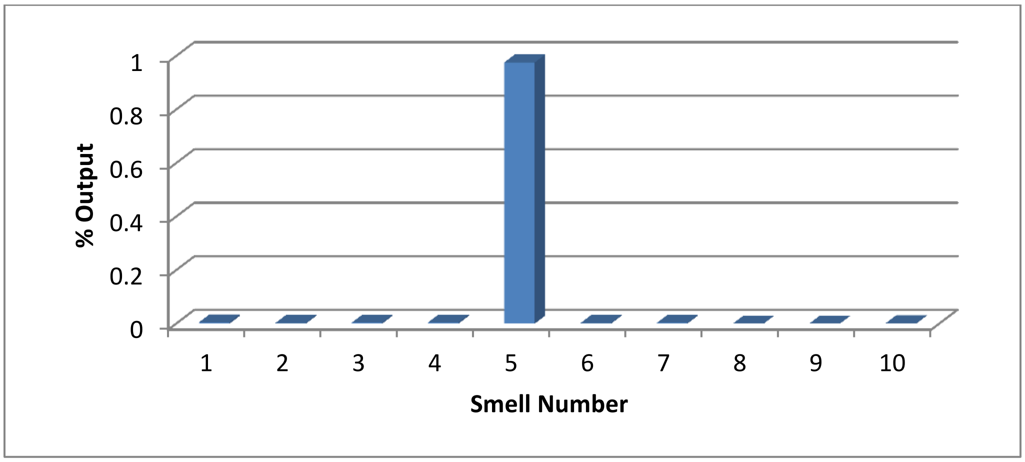

Figure 4.25 Output pattern for Smell No. 5 (Nitrogen Oxides)

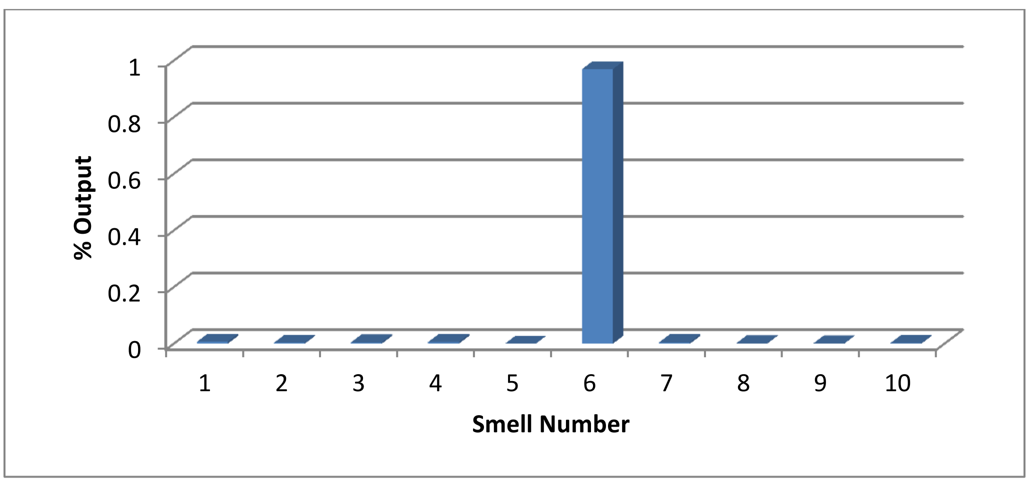

Figure 4.26 Output pattern for Smell No. 6 (Carbon Monoxide)

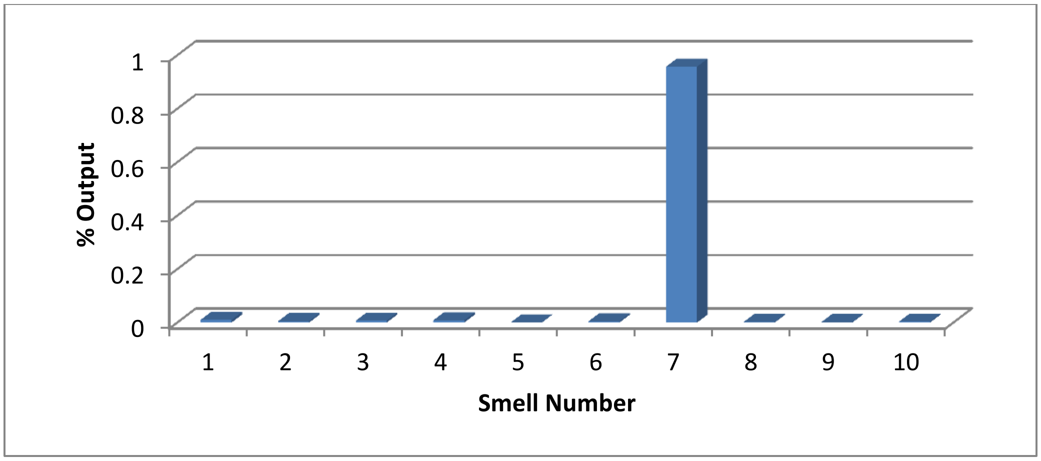

Figure 4.27 Output pattern for Smell No. 7 (Polychlorinated Biphenyls)

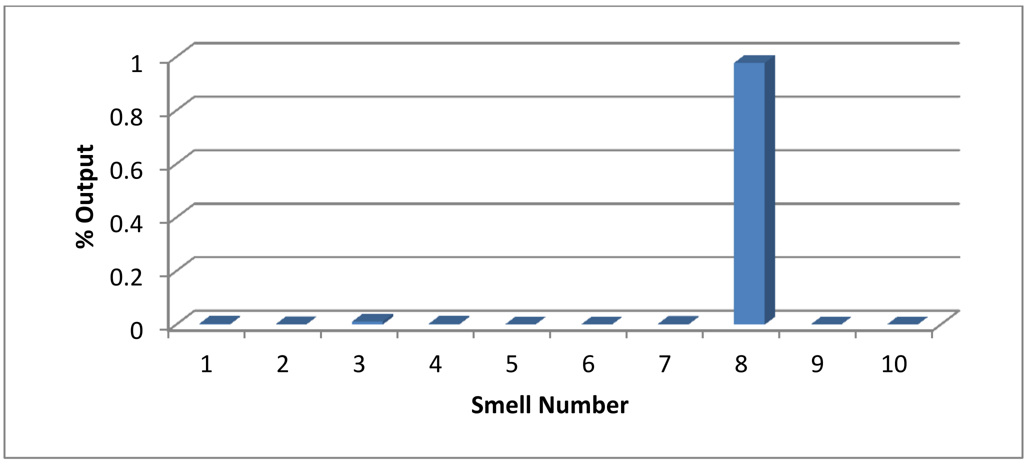

Figure 4.28 Output pattern for Smell No. 8 (DDT)

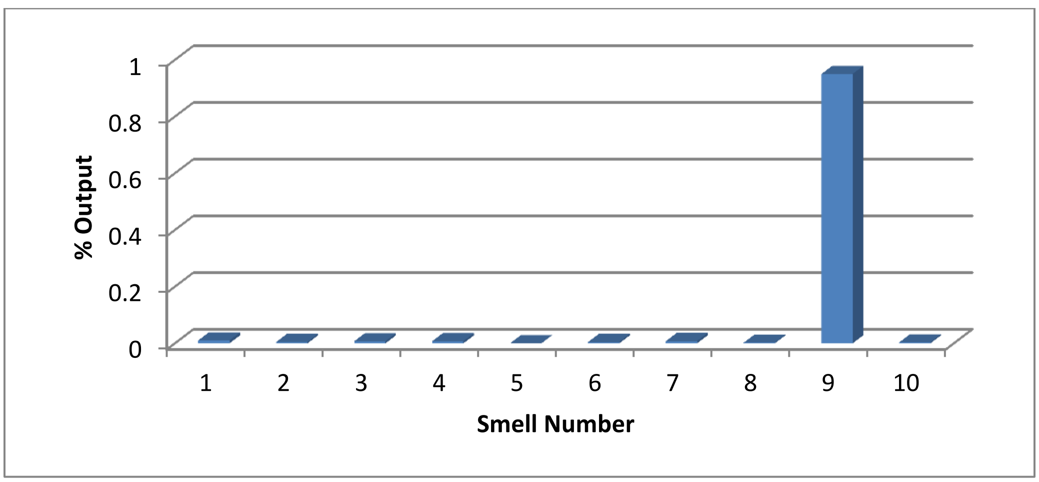

Figure 4.29 Output pattern for Smell No. 9 (Nonylphenol)

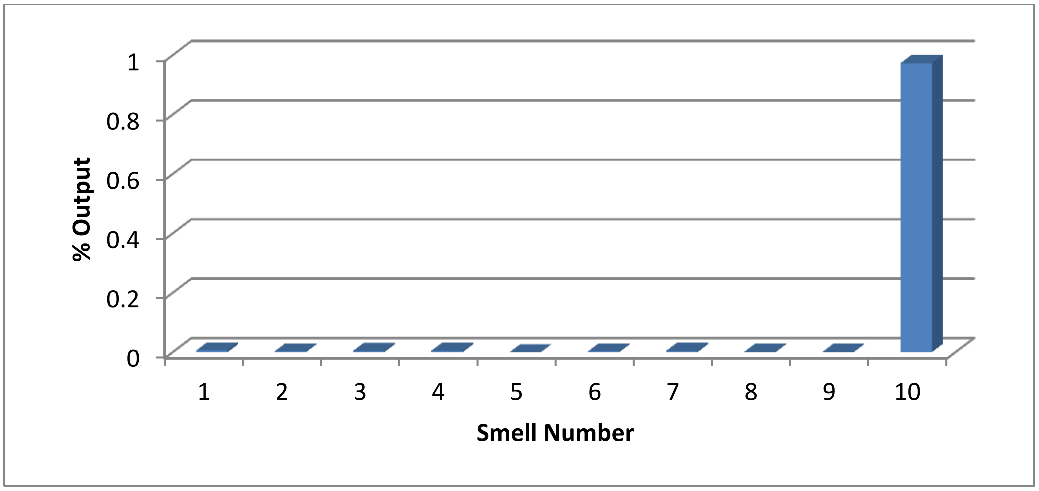

Figure 4.30 Output pattern for Smell No. 10 (Copper)

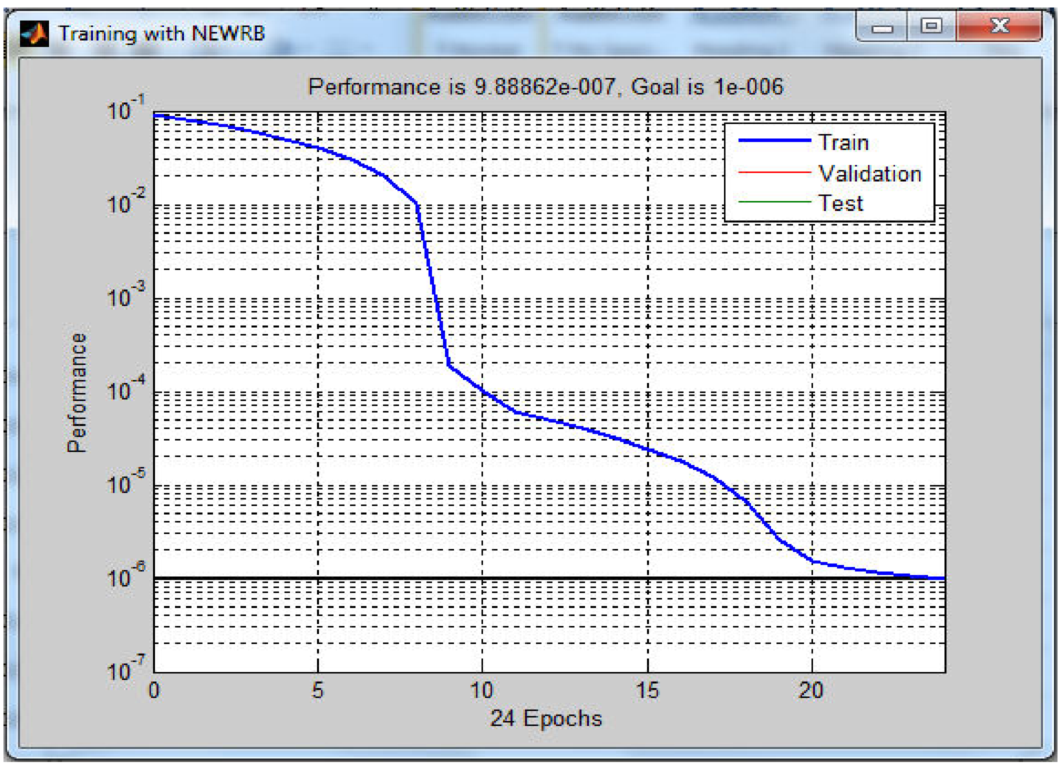

Figure 4.31 Training of RBFN for the ten toxic chemical smells

4.1.4 Output Results from ANFIS

The same database of the 10 toxic chemical smells is applied to the ANFIS network. For the training of the network the 2/3rd of the total database are used and

1/3rd of the total database used as testing data. On applying the testing data for all ten smells, expected results obtained with some errors that are combined together and shown in the following figure 4.32 and figure 4.33.

