PROJECT REPORT ON

Electronic Nose for Air Quality Monitoring

Submitted in partial fulfilment of the requirements for

the award of the degree of

BACHELOR OF TECHNOLOGY

Submitted by

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Under the Guidance of

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SHANMUGHA

ARTS, SCIENCE, TECHNOLOGY & RESEARCH ACADEMY

(SASTRA DEEMED TO BE UNIVERSITY)

(A University Established under section 3 of the UGC Act, 1956)

TIRUMALAISAMUDRAM

THANJAVUR – 613 401

April(2019)

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TIRUMALAISAMUDRAM, THANJAVUR – 613401

BONAFIDE CERTIFICATE

Certified that this project work entitled "**Electronic Nose for Air Quality Monitoring"** submitted to the Shanmugha Arts, Science, Technology & Research Academy (SASTRA Deemed to be University), Tirumalaisamudram - 613401 by Venkata Viswanath.CH (119003208), B.Tech Computer Science and Engineering in partial fulfilment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in their respective programme. This work is an original and independent work carried out under my guidance, during the period December 2018 – April 2019

CEO, FIRST-TBI **ASSOCIATE DEAN**

SCHOOL OF COMPUTING

Submitted for Project Viva Voce held on ___________________

Examiner -I **Examiner-II**

SCHOOL OF COMPUTING

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DECLARATION

I submit this project work entitled "**Electronic Nose for Air Quality Monitoring**" to Shanmugha Arts, Science, Technology & Research Academy (SASTRA) Deemed to be University, Tirumalaisamudram–613401, in partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** and declare that it is my original work carried out under the guidance of **Dr.Sridharan. V,** CEO, FIRST-TBI.

Name: Venkata Viswanath CH Signature:

Reg. No.: 119003208

Date:

Place:

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ABSTRACT

When computers started mimicking human senses like vision, touch etc..., smell was one of them. This was not so easy because we need precise sensors for sensing the odour. But, with technology evolving and Moore's law doing its job well, we are now able to detect minute concentrations in the magnitude of ppm. Electronic-Nose(E-Nose) can be used for solving many real-life issues which involve the sense of odour. It is cost effective and also precise in its working. E-Nose has two major components, one being the "Sensor array" and the other is the "Pattern-recognition system". In this paper, we use E-Nose for the purpose of Air Quality Monitoring which, with the growing pollutants, has become a major concern.

With peaking Industrial Revolution and increased vehicular emissions, there has been an exponential increase in pollutants in the atmosphere. Air quality has become a critical influencing factor for human health. The pollutants such as Carbon Monoxide, Nitrogen Oxides, Carbon Dioxide etc... have an adverse effect on human health. They lead to respiratory ailments and the adversity may range from small health issues like headache, dizziness etc... to larger ones like cancers. As, "Precaution is better than Cure", we must be on the safe side by taking necessary steps to monitor the Air Quality.

The proposed work is to develop a prototype which senses the air through the sensors and then classifies it based on its quality. The classification is done using “Pattern Recognition System” which involves Classification Algorithms of Machine Learning. E-Nose is considered to be a potential way to balance the trade-off between cost and accuracy.

KEY WORDS: Sensors, Air Quality, Pattern Recognition System, Classification algorithms

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ABBREVIATIONS

AI	Artificial Intelligence
ML	Machine Learning
UML	Unified Modelling Language
IDE	Integrated Development Environment
SME	Subject Matter Expert
E-Nose	Electronic Nose
CO	Carbon Monoxide
LPG	Liquid Petroleum Gas
USB	Universal Serial Bus
KNN	K-Nearest Neighbors
LDA	Linear Discriminant Analysis
CM	Confusion Matrix

CHAPTER 1 – INTRODUCTION

Machine Learning is one of the most attracted research areas in the field of Computer Science. It is the science of getting the computers to act without being explicitly programmed. With the advent of more compute facilities, more storage facilities, networking facilities, and improved concepts of Machine Learning, AI has reached a greater height currently. A huge number of prototypes are being published as research articles and good percentage of those are transformed to a product. Establishing the product and marketing it adds a great value to the scientific concept behind it.

The applications of AI and Machine Learning are widely adopted in many fields such as finance and banking, security and surveillance, health diagnostics, manufacturing, supply chain logistics etc.,

One such use-case is monitoring the Air Quality with the help of an array of sensors. Senses are the important thing that distinguishes humans from machines. Sense of sight could be mimicked using CMOS sensor where light is converted to electron and different amounts are accumulated based on the wavelength of light, sense of touch could be mimicked using capacitive touch sensor where position of touch can be identified using the potential difference at that location and sense of hearing could be mimicked using microphone where sound waves are converted to analog electrical signals. Sense of taste and sense of smell are hard to mimic because it involved sensing the chemical compounds present. This posed a challenge because it involved chemical reaction suitable chemical compounds are needed so that they are not consumed on use while sensing. The other difficulty are in converting the reaction between chemical compound to electrical signals and the electrical signal patterns cannot be directly interpreted by humans.

