Rapid lard identification with portable electronic nose

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Abstract. Human sensory systems are limited in many different regards, yet they are great sources of inspiration for development of technologies that help humans to overcome their restraints. This paper signifies the capability of our developed electronic nose in rapid lard identification. The developed device, known as E-Nose, mimics human’s olfactory system’s technique to identify a particular substance. Lard is a common pig derivative which is often used as a food additive, emulsion or shortening. It’s also commonly used as an adulterant or as an alternative for cooking oils, margarine and butter. This substance is prohibited to be consumed by Muslims and Orthodox Jews for religious reasons. A portable reliable device with an ability to identify lard rapidly can be convenient to users concerned about lard adulteration. The prototype was examined using K-Nearest Neighbors algorithm (KNN), Support Vector Machine (SVM), Bagged Trees and Simple Tree, and can identify lard with the highest accuracy of 95.6% among three types of fat (lard, chicken and beef) in liquid form over a certain range of temperature using KNN.

1. Introduction
Lard is pig fat derived from its adipose tissue and is often used in food production as an emulsion, shortening, or as a substitute to butter, margarine or cooking oils. Religions such as Islam and Judaism prohibit the consumption of pig derivatives in any form. Besides this, lard being a common choice of adulterant due to it cheap market price and easy availability is a matter for concern. Hence, detection of such adulteration is of high significance.

Several methods and devices have been developed for lard compound detection in food. Polymerase Chain Reaction (PCR), Gas Chromatography (GC), Gas Chromatography coupled with Mass Spectrometry (GCMS), Differential Scanning Calorimetry (DSC), and Fourier Transform Infrared (FTIR) spectroscopy are among the commonly practiced ones. FTIR is the most commonly used analytical tool in detecting lard adulteration in food and vegetable oils. Some research findings of lard adulterant are reported either by mixing lard with other animal fats or adulterating lard in food [1-3]. The limitation of lard detection using FTIR spectroscopy are identified in Rohman and Che Man [4]. Basically, lard has similar IR spectrum with other animal fats and vegetable oils since they are composed with (Triacylglycerol) TAG, with different length of the fatty acid. Another work on FTIR
by [5] reported that the accuracy of the classification of lard adulterated in virgin coconut oil using FTIR Spectroscopy with Partial Least Square and discriminant analysis could be up to 100% accurate. The applied analytical method could detect 1% lard in the mixture. Though FTIR is a common method for the detection of lard mixture with other animal fats as well as adulteration in food products, it however requires laboratory scale equipment’s. Hence, it is not a method that offer portability.

Each of the aforementioned methods have drawbacks which include but are not limited to their requirement for high power supplies, specific skilled operator, the requirement for controlled environment such as laboratory for testing, bulky sizes and high cost.

An electronic nose functions like a biological nose in recognizing the type of vapour that touches its “receptors”. Receptors in an electronic nose are its sensors which can be selected to detect an odour of interest. In general, an electronic nose is a combination of an odour delivery system, sensor (array), data acquisition and data analysis unit [14]. Electronic noses have various applications in environmental and medical researches. They also play an important role in food industry. Some of the applications of electronic noses include detecting different flavours of milk [6,7], meat [8,9], tea [10], spoiled beef [11] and spoiled fish [12].

As to date, there is no portable E-Nose specifically designed for lard detection. Our developed portable E-Nose has the potential to become a reliable and affordable device for rapid detections of lard. This study reports the developed E-Nose and presents its performance. This paper is organized as follows. Section II describes the features characteristics of the developed E-Nose. Section III explains the experimental procedure. Section IV discusses the results for lard identification and Section V concludes the paper.

2. Device Design

2.1. Features
The version of E-Nose used in this study consists of a single metal oxide gas sensor, an AVR microcontroller, signal conditioning circuits, power supply module, peltier to heat the sample, display module and axial fans to contro the air flow. The general architecture is shown in figure 1. The gas sensor used is selected to be sensitive to volatile organic compounds (VOCs).