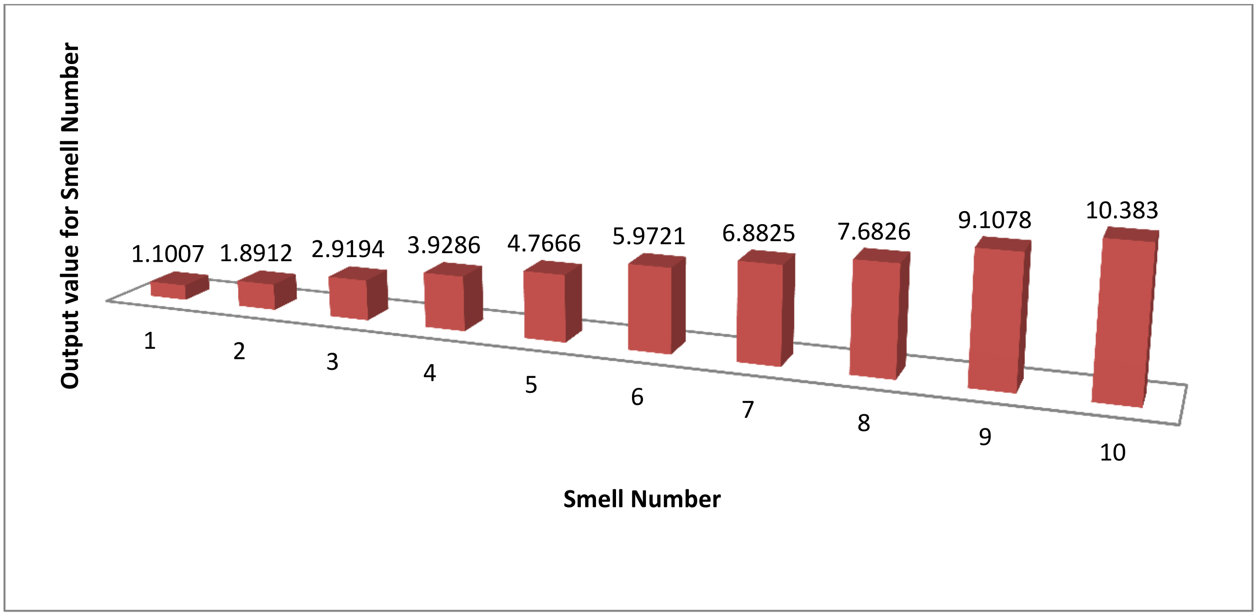

Figure 4.32 Output results from ANFIS for all 10 smells

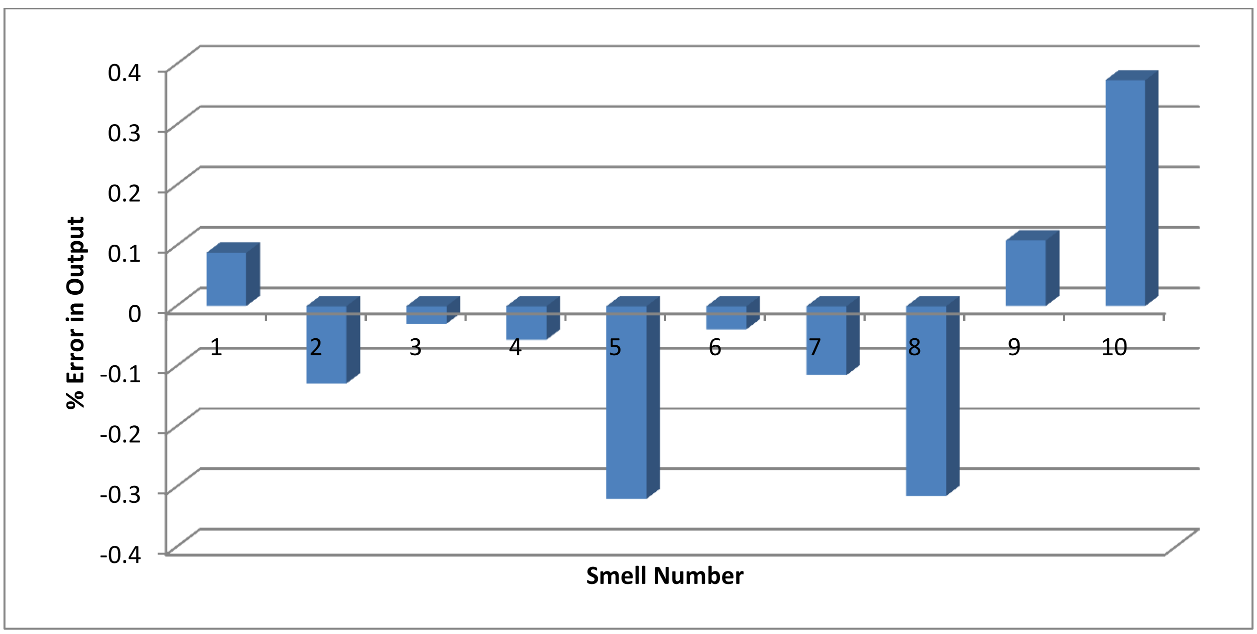

Figure 4.33 Percentage errors in outputs from ANFIS for all 10 smells

4.2 Simulation Results for 14 House Hold Items:-

For household items monitoring 14 different household items have taken and smell of each chemical is applied to the sensor array of 12 sensors consist of eight different TGS800 series sensors having two TGS830, two TGS822, two TGS821, two TGS842, one TGS825, one TGS813, one TGS880, one TGS 826. For recording the signals each sensor is interfaced with NI11.0 LABVIEW software. Due to each smell, resistance change occurred in each sensor of the array that have noted down and have modeled each signal by using Lorentzian model [107].

4.2.1 Lorentzian Model Responses:-

Responses of the sensor array for each chemical smell are given in the figures from Figure 4.34 to Figure 4.47. Here decaying part is also modeled.

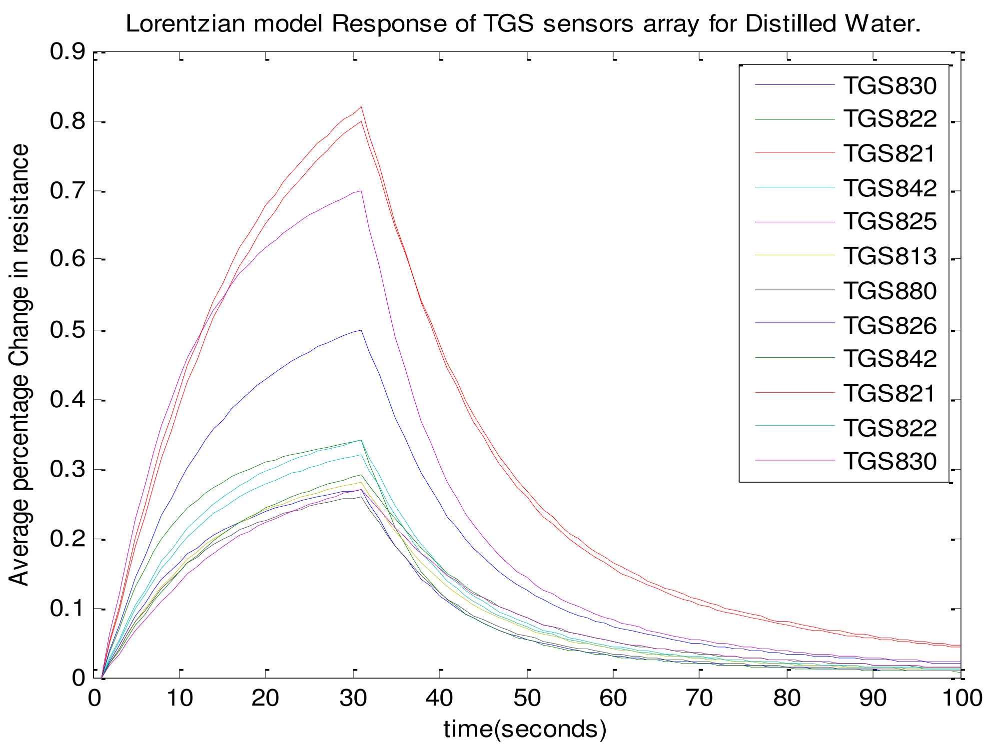

Figure 4.34 Response of Different Sensors in the array for Smell of Distilled Water

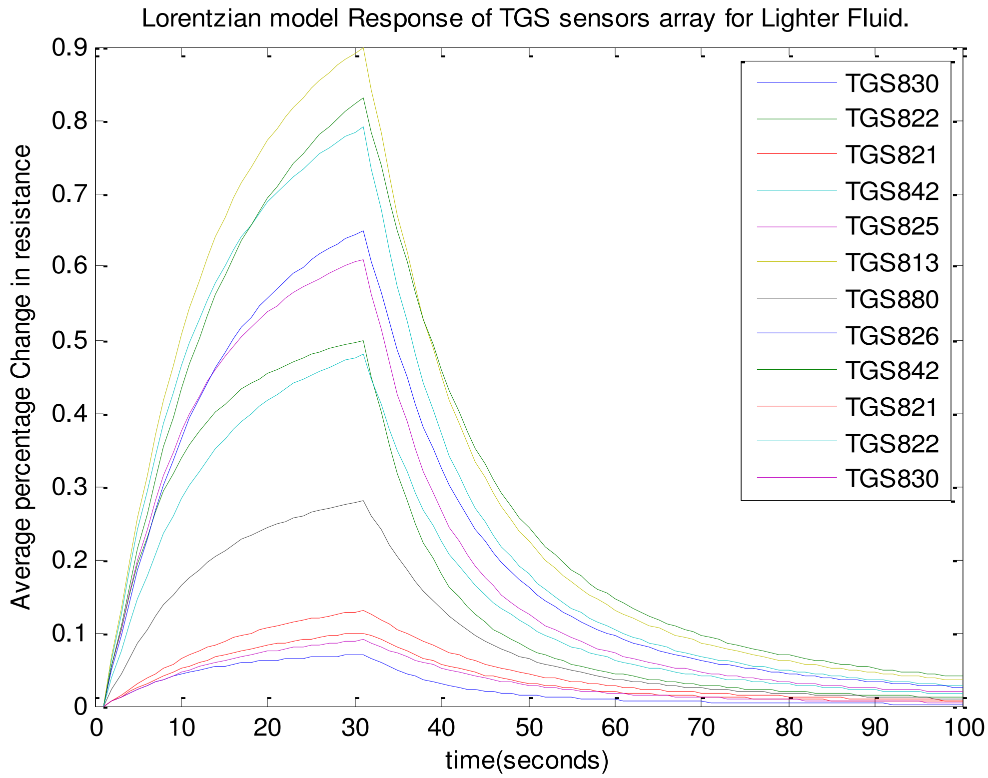

Figure 4.35 Response of Different Sensors in the array for Smell of Lighter Fluid

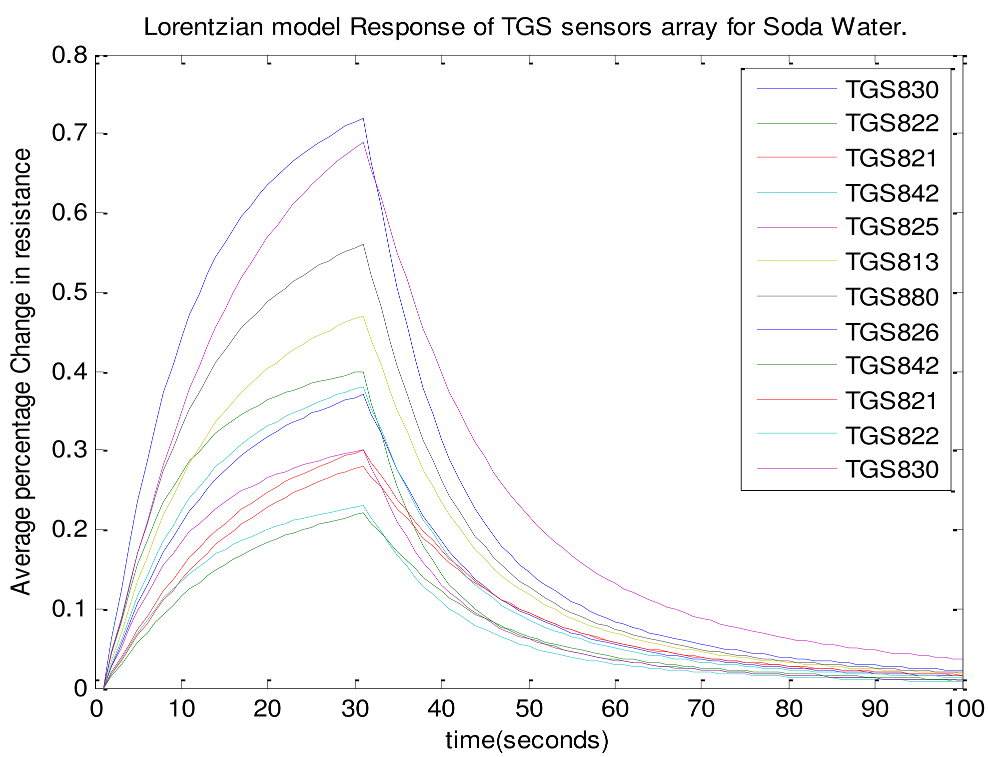

Figure 4.36 Response of Different Sensors in the array for Smell of Soda Water

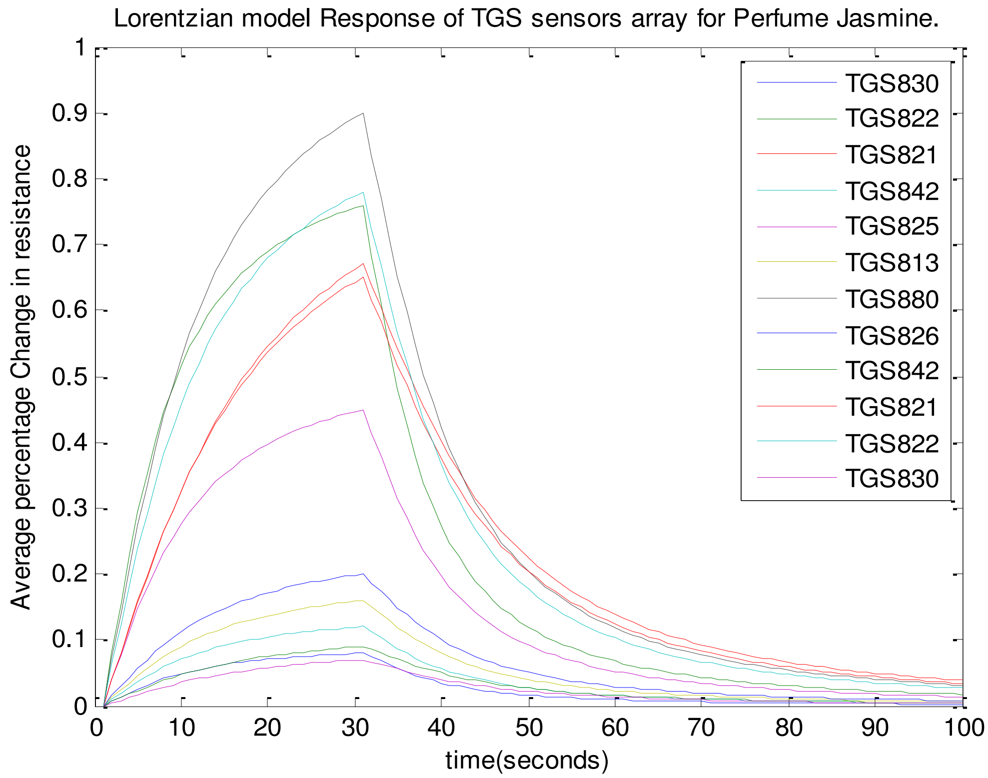

Figure 4.37 Response of Different Sensors in the array for Smell of Perfume Jasmine