The chemical sensor innovation solved the need to convert the chemical compound reaction caused due to chemical sensed into an electric signal and the intensity of chemical compound in the atmosphere has effect on the resistance offered which in turn alters the magnitude of electric signal. The atmosphere has many chemical compounds so there has to be different sensors for different compounds. Now there are different magnitudes from different sensors which form a pattern relatable to particular smell having these chemical compounds. So, to identify the electric signal patterns a machine learning algorithm is to be trained with different known patterns for a particular smell to identify other patterns associated with the smell. The electronic nose can be used in various applications like sensing air quality, sensing marsh gases in mines, detection of explosives, sensing of the quality of food based on the chemical concentration for food industries and for medical purposes so as to identify the onset of the disease by identifying the chemical compounds present in the breathe of the subject.

CHAPTER 2 - PROJECT PLAN

2.1 Requirement Analysis

Brief meetings were held with SME's for gaining the initial base knowledge. During this meet, the requirements that were elucidated were,

(1) The required array of sensors for Air Quality need to be chosen for sensing the pollutants in the air.

(2) Precise Classification algorithms using Machine Learning need to be incorporated for classifying the quality of air sensed.

(3) The prototype for the E-Nose has to be built.

(4) The data set for air quality has to be created and classified using Machine Learning algorithms. Best Machine Learning algorithms have to be applied for better outcome.

With the requirements listed, the feasibility of its completion were discussed.

2.2 Literature Survey

After deciding upon the requirements, a detailed survey was conducted on implementing the features as a prototype. The results of this phase are detailed in Chapter 4.

2.3 Design

Once the survey was completed, diagrammatic representations of the prototype to be developed were created and they are depicted here.

