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Detection of Proportion of Different Gas Components Present in Manhole Gas Mixture Using Backpropagation Neural Network

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Abstract. The article presents a concept of implementing an Intelligent System for detection of proportion of different components present in manhole gas mixture. The determination of proportion of components in manhole gas mixture is important because the manhole gas mixture contains many poisonous gases namely Hydrogen sulfide (H_2S), Ammonia (NH_3), Methane (CH_4), Carbon Dioxide (CO_2), Nitrogen Oxide (NO_x), and Carbon Monoxide (CO). A very limited time exposure to any of these components with human beings may endanger their lives. A gas sensor array is used for recognition of multiple gases simultaneously. At an instance the manhole gas mixture may contain many hazardous gas components. So it is wise to use specific gas sensor for each gas component in the gas sensor array. Use of multiple gas sensors and presence of multiple gases together result in cross-sensitivity. We have used backpropagation algorithm to resolve the multiple gas detection and cross-sensitivity issue quite effectively.

Keywords: manhole gas mixture, gas sensor array, cross-sensitivity, backpropagation.

1. Introduction

In this article our focus is on implementing a backpropagation algorithm for development of an Intelligent Sensory System for proportion detection of components present in a typical manhole gas mixture [1, 2]. The manhole gas mixture found in sewer pipeline is manly containing gases like, Hydrogen Sulphide, Ammonia, Methane, Carbon Dioxide, Nitrogen Oxide, etc. The Sewer pipeline network is built in the cities and towns to drain out waste products from the cities [1]. For cleaning and maintenance purpose there are manholes built across this sewer pipeline. A person, as conventional practice in vogue, has to get down into this pipeline for cleaning and repairing sewer pipeline. As the manholes are built on the roads or on the road sides, many pedestrian also comes vulnerable with these manholes. In [5, 10, 13] the concerned authors express their views on the gas detection issues and presented different methods used for the same.

To design an Intelligent Sensory System for the detection of components in manhole gas mixture, we resort to using neural network. The neural network has to be developed to act like an intelligent agent who can report the proportional presence of poisonous gas component into the manholes. The training of the neural network is done by the backpropagation algorithm. An Intelligent System like this will help labourers to alert them about the presence of poisonous gases before entering into the manholes. A sensor array containing distinct semiconductor based sensors sense the presence of gases according to concentration of the gases in manhole gas mixture. Sensed values by the sensor array are inducing cross-sensitivity, which will be filtered out during the training of neural network.

2. Mechanism

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2.1. The mixed gas detection system

The basic model of Intelligent System for detection of manhole gas mixture is shown in the figure 1. In [3, 6, 7] authors are showing their gas detection models. The gas mixture sample collected into a gas mixture chamber is allowed to pass over the gas sensor array [4, 11]. The sensors present in the sensor array are responsive to their target gas only, but due to the cross-sensitivity effect they have mild response due to other gases too. So the sensor array response is always involving cross-sensitivity effect [12]. A pre-processing block which receives data from the gas sensor array normalizes received data before feeding it to the neural network. The BP neural network acts on this normalized data. The outputs of BP neural network are fed to the report generator module where the outputs are denormalized. The report generator module generates alarm if there is any poisonous gas components proportion exceeding safety limit in the gas mixture. For the training of BP neural network, several data samples are produced.

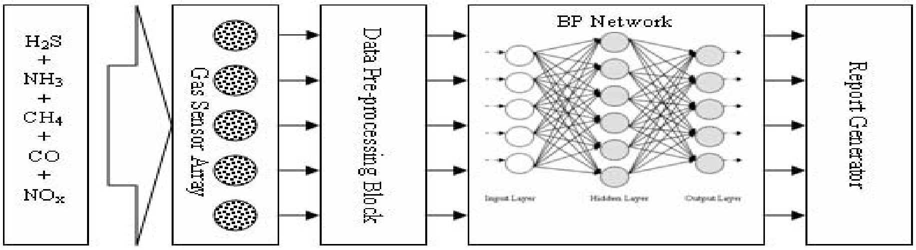


Fig. 1: Mixed Gas Detection System.

