Development of Intelligent Electronic Nose for Livestock Industries

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Abstract*— This paper describes the development and application of our electronic nose (e-nose) machine and algorithms for monitoring of malodor emission. Malodor emission from livestock farms have been known as a significant source of odor nuisance resulting in increased complaints and environmental issues. E-nose technology has provided solutions to variety of these odorous problems with identification of the odor source and real-time monitoring of odor diffusion into the environment. This lab-developed electronic nose system consists of eight metal oxide semiconductor (MOX) gas sensors as sensing materials, including a humidity sensor and a temperature sensor. The gas sensors were specifically selected for the main volatile compounds emitted from the livestock farms. Principal Component Analysis (PCA) was used as classification algorithms combined with data analysis techniques, which enable the recognition of different odor samples. In this work, five commercial poultry farms were selected for odor monitoring using the in-lab developed e-nose machine. The field experiments were conducted at various sites in the farms such as chicken houses, manure storage, biogas facilities, downwind points and in nearby villages. Odor concentrations were mainly detected behind the poultry house fan (Max. 11 odor unit). In addition, the malodor sources have been investigated with the e-nose in each poultry farm. High concentrations of malodor were identified in the poultry farms with poor manure handling system and poor building management. In conclusion, the e-nose technology has the potential of providing monitoring capabilities for livestock and agricultural industries. The use of e-nose device is recommended to apply in the livestock farms to reduce neighbourhood complaints and risk on workers' health and safety.

Keywords—electronic nose, livestock farm, poultry farm, odor emission

I. INTRODUCTION

The livestock industry has played a crucial role in economic development which serves as an important sector of the global food system. The livestock sector contributes to poverty reduction, food security and agricultural development. According to the Food and Agriculture Organization (FAO), livestock contributes to nearly 40% of global value of agricultural output and supports the livelihoods and food and nutrition security of almost 1.3 billion people worldwide [1]. For that reason, the sustainability in the livestock sector must be improved in term of environmental impacts, risk to animal and human health.

Fig. 1. Environmental problems of poultry farm and E-nose station for odor monitoring

In 2019, the Department of Livestock, Ministry of Agriculture and Cooperatives Thailand has announced data on animal and livestock farmers of 2,996,330, divided into 2,644,690 chicken farmers followed by 826,060 beef farmers, 439,626 duck farmers and 185,6988 pig farmers [2]. These large number of livestock farms can cause environmental pollution through wasted water, odor, dust and flies (Fig.1).

Among the major livestock farming, poultry farming has been the one that causes serious environmental problems raised by community expansion towards farm areas as well as farm expansion near the rivers. Nowadays, poultry farms have been operating under the closed-house system with considerable benefits. Nevertheless, there are some negative impacts of closed system such as dust, gas and malodor emission. The main harmful gases produced from decomposing manure are hydrogen sulfide, methane, ammonia and carbon dioxide [3]. High concentration of these gases can pose a risk to human and animal health. These specific gases can be easily detected using gas detecting equipment. However, the malodor emission comprises various complex compounds, which requires a suitable detecting equipment with high precision and reproducibility.

Currently, the odor emission has been identified with human sensory test as the standard test method. This method is a qualitative descriptive analysis and is prone to bias, errors and produces inaccurate results. Hence, development of artificial nose such as electronic nose for odor monitoring

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can solve such disadvantage. Electronic nose technology provides accurate results, quantitative analysis, detection of hazardous gases, accurate results and real-time monitoring for long period of time. Fig. 1. shows the environmental problems in a poultry farm and example of e-nose application for real-time odor monitoring.

II. BACKGROUND

A. *Principles of Odor Measurement*

Odor sensation is induced by the interactions between odorants and specialized receptors in the olfactory epithelium in the top of the nasal cavity [4]. Odorants are volatile, hydrophobic compounds that have molecular weights of less than 300 Daltons. The signals induced by such molecular interactions are transmitted to the olfactory bulb and ultimately to the brain [4]. Odor sensation is produced by mixtures of odor molecules that differ in their components. Humans have limits on the capacity to identify single odorants in mixtures with three to four components being maximum [5].