(i) Activity Diagram

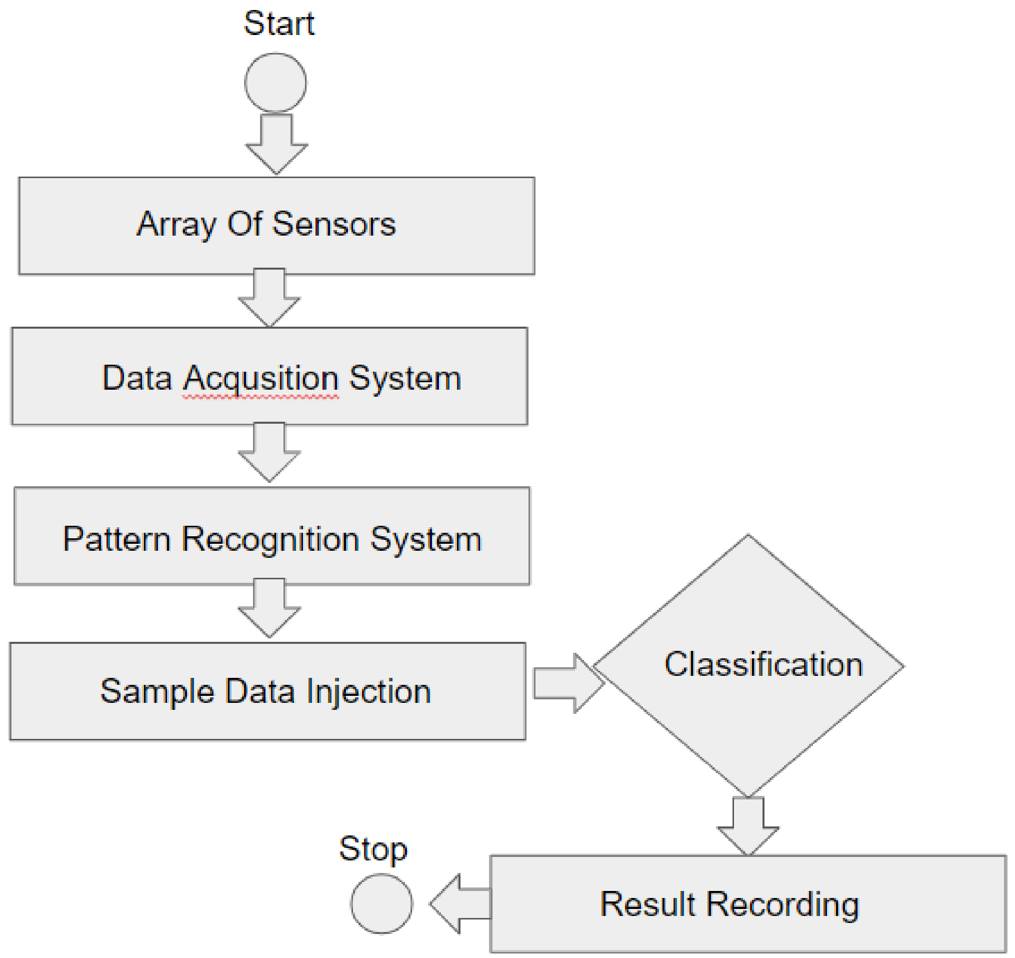

Fig. 2.1 Activity Diagram for E-Nose

Activity diagram is one of the Unified Modelling Language (UML) diagrams used to represent the flow of one activity to another. It represents the sequence of flow and the condition in which the flow occurs. It is a Behavioral diagram as it represents the behavior of the system. We can represent both Sequential as well as Concurrent processing using Activity Diagrams. It is not only similar to a flow chart but an advanced version of it. Developers mainly use Activity diagrams to get the insights of the system and its flow. Once this modelling is done, the remaining phases becomes easy. This representation can further be used in forward and reverse engineering.

In this project, activity diagram starts from the Array of Sensors sensing the data and finally goes to the Classification done by the algorithms and getting the classified label.

(ii) Architecture Diagram

This is detailed in Chapter 6

2.4 Implementation

With the design phase completed, implementation phase was simplified to building the hardware modules required and transforming the software components/modules to a code.

The Hardware implementation comprised of gathering the required sensors for Air Quality monitoring and arranging them together into an array using Arduino board. The circuit basically consisted of Arduino, the array of sensors and the connecting wires.

In this project, code implementation was done with the help of Arduino IDE and Spyder IDE from Anaconda . The Arduino IDE is very sophisticated and offers full support to the developers for code completion, implementation and testing. Anaconda is a free, open source distribution of R and Python languages for scientific development. The language used is Python for its robust, simple and fast execution.

First the data set for the Air Quality is developed by gathering data from the array of sensors of Electronic Nose. The data set basically has 3 labels for Air Quality i.e. Clean, Polluted and Highly Polluted. So, the data set has to be created accordingly in the open environment. Then, the data set is fed as input for training into ML algorithms as Training Set of 80%

and Test Set of 20%. Then the precise algorithms which give better outcome accuracy on Test Set are chosen for Classification.

2.4 Testing

All the components including the sensors, the Arduino board and the connections in the prototype are tested independently initially during development stage. When the Unit Testing gave satisfactory results, the components were combined in pairs and Integration Testing was done.

Example : Unit Testing – Each Sensor tested individually, the Arduino board tested individually .

Integrated Testing – The sensors were combined and the array of sensors were now tested. The sensors were then tested as whole with the Arduino board.

Machine Learning algorithms for classification were tested for Accuracy. All the observations were recorded and suitably noted to make the model better.

2.5 Documentation

Once satisfaction is achieved in the testing phase, the details of the product and the project were documented. The events of the project are recorded in a separate notebook, which was further documented as a report.

Table 2.1 Software Project Plan Summary

Phase	Task	Description	Duration (in days)
1	Analysis	To get brief insights about the product to be developed, from the discussions held during the initial meet, where the requirements were explained in detail	5
2	Literature survey	With the information and details, a literature survey was done by searching from the research articles posted online. Various articles and papers were studied for insights.	10
3	Design	Diagrammatic representations of the system (Activity diagram, Architectural diagram etc.,) were designed for a hazard free implementation of the product.	15
4	Implementation	Once the design is ready, each and every component in the design is implemented, specific to the client's requirements.	15
5	Testing	All the major components in the product are tested sequentially until satisfaction is achieved.	5
6	Documentation	Documentation of the report and research article are prepared.	5

CHAPTER 3 – PROBLEM STATEMENT

Now-a-days, pollution has become a major concern. Many life-threatening diseases are caused by pollution. People face many problems because of the air inhaled which causes serious illness. The air which may seem clean might be polluted because of the blend of poisonous gases contained in it. It is difficult to detect them by human sense. So, we need the technological support for detection and indication of quality of air. The E-Nose can be used to detect such gases and odors.

CHAPTER 4 – LITERATURE SURVEY

A high precise electronic nose for indoor air quality monitoring was implemented by Jie He [1] which describes the measuring of air quality even at low concentration (< 1ppm). The sensors used were temperature, humidity, TGS2600 and TGS2602 were used to collect A Semi-Supervised learning algorithm known as M-Training was implemented by Pengfei Jia [2] where collected data has a lot of unlabeled data samples and very few labeled data samples. The implementation uses m models for training on the labeled data first and then learns from the unlabeled data.

Fish species discrimination using electronic nose authored by Selda Guney[3], where freshness is different for different species of fish so electronic nose was used in discrimination of species.In signal preprocessing stage where raw signal addition is used in addition to baseline manipulation to prevent the drift problem and sub-sampling method is used for feature extraction and a decision based binary tree structure is used for classification from extracted features.