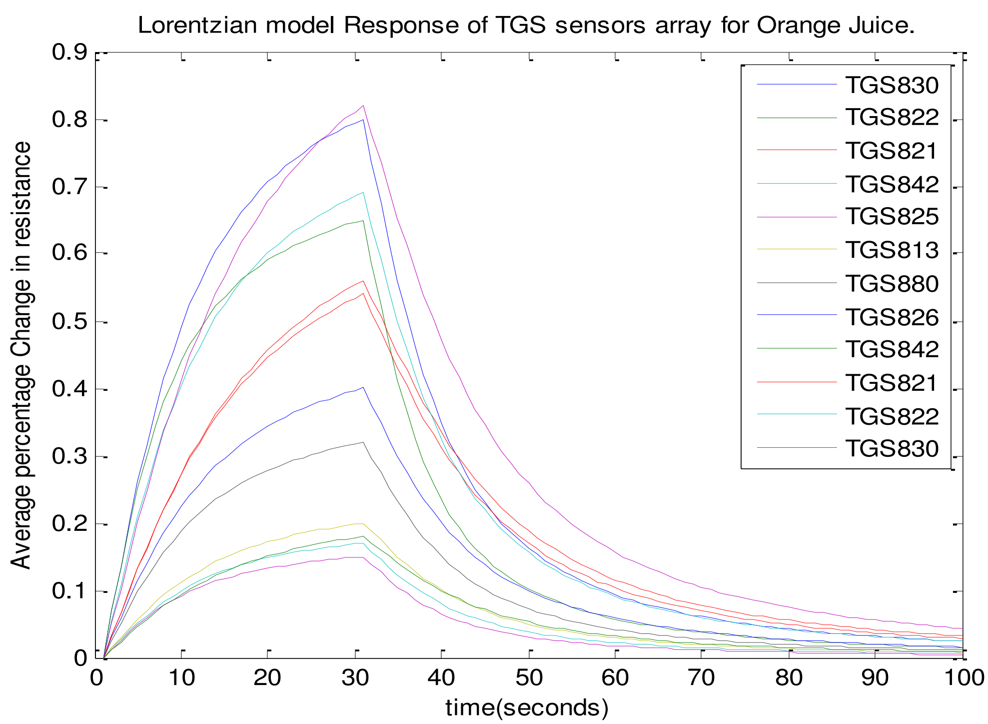

Figure 4.38 Response of Different Sensors in the array for Smell of Fruit Juice Orange

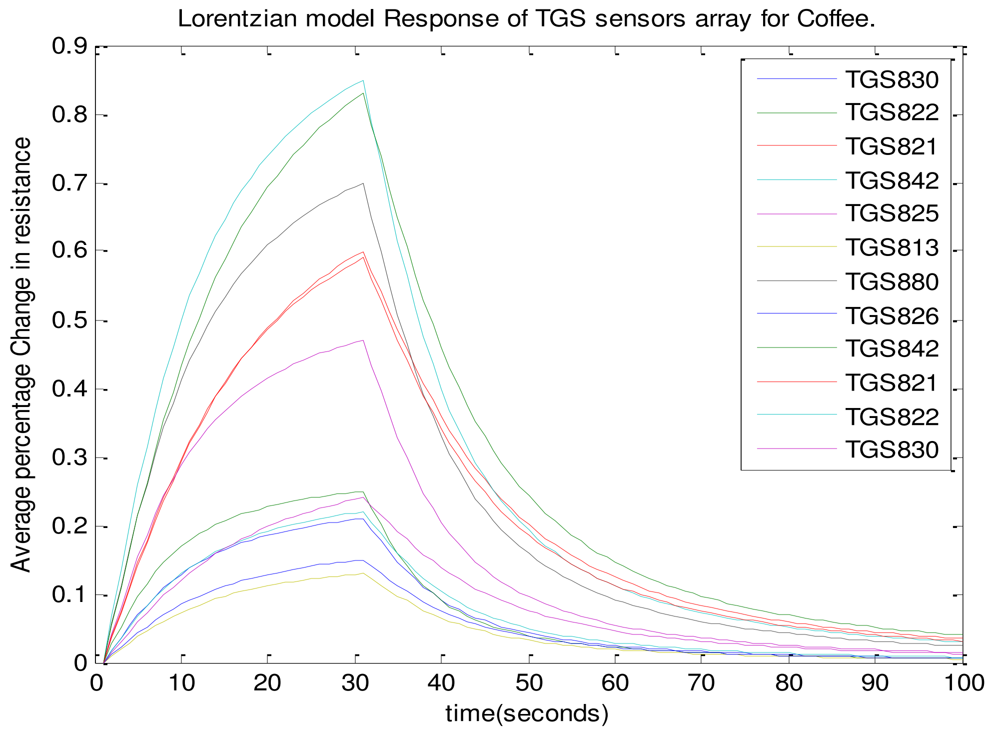

Figure 4.39 Response of Different Sensors in the array for Smell of Coffee

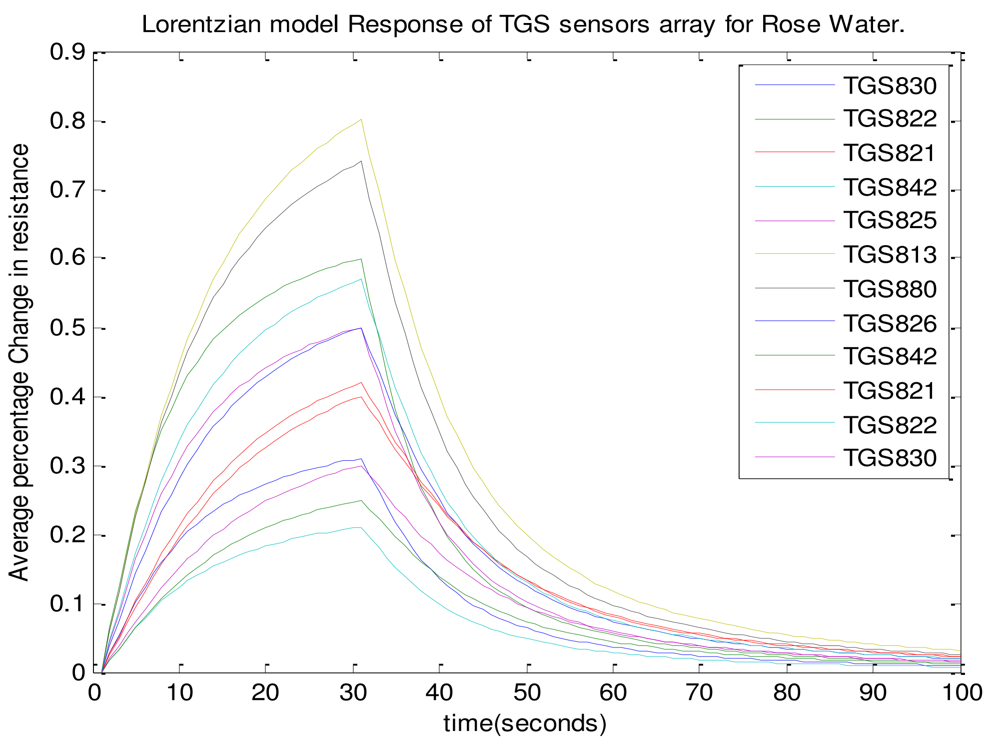

Figure 4.40 Response of Different Sensors in the array for Smell of Rose Water

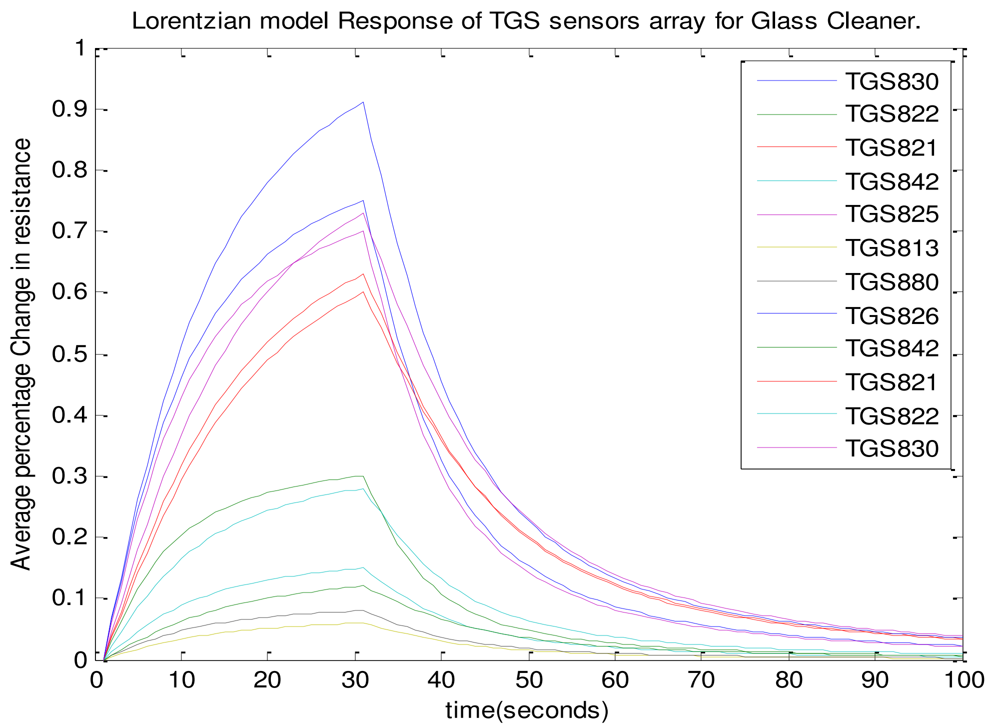

Figure 4.41 Response of Different Sensors in the array for Smell of Glass Cleaner