2.2. Data collection and analysis

We collect the sample of data form gas mixture, where the mixture is mixed in known proportion. The known gas mixture is a synthetic mixture of gases in the known concentration. Data sample is prepared by passing each sample mixture over the sensor array and the sensor responses are taken. In this way we do prepare several data samples. A typical example of this data sample is shown in the Table 1. In Table 1 if we focus on the first and second sample we can see the inherent cross-sensitivity effect in the responses of sensors. The responses of all the sensors were increased due to increase in the concentration of only one gas.

Table. 1: Synthetic data sample (considering mixture of known proportion)

Sample	Gas Mixture in known conc. (PPM)					Sensor response				
	NH_3	CO	H_2S	NO_2	CH_4	NH_3	CO	H_2S	NO_2	CH_4
1	50	100	100	100	2000	0.0531	0.0863	0.0733	0.0267	0.1101
2	50	100	100	100	5000	0.0812	0.1122	0.0749	0.0333	0.1934
3	50	100	100	200	2000	0.0963	0.1182	0.0929	0.0577	0.11952
4	50	100	200	200	5000	0.1212	0.12905	0.1291	0.0699	0.2086
5	50	100	200	400	2000	0.1451	0.1495	0.1399	0.0795	0.1207
6	100	200	200	400	5000	0.1569	0.1573	0.1526	0.0799	0.2559
7	100	200	100	200	2000	0.1693	0.1699	0.0722	0.0615	0.14005
8	100	200	100	200	5000	0.1715	0.1798	0.0883	0.0705	0.30001
9	100	200	100	400	2000	0.1821	0.2231	0.0996	0.1302	0.1544
10	100	200	200	400	5000	0.1924	0.2584	0.1869	0.1648	0.3124

In the pre-processing block we normalize the data samples according to equations (1) and (2). According to equation (1) NC_{si} (normalized value) of gas H_2S of sample 2 is 100/5000 where the 100 appearing in the numerator is C_{si} (concentration of gas itself) and 5000 in the denominator is C_{max} (max concentration among all the samples). Similarly all the sensor responses are also normalized according to equation (2).

$$NC_{si} = C_{si} / C_{max} \quad (1)$$

$$NR_{si} = R_{si} / R_{max} \quad (2)$$

Where, NR_{si} is the Normalized Sensor Response, R_{si} is the Sensor Response and R_{max} is the max value of sensor response among all response of all samples.

Table. 2: Normalized form of data sample considered in Table 1

Sample	Gas Mixture in known conc.					Sensor response				
	NH_3	CO	H_2S	NO_2	CH_4	NH_3	CO	H_2S	NO_2	CH_4
1	0.01	0.02	0.02	0.02	0.4	0.1699	0.2762	0.2346	0.0854	0.3524
2	0.01	0.02	0.02	0.02	1.0	0.2599	0.3591	0.2397	0.1065	0.6190
3	0.01	0.02	0.02	0.04	0.4	0.3082	0.3783	0.2973	0.1846	0.3825
4	0.01	0.02	0.04	0.04	1.0	0.3879	0.4130	0.4132	0.2237	0.6677
5	0.01	0.02	0.04	0.08	0.4	0.4644	0.4785	0.4478	0.2544	0.3863
6	0.02	0.04	0.04	0.08	1.0	0.5022	0.5035	0.4884	0.2557	0.8191
7	0.02	0.04	0.02	0.04	0.4	0.5419	0.5438	0.2311	0.1968	0.4483
8	0.02	0.04	0.02	0.04	1.0	0.5489	0.5755	0.282	0.2256	0.9603
9	0.02	0.04	0.02	0.08	0.4	0.5829	0.7141	0.3188	0.4167	0.4942
10	0.02	0.04	0.04	0.08	1.0	0.6158	0.8271	0.5982	0.5275	1