Compressive sensing based electronic nose platform is authored by Hamza Djelouat [4], where the problems like drift problem where exposure to reactive gases for a long time can result change in gas sensor properties and non selectivity problem where reactivity of chemical sensor to our inference gas different from nominal gas is specified. These problems are overcome by using array of sensors for measuring the same gas. As this increases the dimensionality of collected data a dimensionality reduction algorithm is used before transmission and it is reconstructed before classification.

Extreme ML techniques using MOS electronic nose and ELM for predicting postharvest quality of cherry tomato fruit treated with high pressure argon authored by Lei Feng[5].

CHAPTER 5 – HARDWARE, SOFTWARE REQUIREMENTS SPECIFICATIONS

4.1 Hardware Requirements

1. Arduino UNO board
2. MQ-135 sensor for Air Quality
3. MQ-2 sensor for CO, LPG & Smoke detection
4. DHT-22 sensor for Temperature & Humidity
5. Optical Dust sensor (Shinyei dust sensor)
6. Connecting wires

   The sensors here are used to sense the atmosphere for gases and the board contains these sensors attached by connecting wires.

4.2 Software Requirements

1. Arduino IDE
2. Python IDE

Arduino IDE is a cross-platform application i.e. this application works on Windows OS, mac OS and Linux OS. The application itself is written in Java. This is used to write and upload programs to Arduino compatible boards and also to other vendor development boards but with the support of third party cores. Python is used for training on the data set and result optimization through Classification algorithms of ML.

CHAPTER 6 – PROPOSED ARCHITECTURE

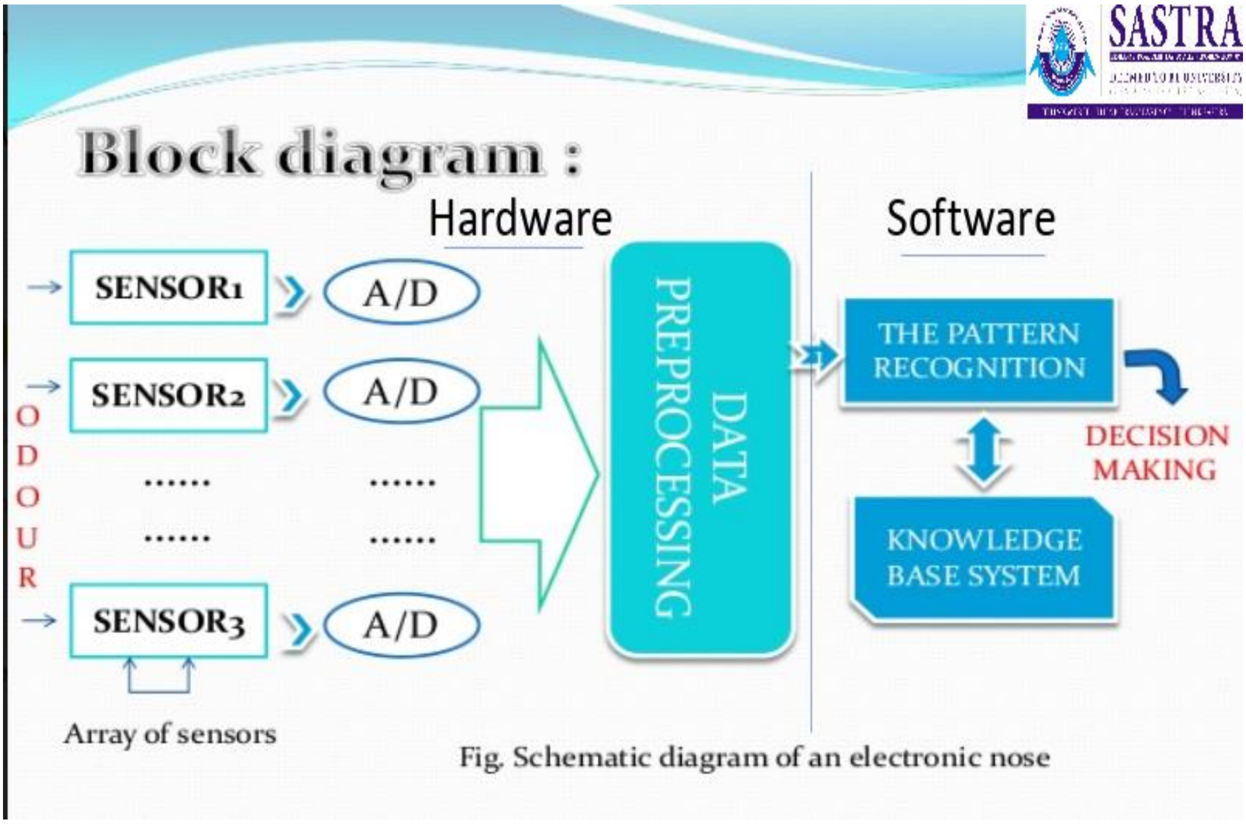

Fig 6.1 Architecture

The architecture of the proposed model is a block diagram of E-Nose.