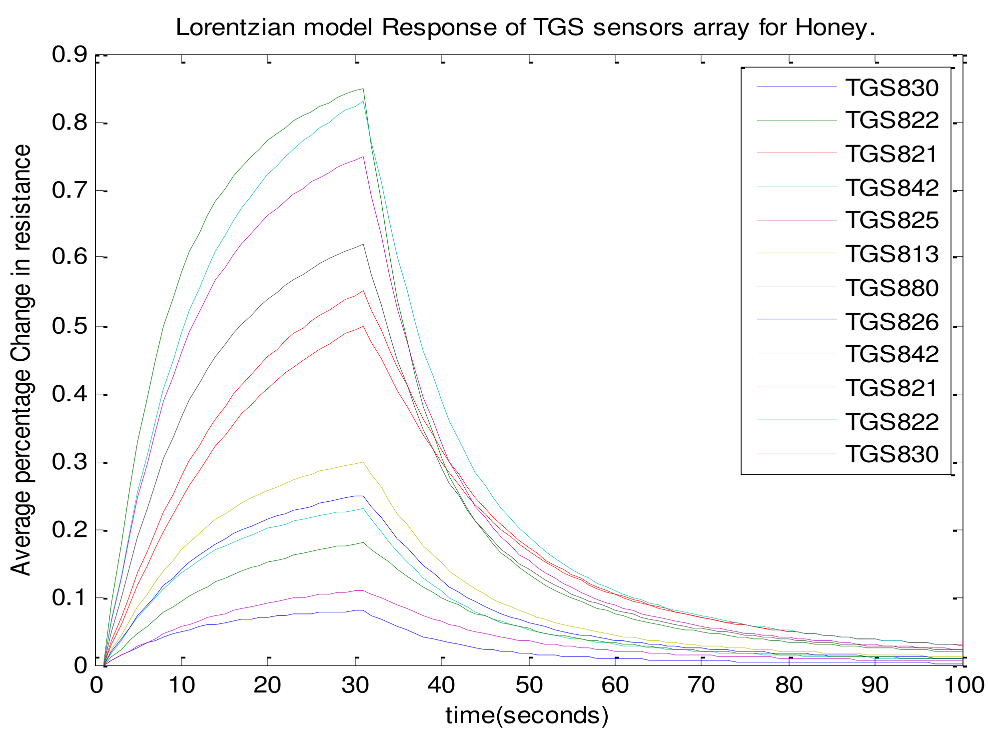

Figure 4.42 Response of Different Sensors in the array for Smell of Honey

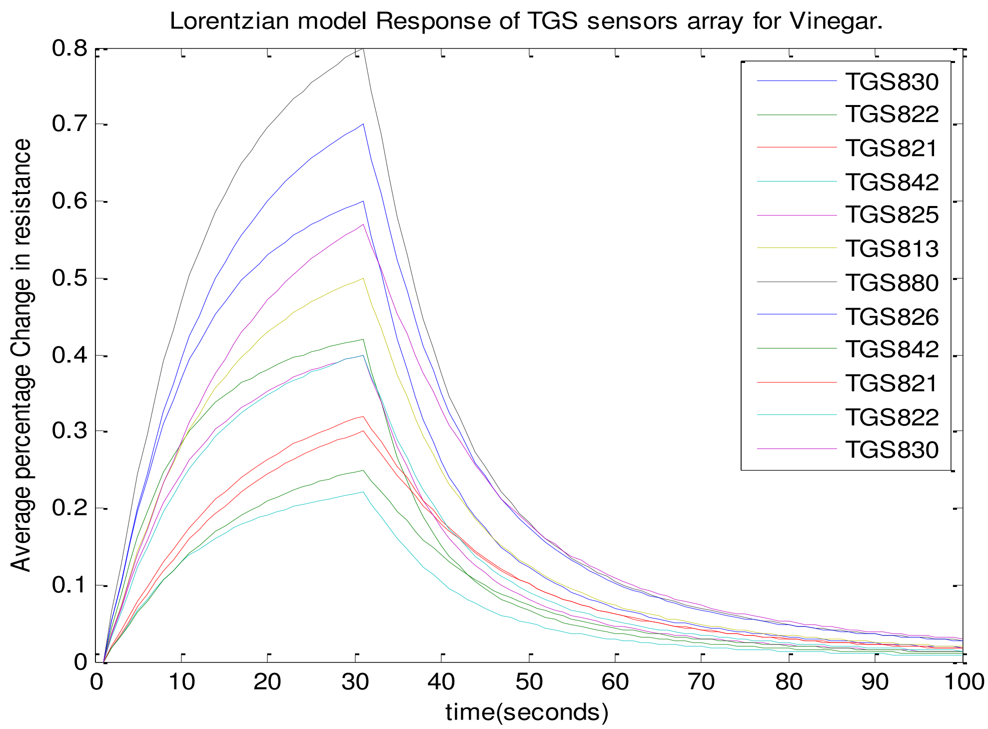

Figure 4.43 Response of Different Sensors in the array for Smell of Vinegar

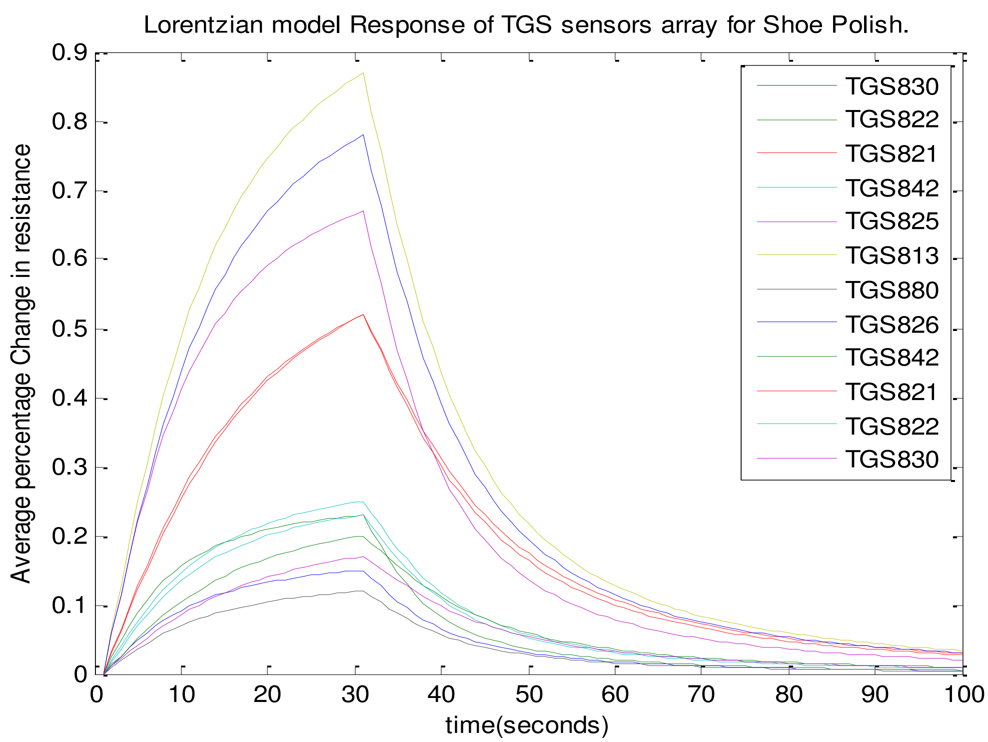

Figure 4.44 Response of Different Sensors in the array for Smell of Shoe Polish

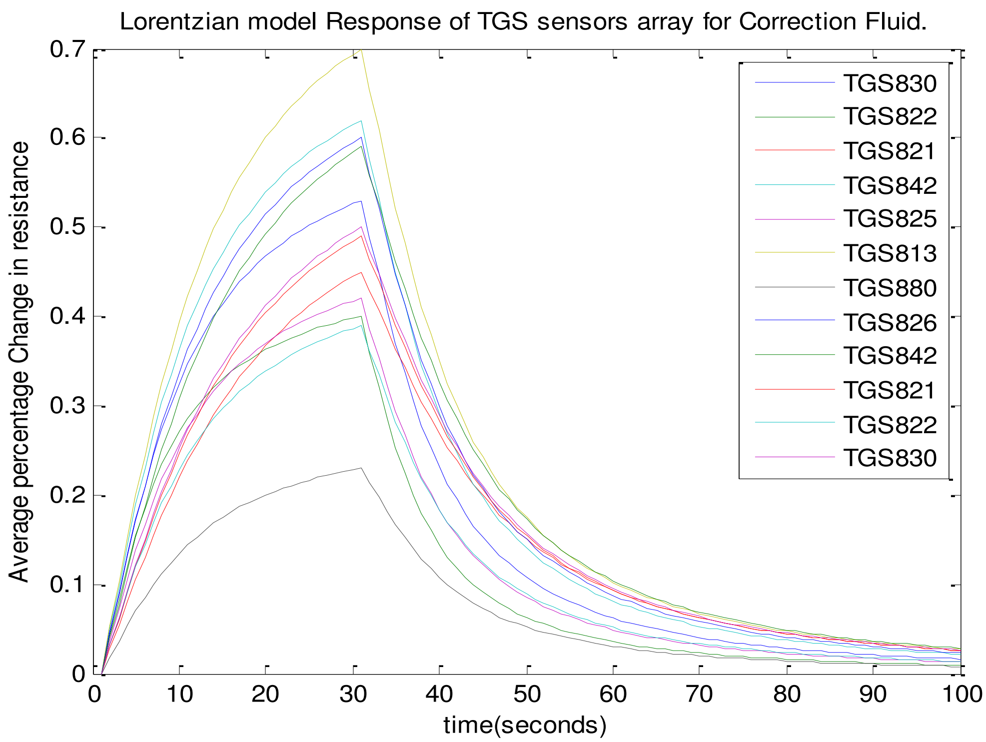

Figure 4.45 Response of Different Sensors in the array for Smell of Correction Fluid

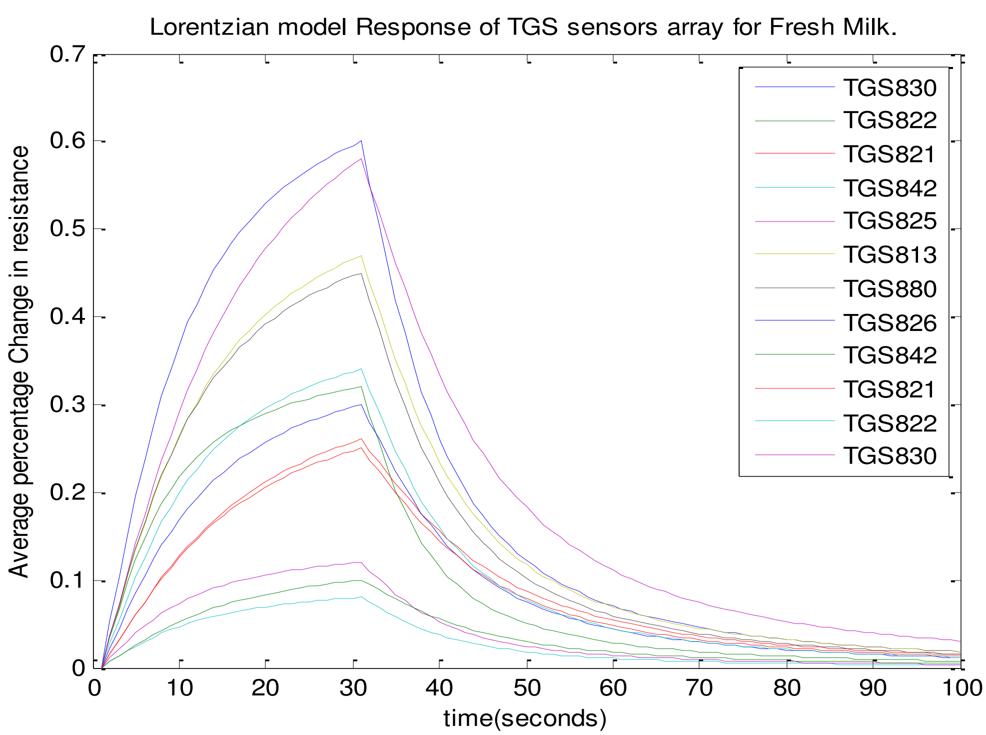

Figure 4.46 Response of Different Sensors in the array for Smell of Fresh Milk

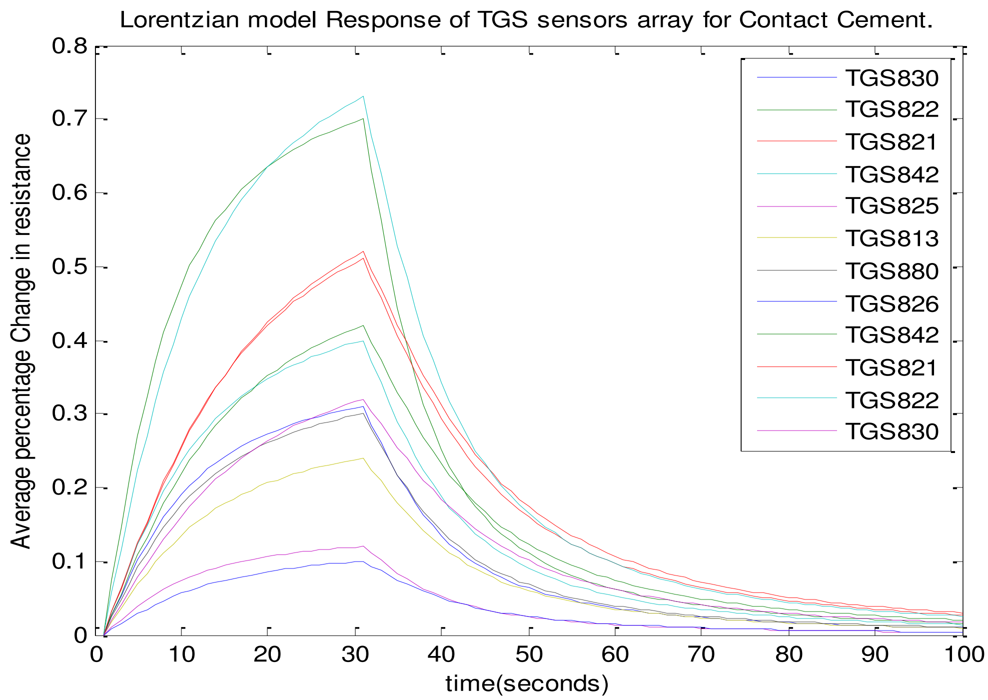

Figure 4.47 Response of Different Sensors in the array for Smell of Contact Cement

4.2.2 Smell Finger Prints:-

From the responses of sensor array modeled by Lorentzian Model, average percentage change in resistance of twelve different sensors of the array are taken and plotted the data using MS-excel as shown in Figure 4.48 to Figure 4.61, to see the pattern of the resistance change that is called signature pattern or finger prints. In the x-axis sensor number is taken and on y-axis percentage change in resistance is taken. In the array sensor no. 1 and 12 are TGS830, sensor no. 2 and 11 are TGS822, sensor no. 3 and 10 are TGS821, sensor no. 4 and 9 are TGS842, sensor no. 5 is TGS825, sensor no.6 is TGS813, sensor no. 7 is TGS880 and sensor no. 8 is TGS826.