Electronic nose is designed to simulate the human olfactory system based on an array of chemical gas sensors. The mechanisms to identify odorous substances of an e-nose machine are similar to human nose mechanisms. The human olfactory system is composed of olfactory cells, an olfactory neural network, and other elements. Compared to the human nose, an electronic nose includes three major parts: (1) a headspace sampler as sample delivery system, (2) an array of gas sensors as detection system, and (3) a computing system. The gas sensors simulate the human olfactory cells, which transform odor molecules attached on the surface into a single group and measured by physical methods [6]. The signal processing system is similar to human olfactory nerve system, which analyses and classifies the data obtained from the sensor array.

B. *Sensing Mechanism*

An electronic nose (e-nose) integrates an array of non-specific sensors. Their important properties include sensing response, sensitivity, selectivity, adsorptive capacity and operating temperature. Sensor types used in an e-nose system can be based on conductive polymer (CP), metal oxide semiconductors (MOS) or quartz crystal microbalance (QCM) [7].

Among these sensor types, metal oxide semiconductor (MOS) sensors are the most widely used for construction of electronic nose due to their good gas sensing layer interactions and consequently higher sensitivity. The most sensing materials of MOS include tin dioxides, zinc oxides, iron oxides, titanium dioxide, nickel oxide and cobalt oxide [8]. Metal oxide based chemiresistive sensors such as WO_3, SnO_2, TiO_2, CuO, ZnO and In_2O_3 have been used mostly for odor detection. However, the use of metal oxides presents some challenges in chemiresistive sensing application, i.e. selectivity and stability [9]. MOS sensors operate at high temperature of 200-500°C, responsive to reducible gases such as H_2, CH_4, C_2H_4 or H_2S leading to an increase in their conductivity [4]. The sensing mechanisms in metal oxide gas sensors are based on oxygen exchange between the volatile gas molecules and the metal coating material on the sensor surface, generating the resistance change between the electrodes. These resistances are converted into an output voltage signal and digital signal by data acquisition circuit (DAQ) [10]. An algorithm processes the sensing signal to a suitable format as required by the classification algorithm. The performance characteristic of sensor is based on properties including sensitivity, selectivity, detection limit, response time and recovery time [11]. The sensing response (S) of a sensor can be determined by the following equation (1).

$$S = \left(\frac{R_f - R_s}{R_s}\right) x100 \quad (1)$$

R_f	is the gas-resistant reference gas (usually air)
R_s	is the resistance of the reference gas containing the target gas

III. METHODOLOGY

In this work, an e-nose station was developed for odor monitoring in livestock farms. The e-nose station consists of odor monitoring subsystem integrated with a weather monitoring subsystem to measure wind speed, wind direction, rainfall, humidity and temperature, which are important factors that contribute to variation of the odor level.

A. *E-Nose System Overview*

An online odor monitoring station was designed to measure the odor intensity using electronic nose technology. The e-nose station consists of three major components: sensor chamber, microcontroller and software program as shown in Fig. 2. This odor monitoring station also has meteorological sensors for measuring the environment around the station to analyze the odor intensity. E-nose station will read odor data and meteorological data every minute and then sends the data to the cloud operating system through the wireless data transmission module. A cloud operating system with an artificial intelligence program and an odor database analyze the odor intensity and source of the odor. Analysis results are displayed on the website.