The architecture has two main components

- Detection system: This system consists of array of chemical sensors which are the reactive part the instrument. The process of adsorption of volatile compounds on the surface of the chemical sensors causes a change in sensor which in turn produces electrical signals and these are recorded and sent to the next system which is computing system.
- Computing system: This system is sometimes referred to as 'Pattern Recognition System'. Before the computing system can be used to detect patterns associated

with a particular volatile compound the computing system is trained with known patterns and its associated volatile compound.

The detection system in electronic nose is comprised of conductivity sensors, piezoelectric sensors and optical sensors. Each sense as specified:

- Conductivity sensors: The Metal oxide type sensors under conductivity sensor induce electric signals because of adsorption of gas molecules.
- Piezoelectric sensors: The adsorption of gas on the surface leads to change in resonant frequency of the crystal which is proportional to concentration of gas molecules.
- Optical sensors: These work based on light modulation measurements.

The Computing system needs to classify the chemical compound based on the electric signal magnitudes recorded. First the computing system is trained with various electrical signal patterns known for various chemical compounds. This training can be achieved using various classification machine learning algorithms. After the training the model can be used to recognize chemical compounds based on the input electrical signals.

CHAPTER 7 – METHODOLOGY AND APPROACH

7.1 E-Nose

The sensors are arranged and connected to the Arduino Uno board as per the hardware architectural block diagram shown in the previous section. The data from the sensors is processed by the board and send to the Compute system / Pattern Recognition System via USB. The processing of classification is done and classified label is obtained.

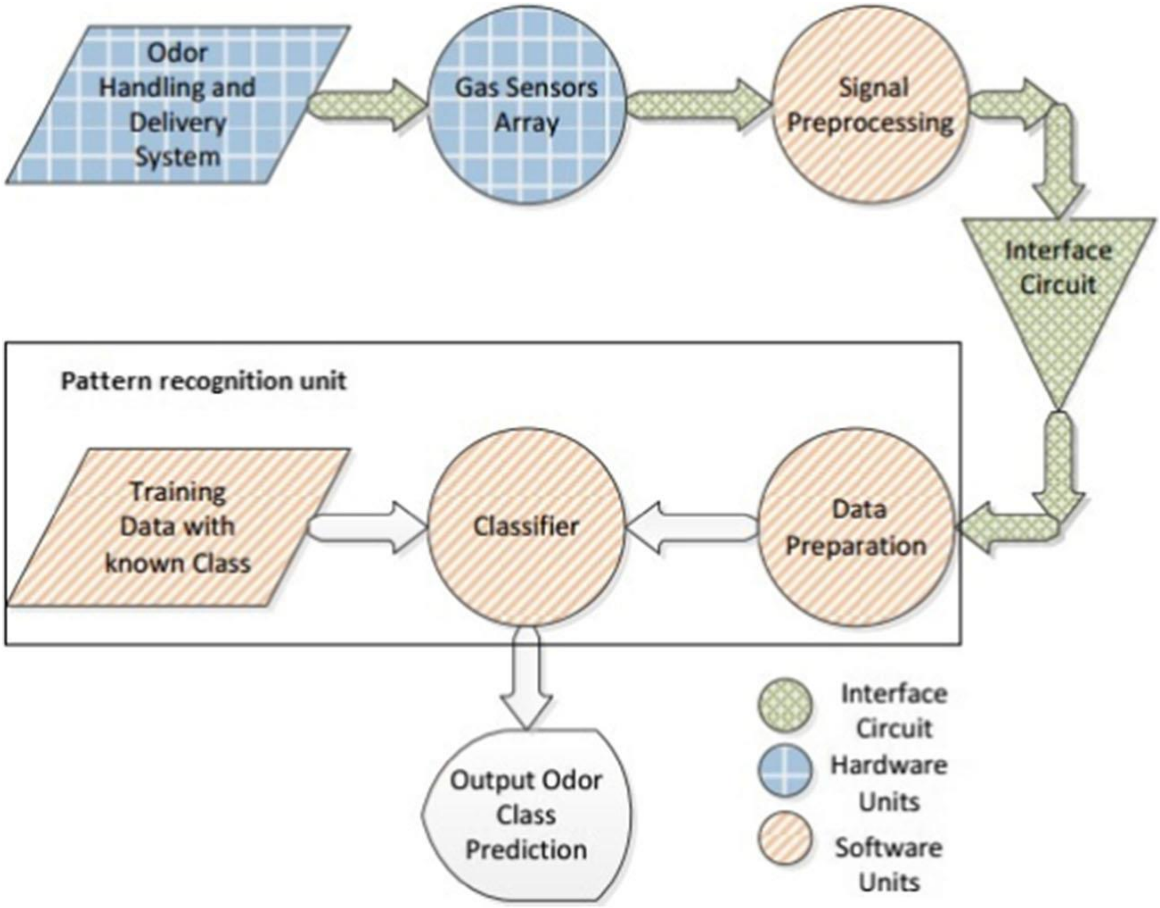

Fig. 7.1 E-Nose Working Methodology

E-Nose consists of the first half components / phases apart from the Pattern Recognition System i.e. odor handling and delivering system, the sensor array, signal preprocessing phase and the interface circuit.