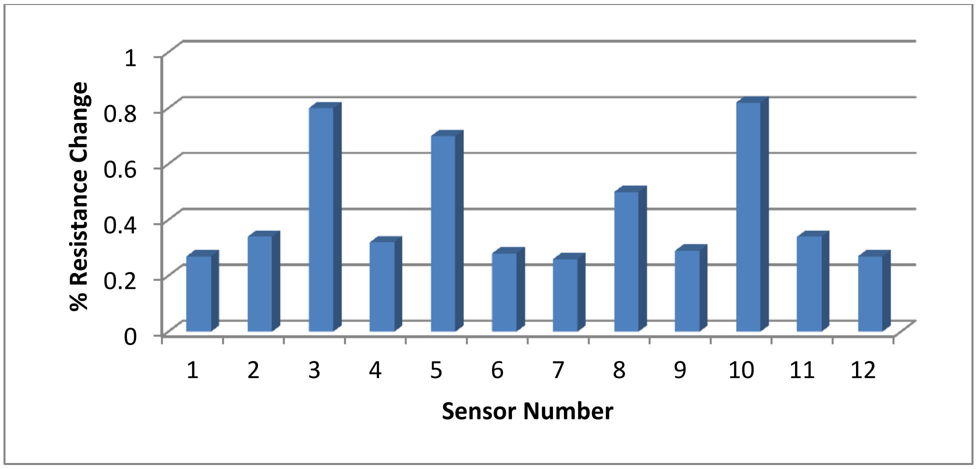

Figure 4.48 Signature pattern for Smell of Distilled Water

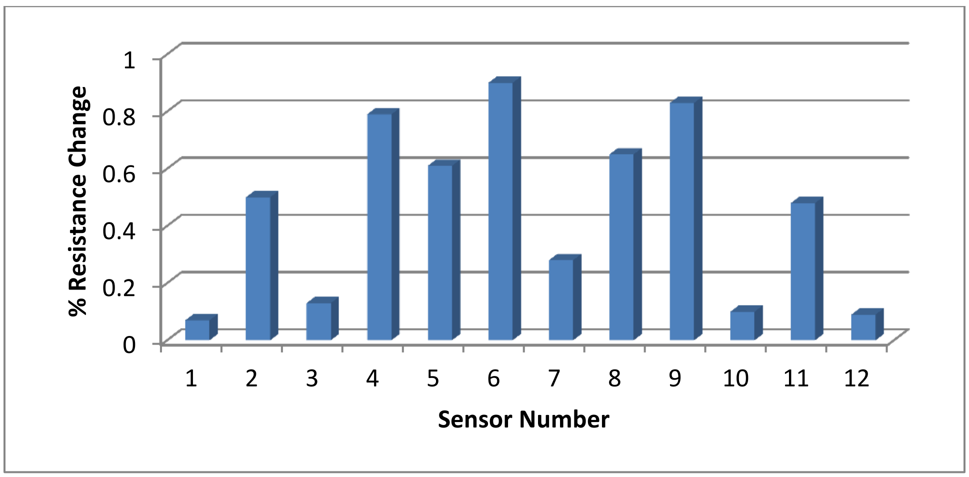

Figure 4.49 Signature pattern for Smell of Lighter Fluid

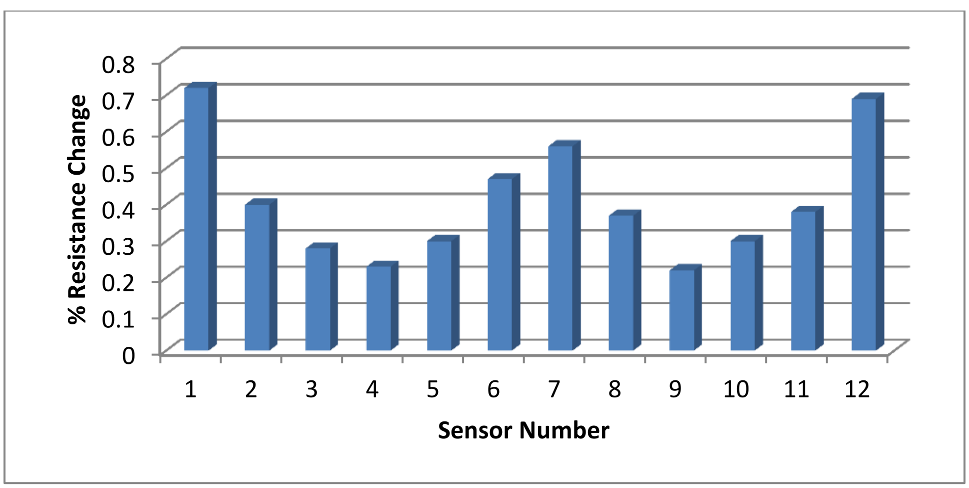

Figure 4.50 Signature pattern for Smell of Soda Water

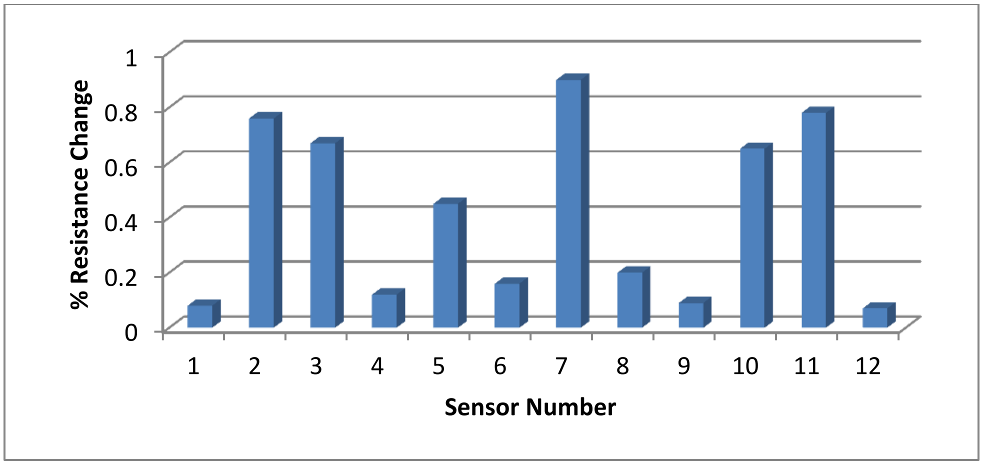

Figure 4.51 Signature pattern for Smell of Perfume Jasmine

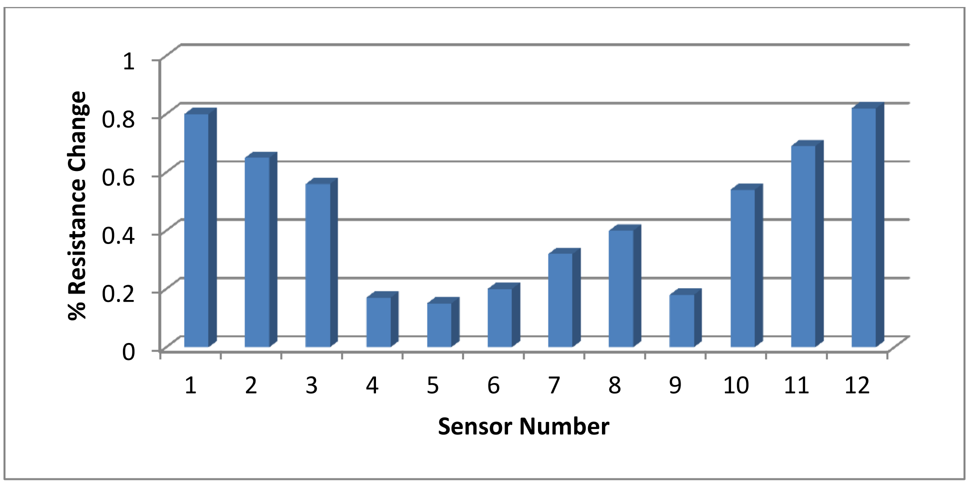

Figure 4.52 Signature pattern for Smell of Orange Juice

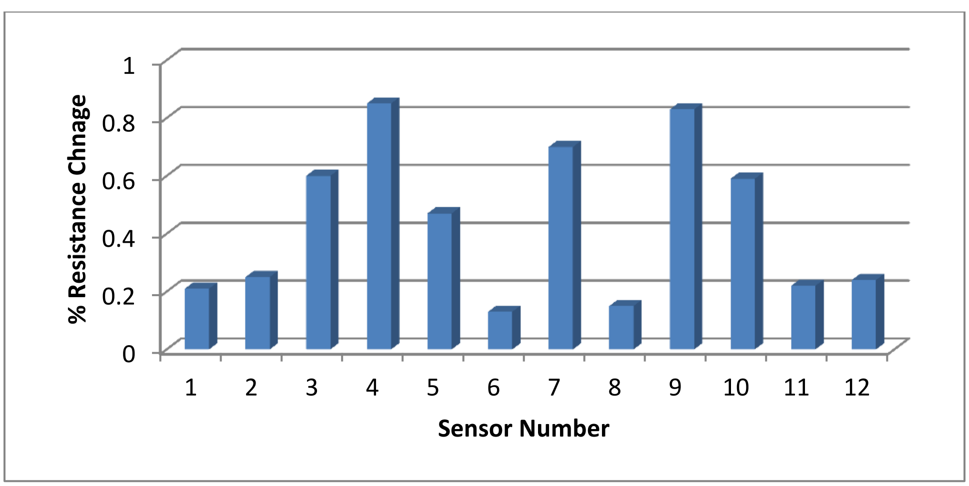

Figure 4.53 Signature pattern for Smell of Coffee

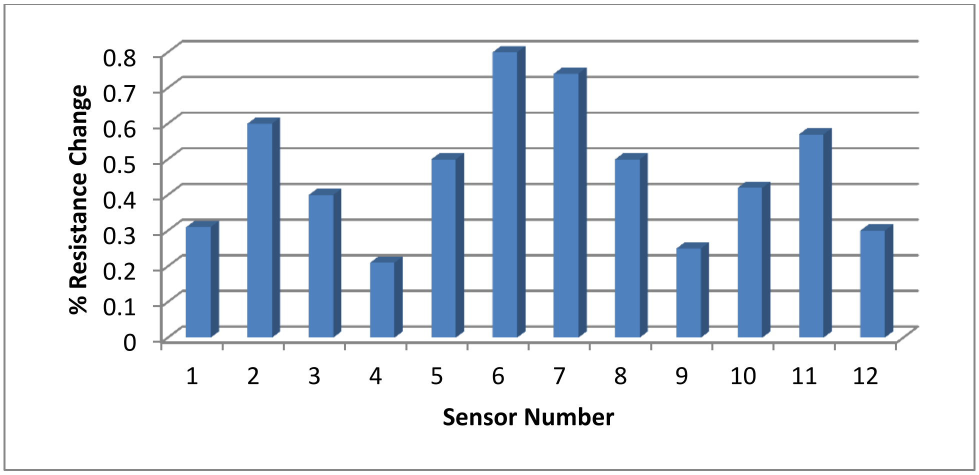

Figure 4.54 Signature pattern for Smell of Rose Water

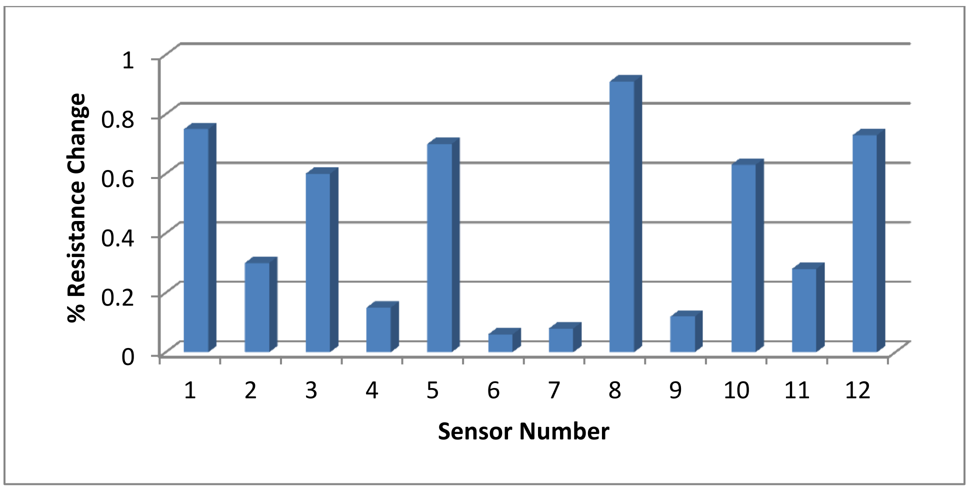

Figure 4.55 Signature pattern for Smell of Glass Cleaner

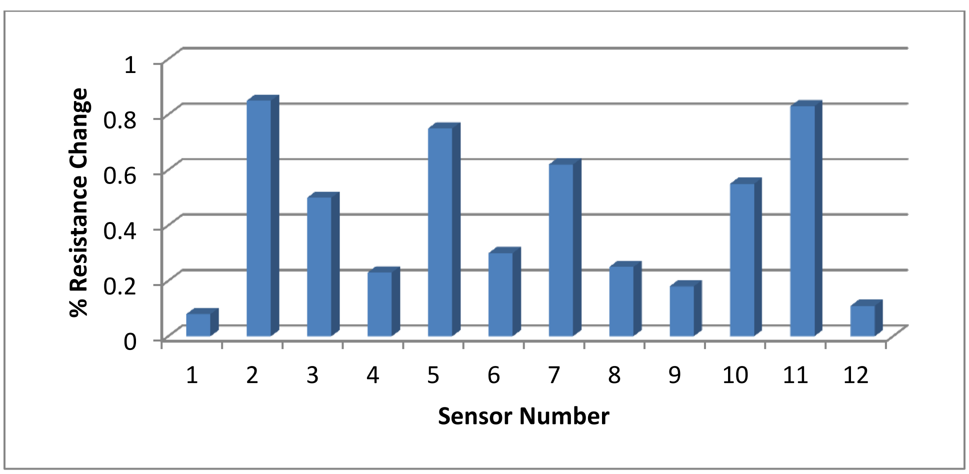

Figure 4.56 Signature pattern for Smell of Honey

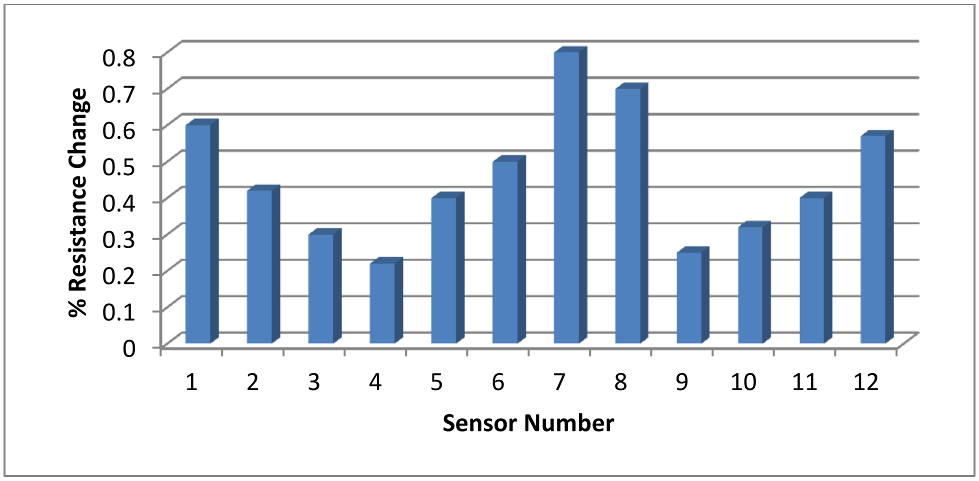

Figure 4.57 Signature pattern for Smell of Vinegar

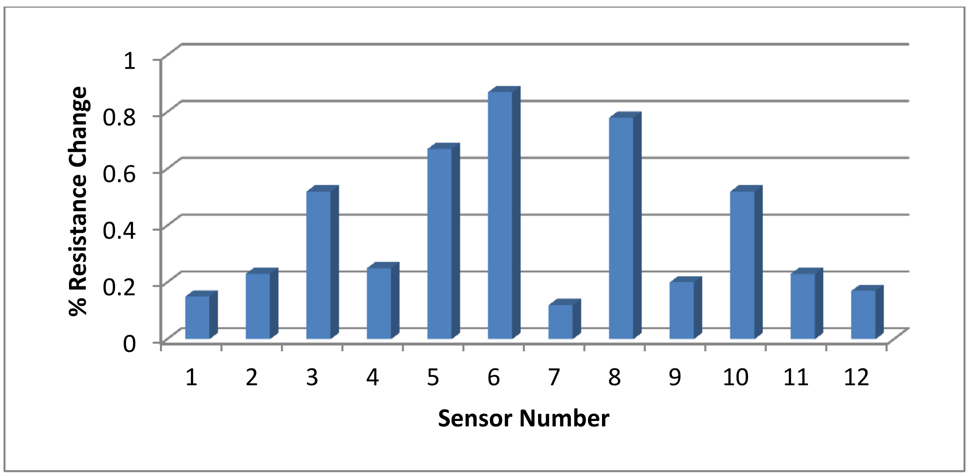

Figure 4.58 Signature pattern for Smell of Shoe Polish

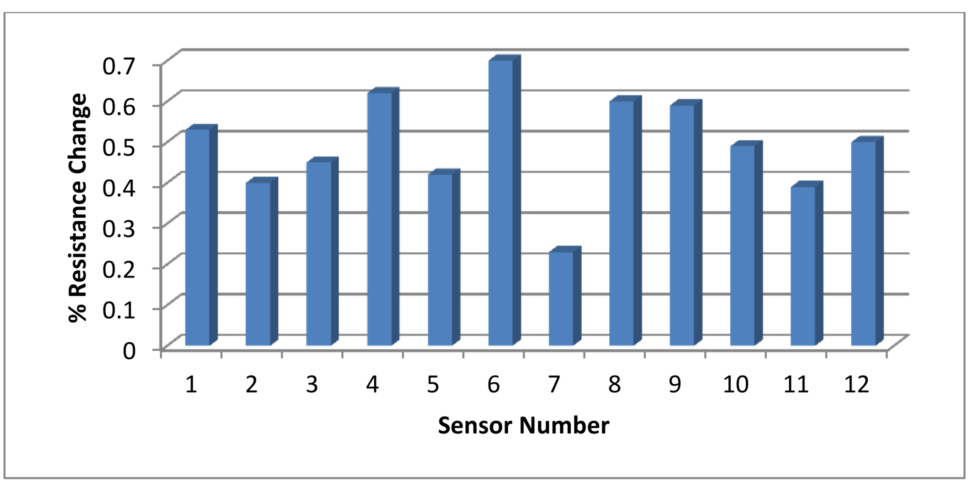