2.3. Data pattern for neural network

Input vector is formed from the sensor response. In the given data sample input vector is a 5 element vector. One vector element is for each gas. For example input vector 'I' for sample 1 of Table 2 is as follows

$$I = [0.1699, 0.2762, 0.2346, 0.0854, 0.3524]$$

Target vector is formed from gas mixture. In the given data sample target vector is a 5 element vector. One vector element is for each gas. For example target vector 'T' for sample 1 of Table 2 is as follows

$$T = [0.01, 0.02, 0.02, 0.02, 0.4]$$

3. Our Backpropagation Approach

From Tables 1 and 2 it is clear that the data sample is prepared from sample gaseous mixture of five gases. We use a multilayer feed forward neural network. A neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use [7]. This network is trained using backpropagation algorithm. The multilayer feed forward neural network shown in the figure 2 is containing 5 input nodes, 6 hidden nodes (reason why we are using 6 nodes in hidden layer is discussed later) and 5 output nodes, leading to a 5 – 6 – 5 architecture. The 5 nodes in the input as well as in the output layer indicate that the system is developed for detecting five gases from the gaseous mixture.

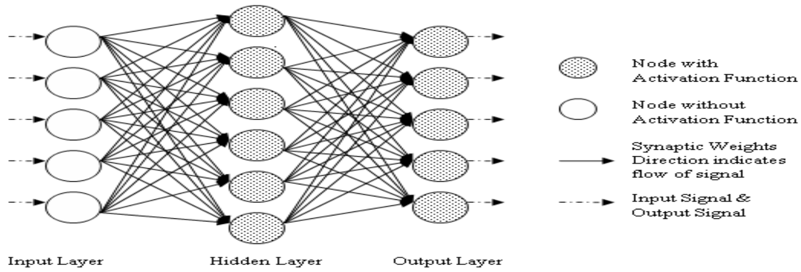


Fig. 2: Two layered backpropagation neural network architecture used in this intelligent system.

3.1. The Backpropagation algorithm

Backpropagation algorithm is a form of supervised learning for multilayer neural networks, also known as the generalized delta rule. Error data at the output layer is back propagated to earlier ones, allowing incoming weights to these layers to be updated [8]. A flow diagram depicting the backpropagation algorithm is shown in figure 3. The error computation methods are as follows.

Instantaneous Error Energy: The instantaneous error energy [8] is the error computed for the network at the output layer for a single input pattern.

$$E(n) = \frac{1}{2}\sum_c (O_c - t_c)^2 \quad \forall c \tag{3}$$

Where, 'c' belongs to the nodes in output layer and 'n' indicates the n^{th} iteration. 'O_c' and 't_c' are the neural networks actual output and target output respectively.

Sum of Squared Error Energy: The sum of squared error energy [8, 9] is the summation of all the instantaneous error energy for all patterns (total no. of pattern = N).

$$SSE = \frac{1}{2}\sum_{p}\sum_{i}(o_{pi} - t_{pi})^2 \qquad (4)$$

Where, 'p' is the index for pattern number and 'i' is the index for nodes in output layer