- Odor handling and delivering system is used to handle the odors from the sensors
- The Gas Sensor Array is used to sense the gases from the atmosphere. Each sensor can sense one or multiple gases. The gases sensed are found as change in the signals by the sensors.
- The Signal Preprocessing is the done by the signals received from the sensor array.
- The Interface circuit provides an interface to the Pattern Recognition System. The interface system used here is USB.

7.2 Pattern Recognition System

The Pattern Recognition System also referred to as Compute System is used to operate on the data obtained from the E-Nose.

There are 3 phases in Pattern Recognition System

- Training data with known class : Here the classification algorithm used is trained on data set with known labels of classes. The labels used in our project are :

  Clean – Representing the Clean air

  Moderately Polluted – Representing the moderately Polluted air

  Polluted – Representing the Highly Polluted air

- Data Preparation : This phase contains the preparation of data for feeding as input to ML algorithms without anomalies.

- The Classifier : This is the Classification Algorithm of ML used to train on dataset provided and classify the test data into the accurate label. There are various machine learning algorithms for classification. They are

1. Support Vector Machines: This algorithms uses support vectors to achieve maximum separation between different classes.
2. Bagging Algorithm: This is an ensemble algorithm. Here n different models are trained using the random samples of training data in a parallel manner. The result class is based on the majority of result class among the n models.
   "Random Forests" is a bagging algorithm used in this project
3. Boosting Algorithm: This is also an ensemble algorithm. Here n different models are trained one after the other in a sequential manner. In Boosting algorithms each classifier is trained on data, taking into account the previous classifiers success. After each training step, the weights are redistributed. Misclassified are given more weight to emphasise the most difficult cases. In this way, subsequent learners will focus on them during their training.
   "XGBoost" is a boosting algorithm used in this project
4. Apart from the above algorithms, we also used other classification algorithms like KNN and Logistic Regression by LDA for Dimensionality Reduction.

7.2.1 Python

Python is a powerful open source scripting language used widely for rapid application development. It comes in two versions, Python 2 and Python 3. The biggest advantage of using python is the use of packages that can be installed whenever necessary. Modularity is introduced in the system to be developed.

Several packages like Scikit-Learn, Open-CV, Matplotlib, Pandas, Numpy, Tensorflow etc., are available online, where each one of them have methods defined for their usage. Scikit-Learn, Numpy and Pandas are few main packages which are used in this project.

CHAPTER 8 – RESULTS AND DISCUSSION

The proposed system to develop E-Nose for Air Quality monitoring was created as a Hardware component integrated with Software using the Interface Circuit. The air is sensed through the Hardware and then processed and classified by the Software.

The dataset is successfully prepared in 3 different environments for getting 3 labels. The dataset totally has 2552 rows of data.

Clean – 766 rows

Moderately Polluted – 1006 rows

Polluted – 780 rows

The sample dataset is shown below. The dataset is prepared and gathered for 4 days to eliminate anomalies. This dataset is fed as input for training for Classification algorithms.