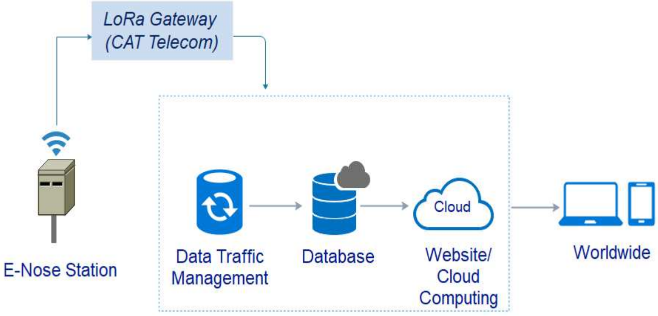


Fig. 2. Overview of E-nose system

B. *Experimental Hardware Architecture*

Sensor unit is a crucial part used for measuring the odor and weather parameters. In this prototype, a sensor array is composed of eight metal oxide gas sensors from Figaro company and each of them is designed to be sensitive to specific volatile compounds as shown in Table I.

These gas sensors were enclosed in a specially designed Teflon chamber. Polytetrafluoroethylene material (trade name "Teflon") has excellent properties, e. g. chemical resistance, heat resistance, weathering resistance, anti-adhesion properties and withstands temperature variations. The system comprises of electrical and mechanical parts. The electrical parts included a circuit board with microcontroller (MCU), memory chip and other peripheral components. The mechanical parts included gas delivery system to transfer the volatiles from headspace sampler to the chamber containing MOS sensors. The sensor chamber has an exterior dimension of 45x30x20 cm. Input voltage is typically 220 Volt (50 Hz). Power consumption is max. 100 watt/hours. Operating temperature range is typically -10°C to 80°C. A relative humidity is between 0% to 10%. Flow rate can vary between 0.5-1.0 liter/minute.

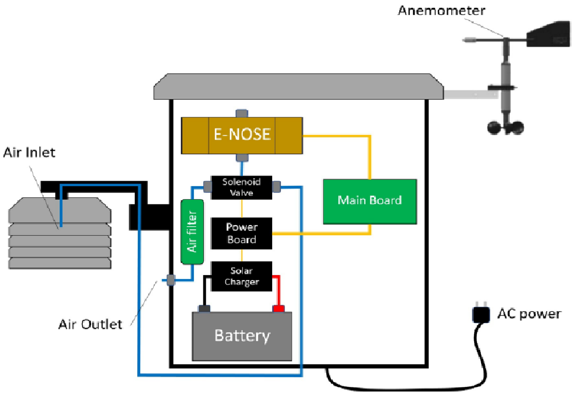


Fig. 3. Hardware architecture

TABLE I. SENSORS USED FOR DEVELOPED INTELLIGENT ELECTRONIC NOSE

No.	Sensor	Target Gas
1	TGS 816	Combustible Gases (Methane, propane, butane)
2	TGS 826	Ammonia (Low concentration)
3	TGS 823	Organic Solvent Vapor
4	TGS 2600	Air Contaminants
5	TGS 2602	Air pollutants (VOCs, Ammonia, H_2S)
6	TGS 2603	Methyl mercaptan and Trimethyl amine
7	TGS 2610	LP and its component gases
8	TGS 2620	Alcohol, Solvent Vapor

Table I lists the metal oxide semiconductor (MOS) gas sensor used in the e-nose. The selection of MOS sensors is primarily based on chemical specificity and sensitivity. Secondary considered parameters are size, cost and power consumption. The sensing element of Figaro gas sensors is typically based on tin dioxide (SnO_2) semiconductor with high sensitivity property to target gases. Depending on gas concentration, the gas sensor will increase in their conductivity, which is converted to output signal by electrical circuit [12].

C. *Experimental software Architecture*

Wireless transmission technology has been widely used for online monitoring. In this e-nose prototype, a software program was developed to perform data acquisition, analysis of the signals generated by e-nose machine and control of mechanical devices. The e-nose station transmits data to the cloud through a wireless communication system via LoRa Gateway and network server.