Figure 4.59 Signature pattern for Smell of Correction Fluid

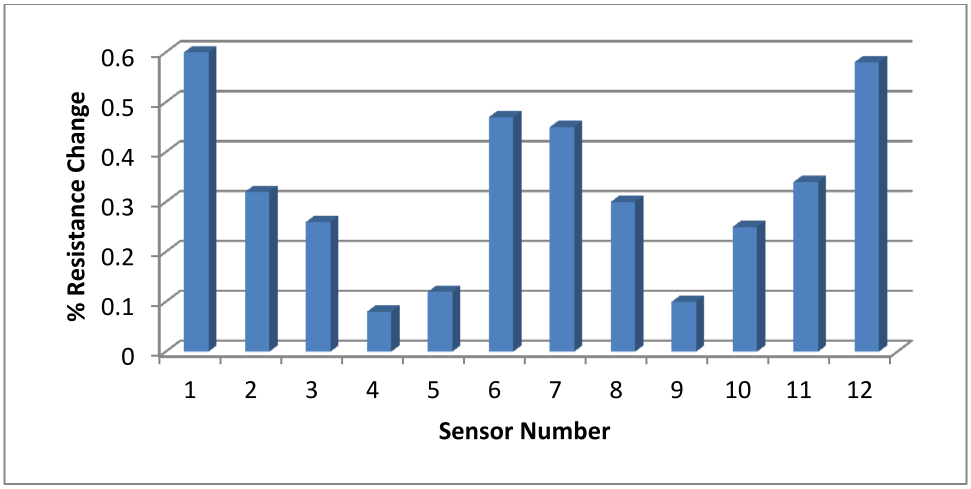

Figure 4.60 Signature pattern for Smell of Fresh Milk

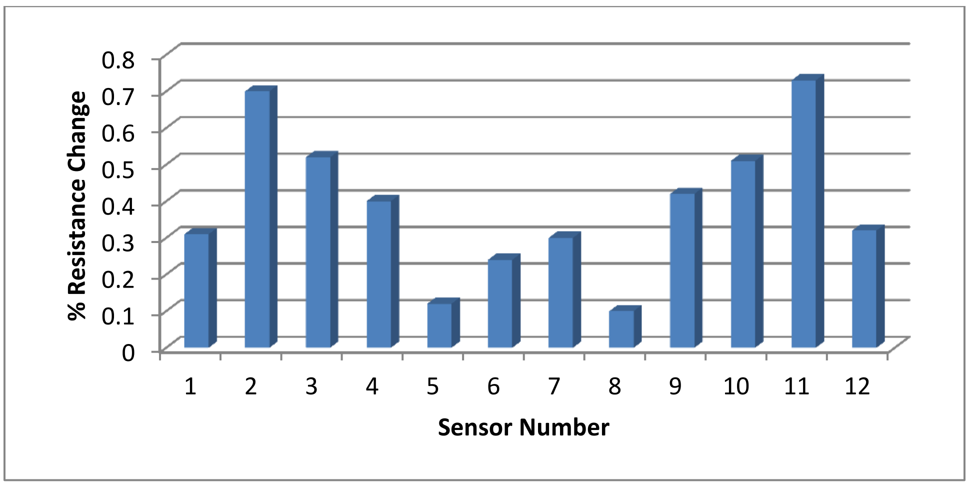

Figure 4.61 Signature pattern for Smell of Contact Cement

4.2.3 RBFN Results

The above signature patterns or smell finger prints are applied in a radial basis function based neural network using MATLAB. For the training of the network the 2/3rd of the total database are used and 1/3rd of the total database used as testing data. On applying the testing data the results are obtained that are shown in Figure 4.63 to Figure 4.76. Figure 4.62 shows training of RBFN network for 14 household items smell dataset.

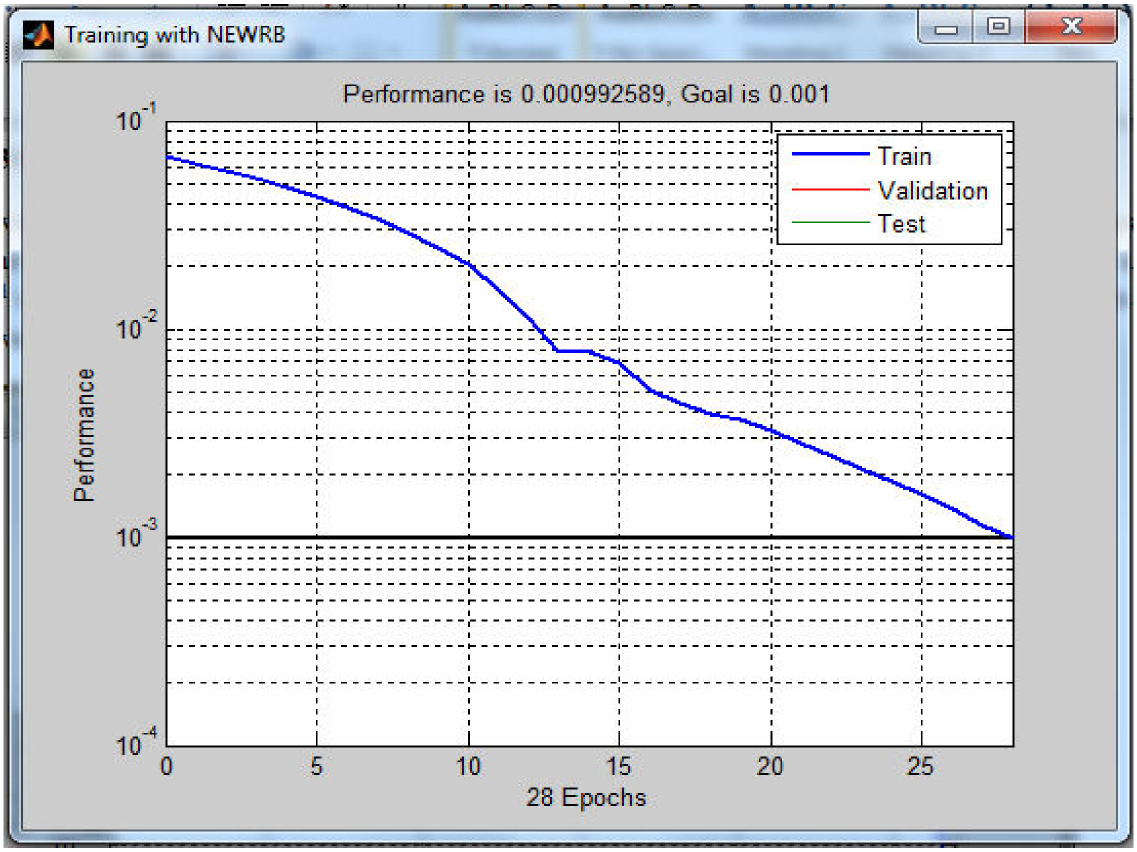

Figure 4.62 Training of RBFN for 14 household items smells

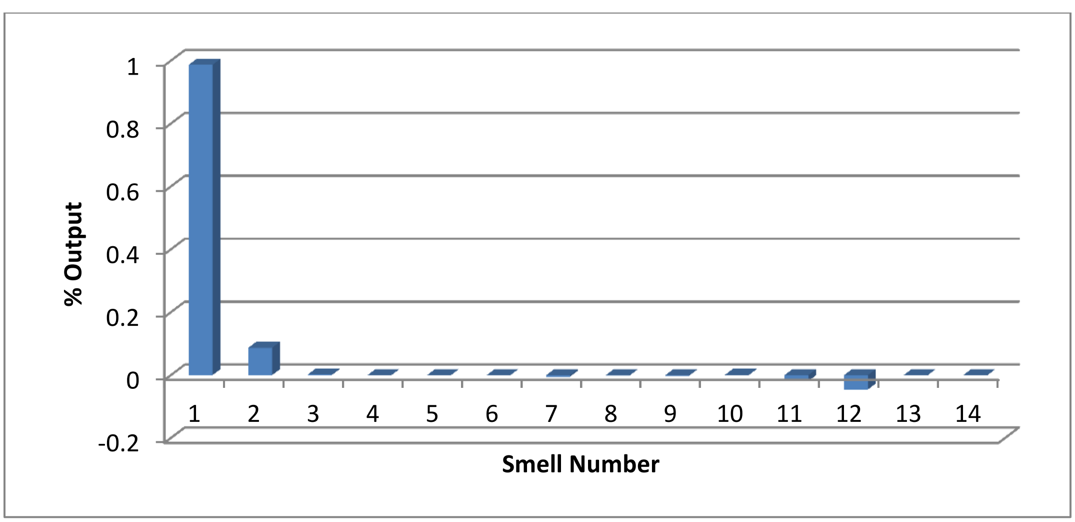

Figure 4.63 Output pattern for Smell No.1 (Distilled Water)

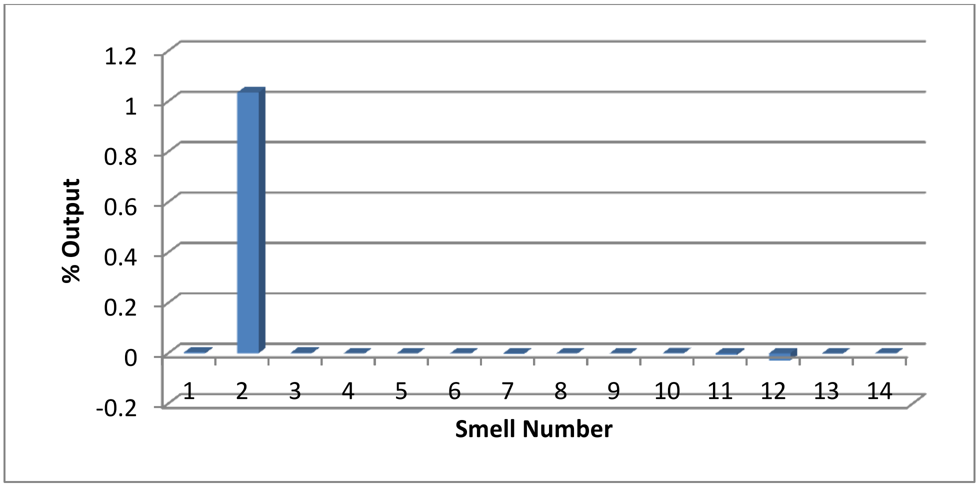

Figure 4.64 Output pattern for Smell No.2 (Lighter Fluid)

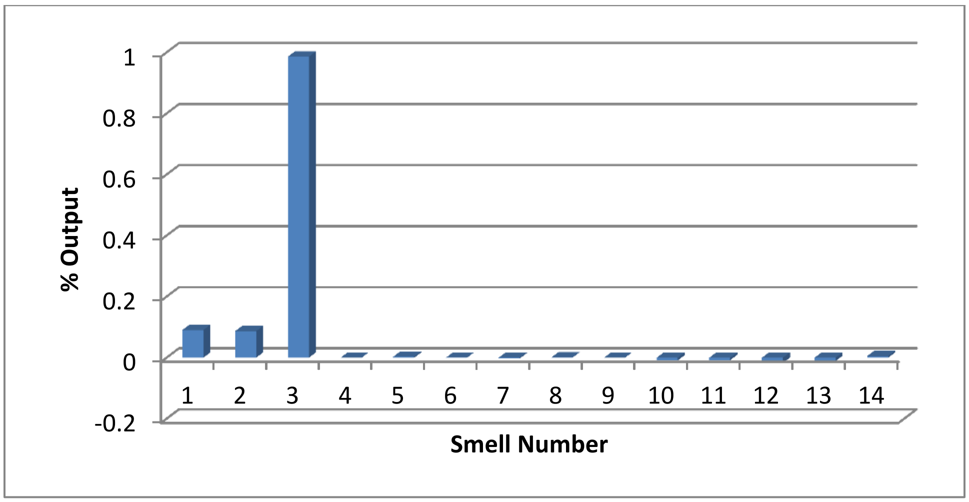

Figure 4.65 Output pattern for Smell No. 3 (Soda Water)