G	H	I	J	K	L	M	N	O	P	Q	R	S	T
time	place	Humidity:	Temperat	AirQua	LPG	CO:	SMOKE:	dust_concentration					
34:00.5	Clean	73.3	28.5	110	0	0	0	1005.01					
34:01.3	Clean	73.3	28.5	110	0	0	0	781.48					
34:02.3	Clean	73.3	28.5	111	0	0	0	2220.53					
34:03.1	Clean	73.3	28.5	111	0	0	0	1203.18					
34:03.9	Clean	73.3	28.5	110	0	0	0	1325.85					
34:04.9	Clean	73.2	28.5	111	0	0	0	997.93					
34:05.7	Clean	73.2	28.5	111	0	0	0	526.46					
34:06.4	Clean	73.2	28.5	111	0	0	0	1143.4					
34:44.0	Moderately Polluted	54.9	32.2	193	0	0	0	3358.3					
34:45.1	Moderately Polluted	54.9	32.1	194	0	0	0	3855.86					
34:45.9	Moderately Polluted	54.9	32.1	189	0	0	0	3995.34					
34:46.6	Moderately Polluted	54.9	32.1	188	0	0	0	5419					
34:47.6	Moderately Polluted	54.9	32.1	187	0	0	0	6375.45					
34:48.4	Moderately Polluted	54.9	32.1	184	0	0	0	8791.25					
34:49.1	Moderately Polluted	54.9	32.1	185	0	0	0	10301.03					
34:50.2	Moderately Polluted	54.8	32.1	188	0	0	0	3766.68					
45:42.6	Polluted	43.2	39.9	236	0	0	0	7146.82					
45:43.6	Polluted	41.9	40	236	0	0	0	6301.76					
45:44.4	Polluted	41.9	40	251	0	0	0	7661.74					
45:46.9	Polluted	41.6	40	295	0	2	2	7286.93					
45:47.7	Polluted	41.6	40	294	0	2	2	11880.29					
45:48.7	Polluted	47.7	40.2	290	0	1	1	2565.87					
45:49.5	Polluted	47.7	40.2	282	0	2	3	2890.51					
45:50.2	Polluted	47.7	40.2	296	0	4	4	11498.33					
45:51.3	Polluted	48.6	40.2	309	2	9	6	5051.66					
45:52.0	Polluted	48.6	40.2	311	1	4	2	4797.65					
45:52.8	Polluted	48.6	40.2	294	0	0	0	7879.43					

Fig. 8.1 Dataset for E-Nose Air Quality Monitoring

"Grid Search" is performed and found that the dataset is Non-Linear. Hence, we use different Non-Linear Classification Techniques to classify the data.

For all the following results, Training set = 80% of Dataset

Test set = 20% of Dataset

The tuned parameters for each algorithm, if performed 'Parameter Tuning', are indicated while the rest are default parameters.

1. **K – Nearest Neighbors**

   Tuned Parameters : number of neighbors = 5

   metric = 'minkowski'

   Confusion Matrix :

	0	1	2
0	143	0	6
1	0	150	0
2	13	0	199

Fig. 8.2 Confusion Matrix for KNN

Accuracy in Percentage : 96.2%

```
In [3]: classifier.score(x_test, y_test)
Out[3]: 0.9628180039138943

In [4]:
```

Fig. 8.3 Accuracy for KNN

2. Logistic Regression by LDA

Here 0,1,2 in the scatter plot are Clean, Moderately Polluted and Polluted labels respectively.

Confusion Matrix :

	0	1	2
0	134	0	15
1	0	150	0
2	19	0	193

Fig. 8.4 Confusion Matrix for Logistic Regression by LDA

Training Set Scatter Plot :

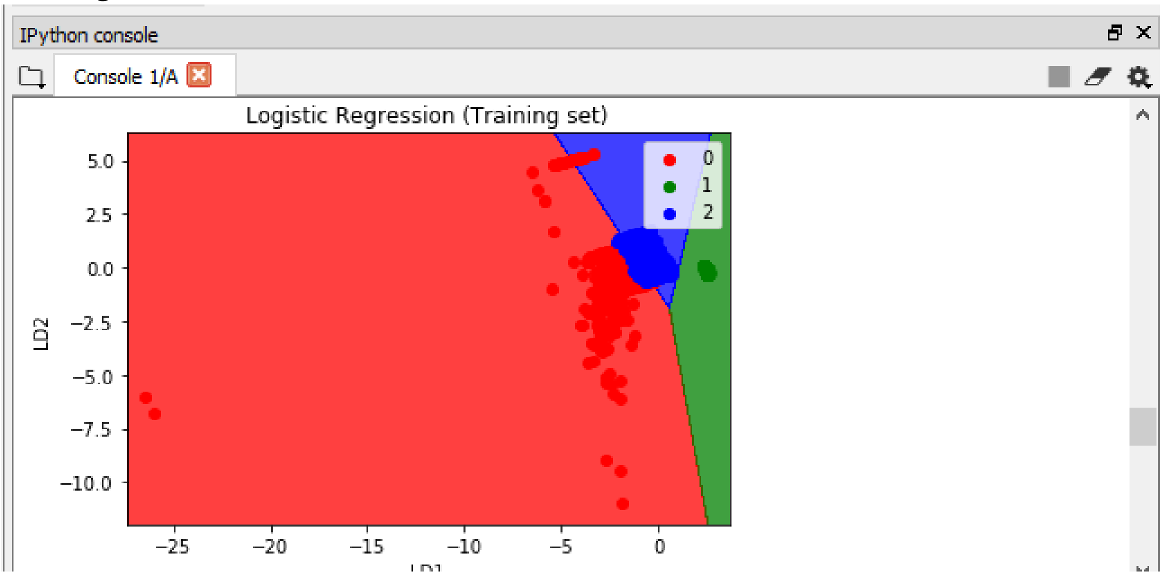

Fig. 8.5 Training Set Scatter Plot for Logistic Regression by LDA

Test Set Scatter Plot :