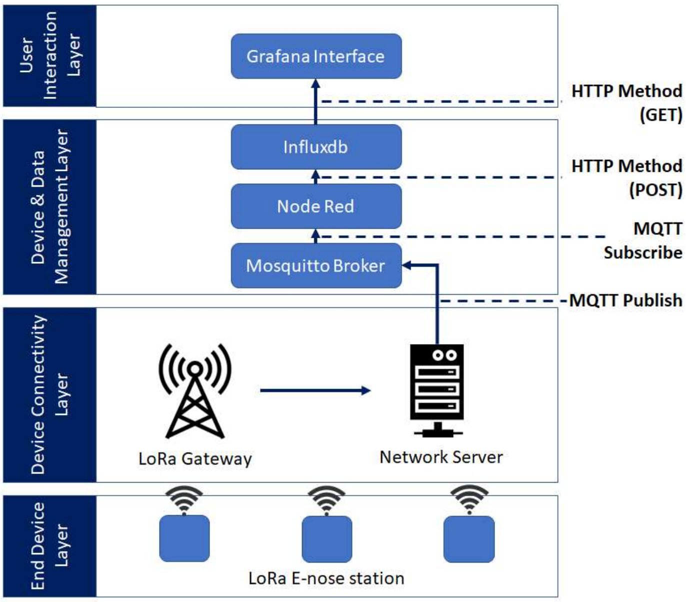


Fig. 4. Architecture of wireless e-nose network

An architecture of developed wireless e-nose network system was shown in Fig. 4. The system consists of four layers: (1) end device layer, (2) device connectivity layer, (3) device & data management layer and (4) user interaction layer. Node red is a data acquisition system for gathering data from the e-nose station by MQTT method (Message Queuing Telemetry Transport). InfluxDB based database is used for storing odor data, which will be transmitted to user interaction layer (Grafana Interface) by HPTT-GET method (Hypertext Transfer Protocol).

D. *Correlation between E-nose signal and human olfactory verification*

This study attempts to establish a prediction model for odor intensity by using a machine learning technique. The odor samples were prepared for the experiment. Two methods were employed to measure the odor intensity of odor samples: an e-nose machine and a sensory panel (8-14 human assessors). The dataset obtained from both methods was analyzed with artificial neural network (Radial Basis Function; RBF) to learn the e-nose signal pattern and human sensory results. This RBF neural networks will transform inputs into outputs (odor unit). Fig. 5 shows the correlation procedure for odor intensity verification.

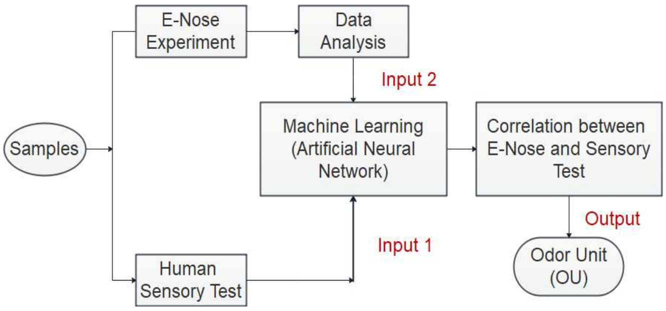


Fig. 5. Correlation method for odor intensity

E. Description of experimental sites

Five commercial poultry farms located in the central part of Thailand were examined in this study (Table II). The chicken buildings in all farms are closed system with similar manure handling process, in which the manure collection was accomplished after harvesting of poultry (45-46 days). In each farm, the parameters such as chicken age, chicken density in the building, temperature and relative humidity were recorded for further root cause analysis of malodor emission. Furthermore, the influence of various factors on odor intensity must be determined such as manure storage facilities, manure storage duration, type of house and ventilation. This information was collected through survey and interviews with the owner and farm workers.