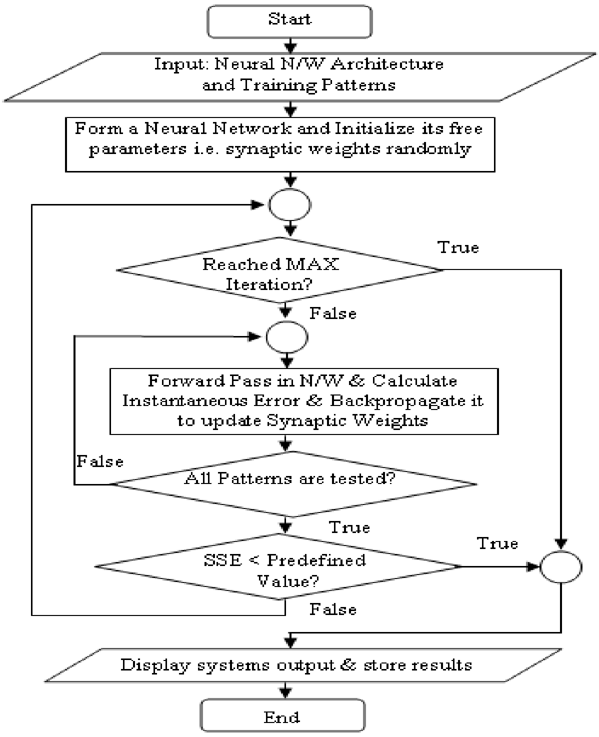


Fig. 3: Flowchart of backpropagation neural network algorithm.

Back-propagation learning may be implemented in one of two basic ways [8], as summarized here:

1. Sequential mode (also referred to as the online mode or stochastic mode): In this mode of BP learning, adjustments are made to the free parameters of the network on an example by example basis. In this mode the learning takes place on the basis of back propagating instantaneous error energy.

2. Batch mode: In this second mode of BP learning, adjustments are made to the free parameters of the network on an epoch by epoch basis, where each epoch consists of the entire set of training examples. In this mode the learning takes place on the basis of back propagating average squared error energy.

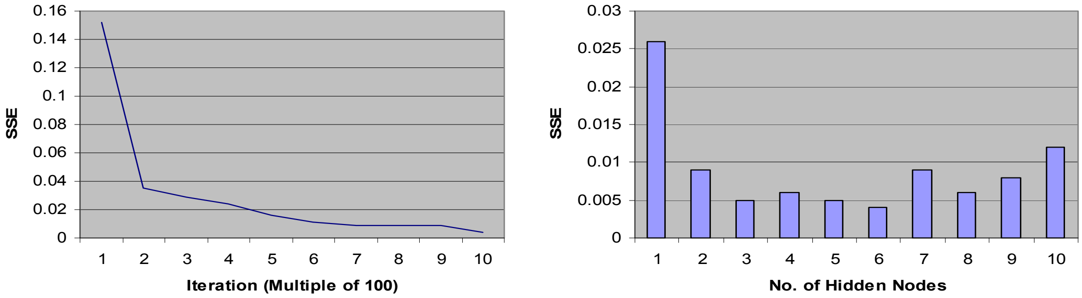
For the present we have used sequential mode of learning. Figure 3 also indicates the same kind of learning methodology. Training in the sequential mode is advantageous because it is stochastic in nature and hence can escape/avoid local minima [8].

4. Results and Discussions

The BP algorithm is implemented in the JAVA programming language and the algorithm executed in the JDK 1.6 environment. The neural network trained using the data sample mentioned in the Table 2 and the performance is observed accordingly.

In figure 4(a) we can see that the network converges at iteration 450 to give a SSE below 0.02 and further decreases on increasing iterations. In the graph 4(b) we can see that the network architecture of 5-6-5 provides best result in terms of SSE that is below 0.005 and all other architectures provide SSE over and above SSE 0.005.

From the prepared data samples we consider 80% samples for training and 20% for testing purpose. The output of the network is denormalized (multiplying neural network output with *Cmax*) to report in terms of concentration (in ppm) of gases present in a given gaseous mixture.



(a) (b)

Fig. 4: 4(a) SSE vs. Number of iteration 4 (b) SSE vs. Number of nodes in the hidden layers

5. Conclusion

In the article an intelligent sensory system comprising semiconductor based gas sensor array and backpropagation neural network algorithm together provides a solution to the manhole gas detection issue. We also deal with the cross-sensitivity issue by incorporating cross-sensitivity information while preparing data samples and training the BP network.

6. Acknowledgement

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