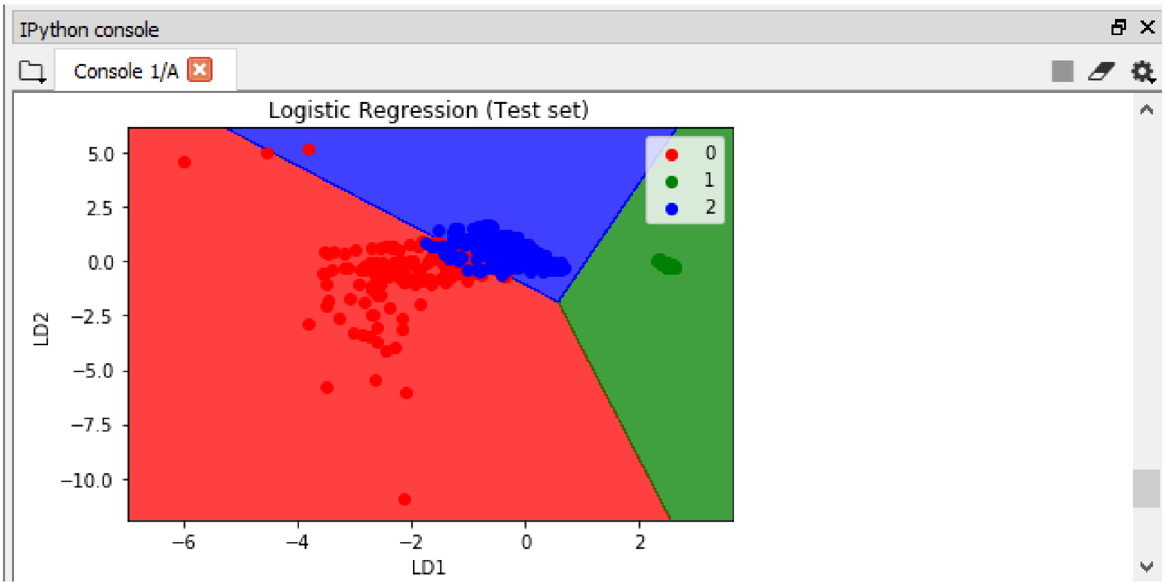

Fig. 8.6 Test Set Scatter Plot for Logistic Regression by LDA

Accuracy in Percentage : 93.3%

```
In [2]: classifier.score(x_test, y_test)
Out[2]: 0.9334637964774951
```

Fig. 8.7 Accuracy for Logistic Regression by LDA

3. Support Vector Machine

Tuned parameters : kernel = ‘rbf’

Confusion Matrix :

	0	1	2
0	134	0	15
1	0	150	0
2	16	0	196

Fig. 8.8 Confusion Matrix for SVM

Accuracy in Percentage : 93.7%

```
In [2]: accuracies.mean()
Out[2]: 0.9377602385724717

In [3]:
```

Fig. 8.9 Accuracy for SVM

4. Random Forests

Tuned Parameters : number of estimators = 10

Criterion = ‘entropy’

Confusion Matrix :

	0	1	2
0	144	0	5
1	0	150	0
2	12	0	200

Fig. 8.10 Confusion Matrix for Random Forests

Accuracy in Percentage : 96.6%

```
In [2]: classifier.score(x_test, y_test)
Out[2]: 0.9667318982387475

In [3]:
```

Fig. 8.11 Accuracy for Random Forests

5. XGBoost

Tuned Parameters : estimator = 'classifier'

Confusion Matrix :

	0	1	2
0	147	0	2
1	0	150	0
2	2	0	210

Fig. 8.12 Confusion Matrix for XGBoost

Accuracy in Percentage : 98.3%

```
In [2]: accuracies.mean()
Out[2]: 0.9833185156447222

In [3]:
```

Fig. 8.13 Accuracy for XGBoost

CHAPTER 9 – FUTURE PLANS

1. Since the prototype works on the sensors, the next step is to populate the array of sensors and analyze more different pollutants for Air Quality.
2. Addition of wireless and Cloud technology to transfer the data remotely from the E-Nose to the compute / Pattern Recognition system is to be done. This helps to monitor ad operate on the data remotely.
3. In the existing system, the hardware can be optimized to convert the prototype into product. There can be a Circuit board affixed with sensors. All the connections can be automatically done using the board.
4. Since the prototype relies heavily upon the Hardware aspect, the size is one of the major considerations. The aim will hence be to develop a circuit board having inbuilt sensors and the connections and an interface unit, which thereby reduces the size and complexity.
5. Finally, to check if the device fits in carious working environments, virtually, an augmented reality model of the device and the environment can be created to check if it fits rightly.

CHAPTER 10 – REFERENCES

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