TABLE II EXPERIMENTAL SITES

Farm	Number of Chicken	Number of Building	Age (Days)	Chicken density (chicken/m^2)	T (°C)	RH (%)
1	44,000	4	40	0.12	31.5	75.7
2	52,000	2	46	0.1	28	61
3	183,000	6	46	0.1	29.2	79.2
4	450,000	14	30	0.12	31	68.8
5	900,000	37	42	0.08	29.5	79

F. Experimental design in poultry farms

The experiment procedure started with the survey of the farm area, installation location and wind direction. Installation of the e-nose station was carried out in the evening to perform the measurement for 24 hrs. It was recommended that the e-nose station should be installed in the following areas: near the odor source, at the farm fence, community complaint area or where an unpleasant odor is expected. The installation location depends on the type of odorous problems. Fig. 6. shows an example of experimental design in a poultry farm, where an e-nose station was installed behind the poultry building. Measured parameters using e-nose station includes odor intensity, temperature, relative humidity, wind speed and wind direction.

Before the experiment, the gas sensors in the e-nose system were preheated for 30 minutes to reach a proper operating temperature (above 200°C) and then cleaned by reference gas (air zero grade) after the experiment.

Fig. 6. Experimental design in a poultry farm

IV. RESULTS AND DISCUSSION

In this section, test results of five poultry farms were interpreted in term of odor intensity (odor unit; OU) using continuous odor monitoring method combined with wind speed and wind direction data. Fig. 7-11 demonstrates the results of odor intensity during the period 24 hours.

A. Odor Emission

1) Farm 1 (Ratchburi Province)

In farm 1, the odor intensity at levels 4-8 OU was obtained. The highest odor intensity was 11 OU in the evening due to windless period or low wind speed. The wind blows from the east, which is the direction of the housing fan.

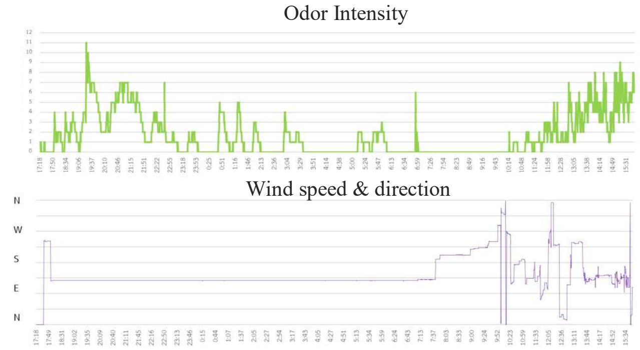


Fig. 7. Experimental results of farm 1

2) Farm 2 (Ratchaburi Province)

In farm 2, the odor intensity at levels 8-10 OU was obtained and the highest odor level was found after 3 pm onwards with most wind direction blowing from the west (Housing fan direction).

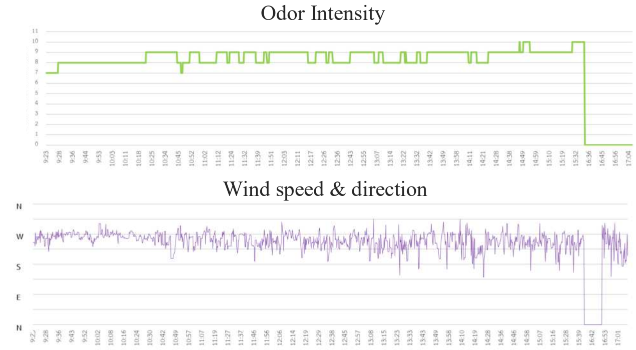


Fig. 8. Experimental results of farm 2

3) Farm 3 (Nakhon Pathom Province)

In farm 3, the odor intensity at level 2-4 OU was obtained in the morning and evening, especially when the wind blows from the east of the e-nose station. The odor level has been reduced when the monsoon wind blows normally during the day.