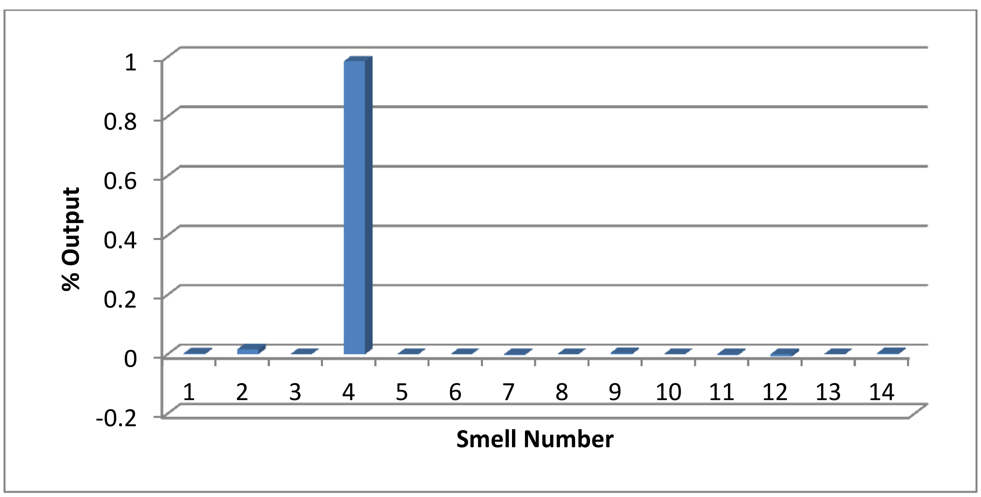

Figure 4.66 Output pattern for Smell No. 4 (Perfume Jasmine)

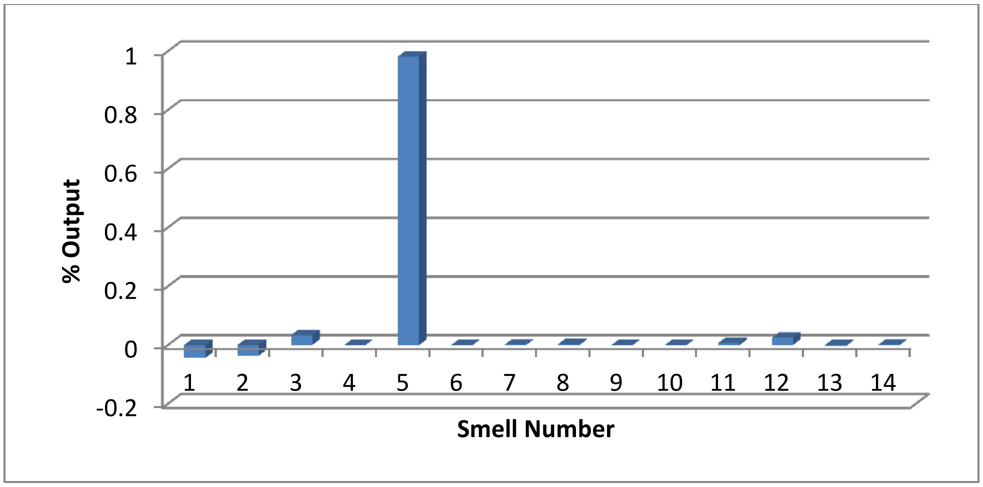

Figure 4.67 Output pattern for Smell No. 5 (Orange Juice)

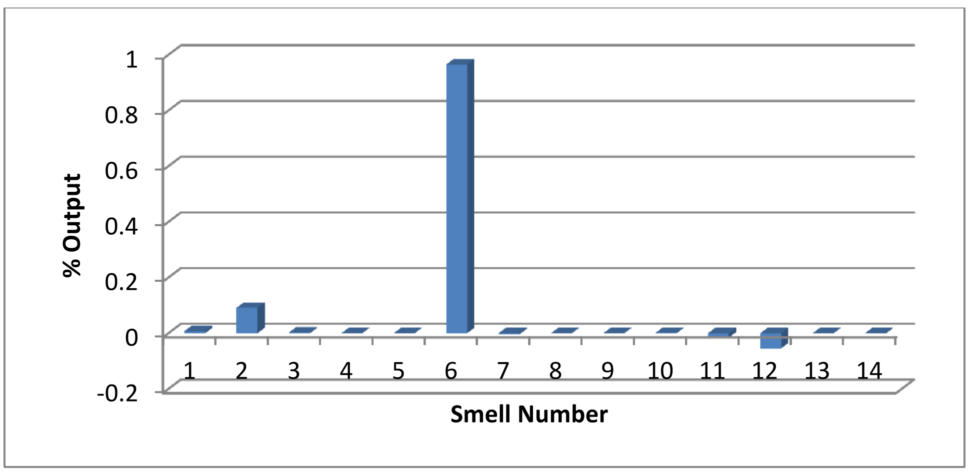

Figure 4.68 Output pattern for Smell No. 6 (Coffee)

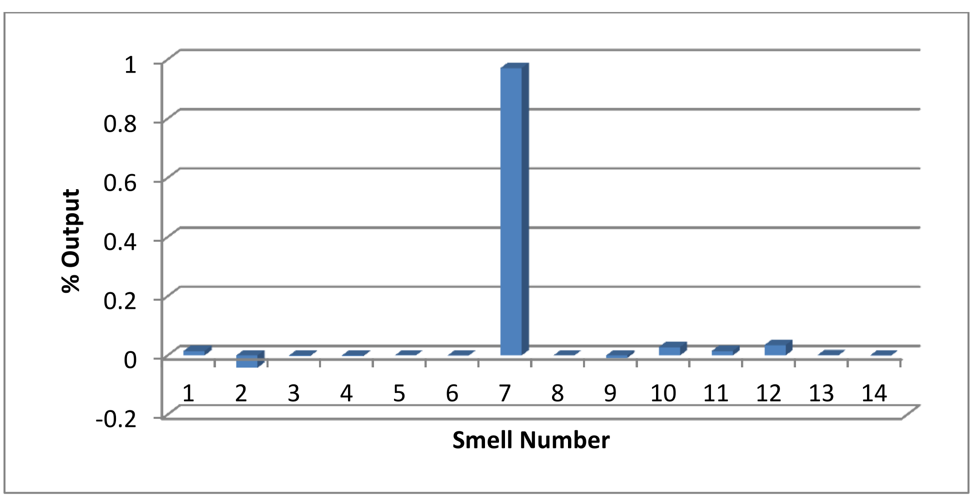

Figure 4.69 Output pattern for Smell No. 7 (Rose Water)

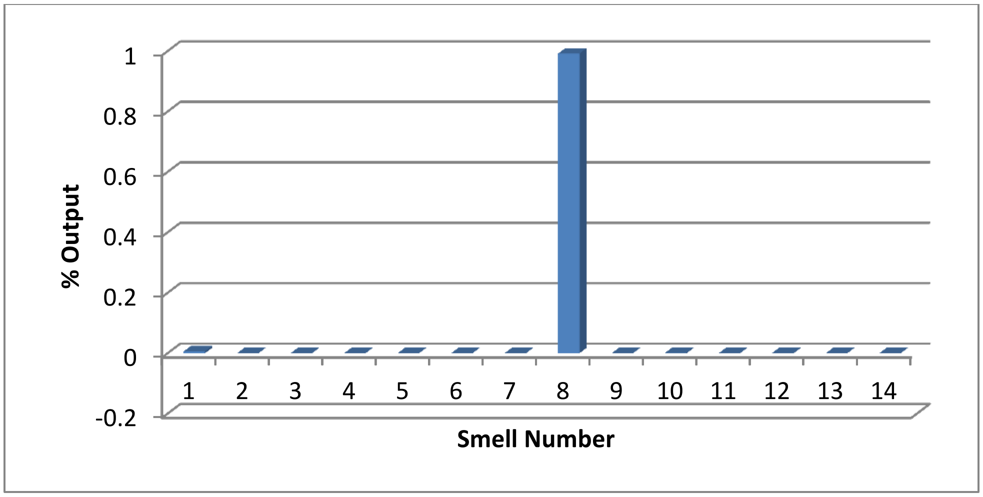

Figure 4.70 Output pattern for Smell No. 8 (Glass Cleaner)

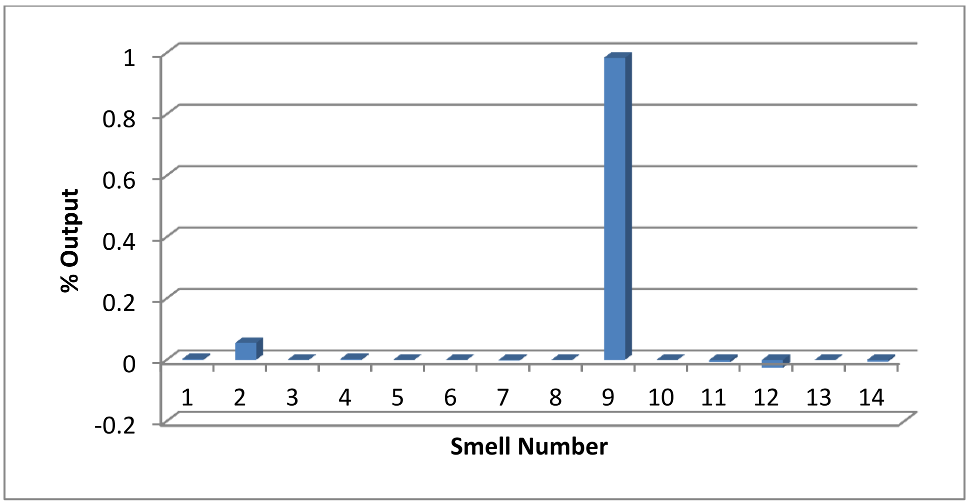

Figure 4.71 Output pattern for Smell No. 9 (Honey)

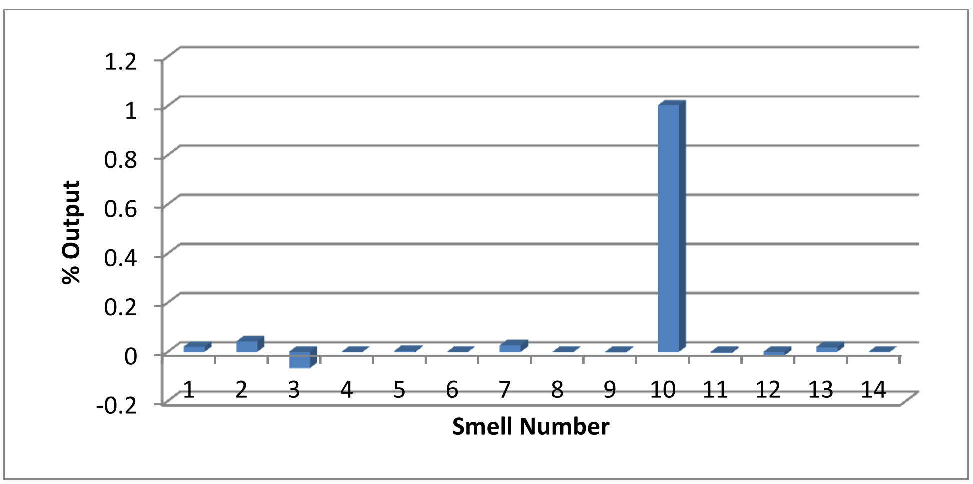

Figure 4.72 Output pattern for Smell No. 10 (Vinegar)

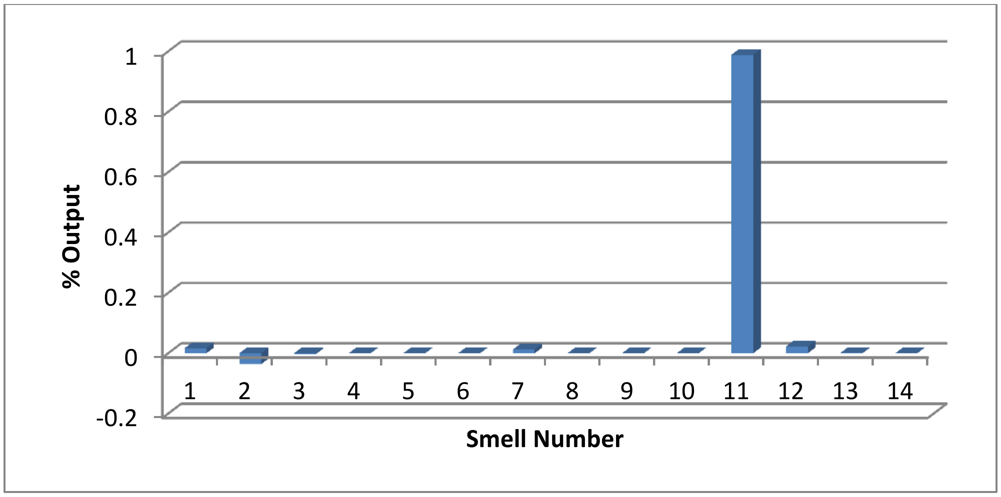

Figure 4.73 Output pattern for Smell No.11 (Shoe Polish)

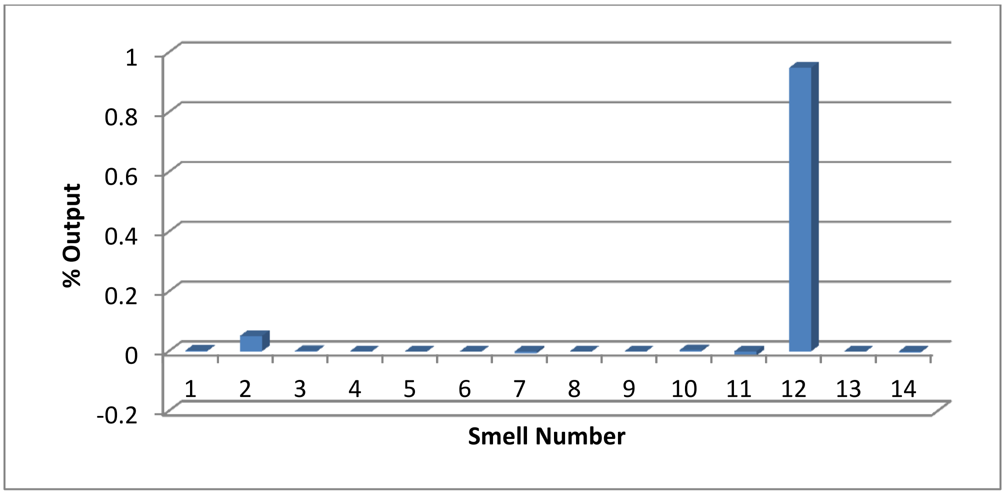

Figure 4.74 Output pattern for Smell No. 12 (Correction Fluid)