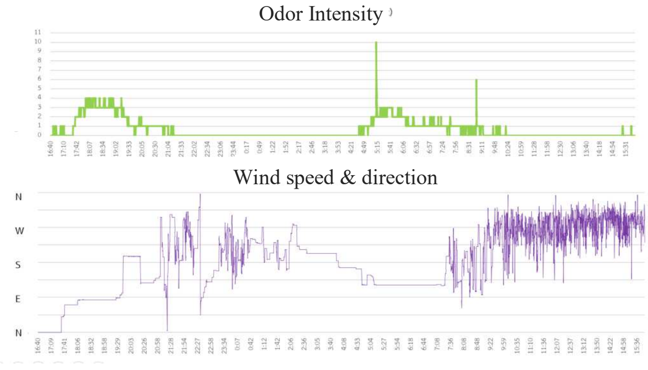
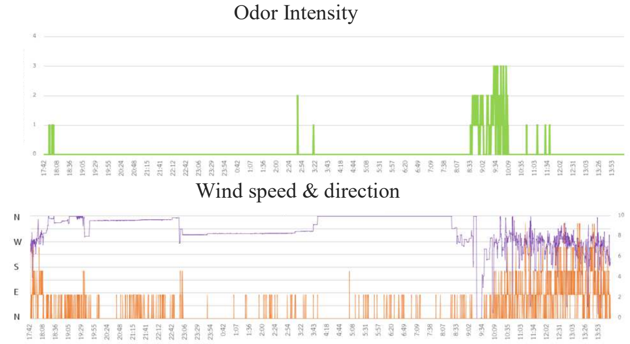


Fig. 9. Experimental results of farm 3

4) *Farm 4 (Nakoen Nayok Province)*

In farm 4, the odor intensity at 1-3 OU was obtained. The highest odor level was 3 OU in the morning around 8.30 am onwards, when most wind blows from the west and southwest, which is from the housing fan direction.

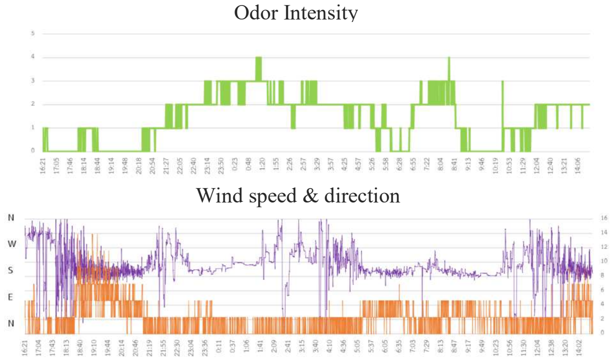

Odor Intensity

Wind speed & direction

Fig. 10. Experimental results of farm 4

5) *Farm 5 (Nakhon Pathom Province)*

In farm 5, the odor intensity was measured at levels 2-3 OU. The highest odor level was found in the middle of the night, when there was no blow of the wind.


Odor Intensity

Wind speed & direction

Fig. 11. Experimental results of farm 5

V. CONCLUSION

In this work, a real-time electronic nose station with a metal oxide semiconductor (MOS) gas sensors array was developed for malodor monitoring in livestock farms.

E-nose station comprises of three main components: gas sensor array, microcontroller and wireless transmission system. The design of e-nose station has considered the ease of use, durability, online and real-time monitoring capability. The e-nose data will be transmitted through LoraWan to a cloud server consisting of Node-red, InfluxDB and Grafana.

This in-lab developed e-nose station was used in five commercial poultry farms to monitor the odor emission. The field experiments were conducted behind the chicken house fan and downwind point of the farms. Farm 1 showed the highest odor intensity at level 11 OU. From the experiment, the high odor concentration usually occurs in the morning and night time. Factors effected to the test results include wind direction, wind speed, temperature, humidity, air pressure and distance from odor source.

According to the experiments, the e-nose technology has the potential of providing monitoring capabilities in the livestock and agricultural industries. The use of e-nose machine is recommended to apply in the livestock farms to reduce neighbourhood complaints and risk on workers' health and safety.

Compared to other established methods used for livestock farm monitoring, this in-lab developed e-nose station provides a real-time odor monitoring and automatic notification for odor exceedance levels.

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