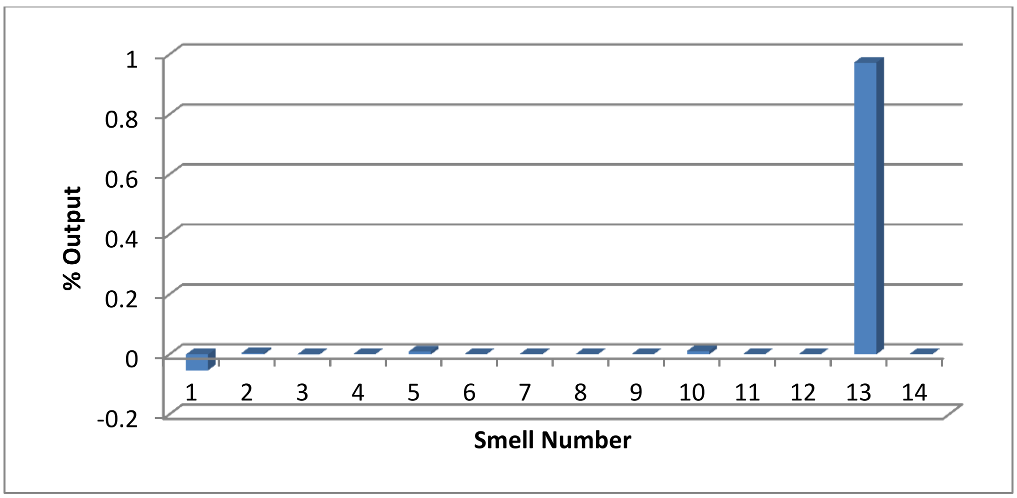

Figure 4.75 Output pattern for Smell No. 13 (Fresh Milk)

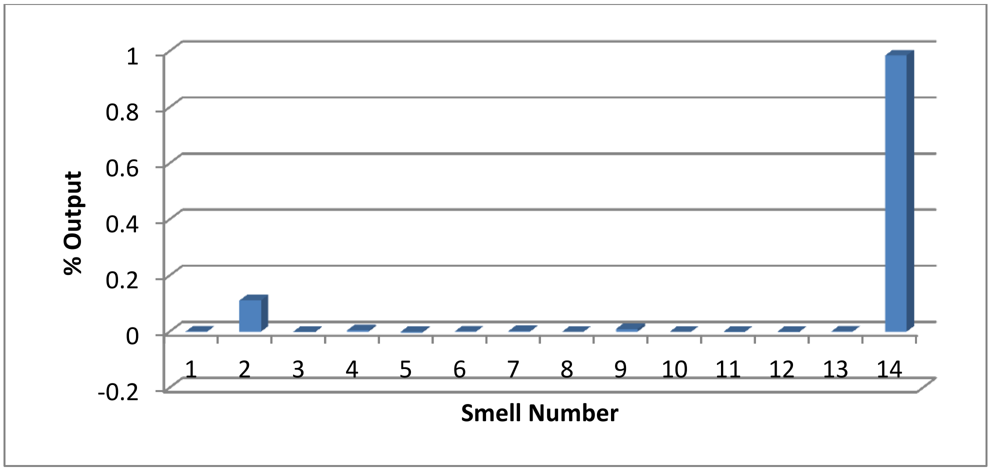

Figure 4.76 Output pattern for Smell No. 14 (Contact Cement)

4.2.4 Output Results from ANFIS

The same database of 14 household item smells is applied to the ANFIS network. For the training of the network the 2/3rd of the total database are used and 1/3rd of the total database used as testing data. On applying the testing data for all 14 smells, expected results are obtained with some error that are combined together and shown in the following Figures 4.77 and Figure 4.78.

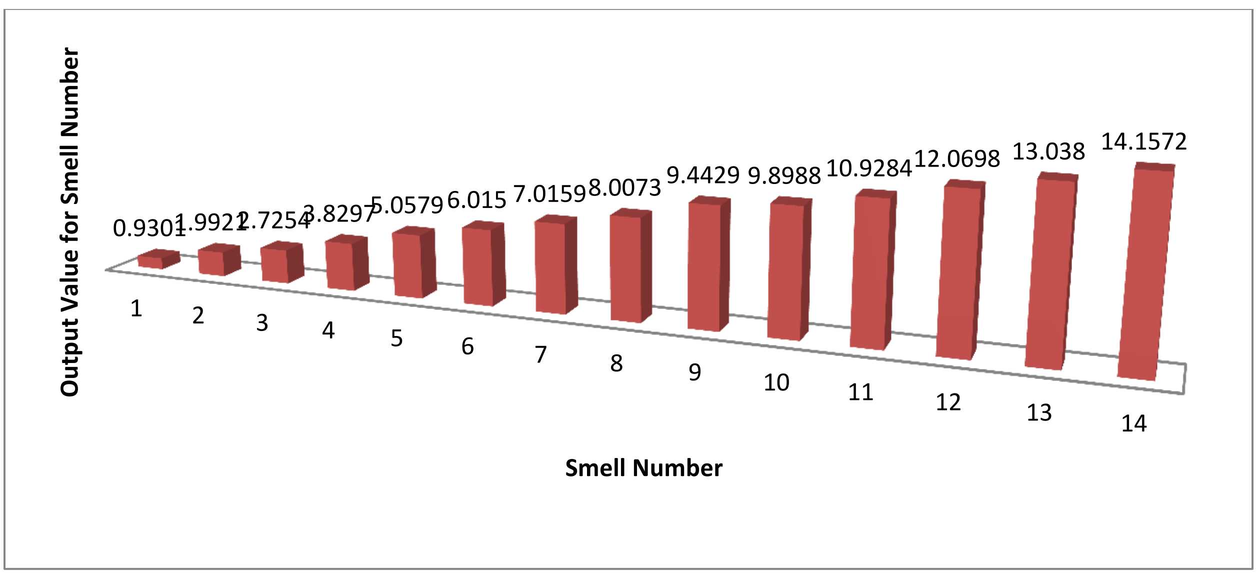

Figure 4.77 Output results from ANFIS for all 14 smells

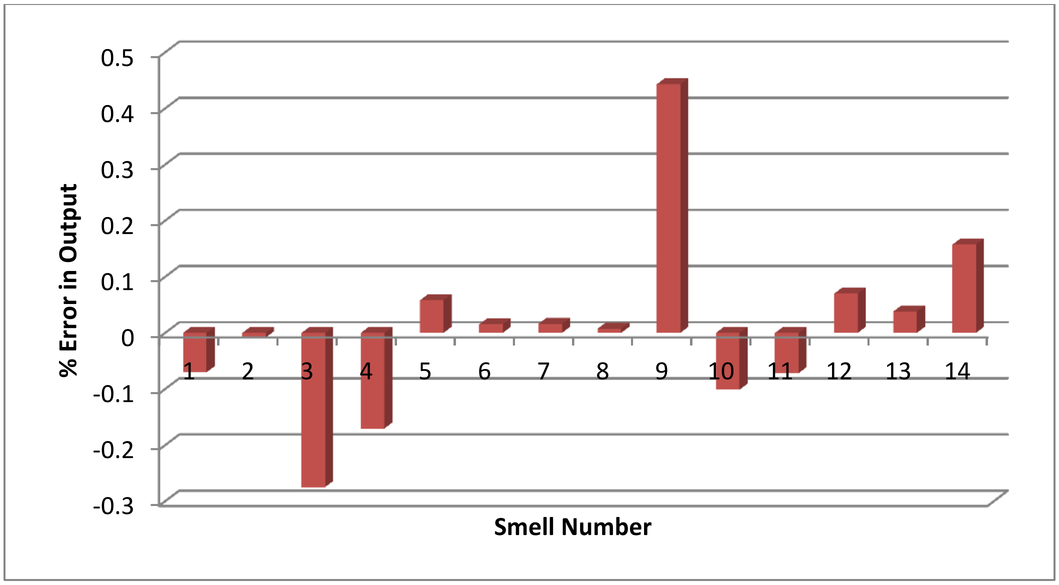

Figure 4.78 Percentage errors in outputs from ANFIS for all 14 smells

4.3 Results Analysis

To compare the classification accuracy of RBFN and ANFIS, the data set of 90 data vectors or measurements are divided into 5 subsets each subset having 18 data vectors. Each data vector has 10×12 matrix for 10 smell responses from the array of 12 sensors. In each subset 12 datasets are used for training the network and 6 datasets for testing. Let's analyze the results for environmental monitoring i.e. for ten toxic chemicals.

4.3.1 Analysis for the Application of Environmental Monitoring

In the Table 4.2 the outputs and percentage errors are given for different smells of chemicals exist in the environment. Table 4.3 shows percentage error by RBFN and ANFIS for second subset of data then Table 4.4 shows average percentage error for whole data (5 subsets).

Table 4.2 Percentage error by RBFN and ANFIS for first subset of data

Environmental Monitoring	Output (w.r.t. 1)		%Error	
Name of Chemical Smell	**RBFN**	**ANFIS**	**RBFN**	**ANFIS**
Ammonia (NH3)	0.8855	1.1007	11.45	8.8
Sulfur Dioxide	0.8692	0.8912	13.1	12.8
Polybrominated Diphenyl Ethers	0.852	0.9194	14.8	2.9
Lead	0.8658	0.9286	13.42	5.6
Nitrogen Oxides (NOx)	0.8759	0.7666	12.41	32
Carbon Monoxide	0.8698	0.9721	13.02	3.8
Polychlorinated Biphenyls	0.8573	0.8825	14.37	11.4
DDT	0.6783	0.6826	32.2	31.5
Nonylphenol	0.8502	1.1078	15	10.8
Copper	0.5733	1.383	42.7	37.3
Average percentage error			**18.247**	**15.69**

Table 4.3 Percentage error by RBFN and ANFIS for second subset of data

Environmental Monitoring	Output (w.r.t. 1)		%Error	
Name of Chemical Smell	**RBFN**	**ANFIS**	**RBFN**	**ANFIS**
Ammonia (NH3)	0.7850	1.145	21.5	14.5
Sulfur Dioxide	0.7692	0.875	23.1	12.5
Polybrominated Diphenyl Ethers	0.7252	0.815	27.8	18.5
Lead	0.861	0.903	13.9	9.7
Nitrogen Oxides (NOx)	0.772	0.876	22.8	12.4
Carbon Monoxide	0.8198	0.943	18.1	5.7
Polychlorinated Biphenyls	0.713	0.821	28.7	17.9

DDT	0.673	0.7826	32.7	22
Nonylphenol	0.855	1.11	14.5	11
Copper	0.673	1.21	32.7	21
Average percentage error			**23.58**	**14.52**

Table 4.4 Average percentage error for whole data (5 subsets)

Subsets (Fold)	RBFN(% error)	ANFIS(% error)
1	18.247	15.69
2	23.58	14.52
3	26.14	11.43
4	32.34	16.21
5	36.25	15.36
Average (% error)	**27.31**	**14.64**

4.3.2 Analysis for the application of Household Items Identification

Now analyze the results for household items identification i.e. for fourteen household items. In the Table 4.5 the outputs and percentage errors are given for different smells of household items.

Table 4.5 Percentage Error by RBFN and ANFIS for first subset of data

Household Items monitoring	Output (w.r.t. 1)		%Error	
Name of Items Smell	**RBFN**	**ANFIS**	**RBFN**	**ANFIS**
Distilled Water	0.688	0.731	31.2	26.9
Lighter Fluid	0.748	0.692	25.2	30.8

Soda Water	0.693	0.824	30.7	17.6
Perfume Jasmine	0.787	0.841	21.3	15.9
Fruit Juice Orange	0.683	1.157	31.7	15.7
Coffee	0.712	1.213	28.8	21.3
Rose Water	0.594	1.173	40.6	17.3
Glass Cleaner	0.734	1.073	26.6	7.3
Honey	0.653	1.142	34.7	14.3
Vinegar	0.795	0.898	20.5	10.2
Shoe Polish	0.811	0.928	18.9	7.2
Correction Fluid	0.671	1.118	32.9	11.8
Fresh Milk	0.726	1.083	27.4	8.3
Contact Cement	0.6618	1.152	34	15.2
Average percentage error			**28.89**	**15.7**

Table 4.6 shows percentage error by RBFN and ANFIS for second subset of data then Table 4.7 shows average percentage error for whole data (5 subsets).

Table 4.6 Percentage error by RBFN and ANFIS for second subset of data

Household Items monitoring	**Output (w.r.t. 1)**		**%Error**	
Name of Items Smell	**RBFN**	**ANFIS**	**RBFN**	**ANFIS**
Distilled Water	0.772	0.921	22.8	7.9
Lighter Fluid	0.683	0.821	31.7	17.9
Soda Water	0.593	0.754	40.7	14.6
Perfume Jasmine	0.687	0.897	31.3	10.3
Fruit Juice Orange	0.618	1.157	38.2	15.7
Coffee	0.732	1.113	26.8	11.3

Rose Water	0.585	1.219	41.5	21.9
Glass Cleaner	0.772	1.173	22.8	17.3
Honey	0.578	1.229	42.8	22.9
Vinegar	0.794	0.892	20.6	10.8
Shoe Polish	0.788	0.914	21.2	8.6
Correction Fluid	0.696	1.168	30.4	16.8
Fresh Milk	0.626	1.131	37.4	13.1
Contact Cement	0.868	1.072	13.4	7.2
Average percentage error			**30.11**	**14.02**

Table 4.7 Average percentage error for whole data (5 subsets)

Subsets (Fold)	RBFN(% error)	ANFIS(% error)
1	28.89	15.7
2	30.11	14.02
3	29.14	14.53
4	30.42	17.15
5	32.52	16.45
Average(% error)	**30.216**	**15.57**

From the above given tables it can be seen that ANFIS is giving superior results than RBFN. So ANFIS is very promising technique to be used is electronic nose system for classification purpose. The distinguishment of a particular odor is 100 percent accurate in both the techniques because from the output pattern anyone can easily find the odor number but some error is coming in the number of odor. Here only one feature of the signal is used i.e. difference between the peak and the baseline of the signal and getting results with almost 70% accuracy from RBFN and with 85% accuracy from ANFIS. But if more features of the signal are used results with accuracy close to 100% can be easily obtained.