2.2. Sensor Selection
Animal fats have several chemical compositions which mostly include TAG. In fact, fats share the same fatty acid compounds but different concentration [13]. According to [4], analysis of fats/oils is possible by focusing on lipids components as fats belong to a group of biological substances called lipid. A triglyceride is a chemical compound that is formed from one molecule of glycerol and three fatty acids [15]. Triglyceride is the main constituent of animal fat including pig fat. In addition, lard is mainly composed of saturated fatty acid [15].

![Figure 1: General architecture of the E-Nose for lard detection](image)
In [15] the composition and classification of pig fat is elaborated. It is reported that lard contains up to 10% linoleic acid and small amount of arachidonic acid, which are in the group of unsaturated fatty acids. Another study on lard adulteration using FTIR spectroscopy resulted in identifying both saturated acyl groups and oleic acyl group in lard [2].

The selected gas sensor for this study is capable of detecting VOCs rapidly. Metal oxide gas sensors are commonly used in electronic noses for various applications including pork adulteration [16] quality control [17,10] and as a formaldehyde sensor [18]. Sensing materials used in metal oxide sensor are Tin dioxide [SnO$_2$] and tungsten trioxide [WO$_3$] as both materials are claimed to be highly sensitive to various types of volatile compounds.

Sensor selection was based on the literature, which listed the chemical compounds found in lard [13]. Based on the study, decanal was the chemical compound found abundantly in lard but didn’t have significant presence in chicken fat and beef fat. Table 1 lists the decanal content in the fats of interest in terms of Kovats indices. A set of experiments by [19] revealed that both the sensing materials used in metal oxide sensors are sensitive to the presence of aldehydes. The study investigated the effect of aldehydes when exposed to a based metal oxide sensor. It was revealed that decanal, an aldehyde gives a significant signal change when exposed to the sensor [19]. As such the selected sensor is expected to be significantly more sensitive towards lard than other fats.

The sensor used in our case is coated with a SnO$_2$ layer. Exchange of oxygen molecules due to a reaction of the sample odour molecules and the sensing layer takes place in the identification process. This exchange changes the electrical conductivity of the sensor [20] and is recorded.

Table 1 - Decanal profile, measured in Kovats indices [13].

| Animal Fat  | Decanal (dimensionless) |
|-------------|-------------------------|
| Lard        | 17 444                  |
| Chicken     | 586                     |
| Beef fat    | 408.5                   |

The selected sensor also consumes low power and is small in size. These properties of the sensor contribute towards the portability of E-Nose.

3. Experiment

3.1. Sample Preparation
Adipose tissues from various parts of slaughtered pigs (lard), cows (beef) and chickens were obtained from a local market. The tissues were cut into small pieces, melted at 75°C, and strained through a triply folded muslin cloth. The filtered samples were put through a centrifuge to allow the fat to rise. The separated fat was collected and kept in a tightly closed container under nitrogen blanket in refrigerator for later analysis. Sample preparation was carried out intentionally without the addition of any chemical substances. Addition of chemicals will alter the original nature of the samples.

3.2. The effect of Temperature
It is known in analytical chemistry that changes in samples’ temperatures causes changes in chemical structure. Organic substances like fat are sensitive to temperature. Temperature change applied on fat samples implies change in their physical and chemical properties.
The chemical properties will change due to a radical reaction triggered by breaking and forming of new bonds. Radical reaction occurs in three stages namely initiation, propagation and termination, each of which depend on the molecular concentration in the samples. An oil-profile comparison of different fats proved that all four examined fats, including beef, chicken, lamb and lard shared the same fatty acid components but different concentrations [13]. The same study indicates that concentration of fatty acids determines the type of fat and its chemical and physical properties.

In order to understand the effect of temperature and whether there would be any changes in the odor produced, experiments were performed at the end different temperature levels – 40˚C, 50 ˚C and 60˚C.

3.3. Scanning Process
A sample fat can be scanned by placing it in the device heating chamber. Odor fumes generated are transferred to the sensing chamber using the axial fan. At a sampling rate of 2 hertz the test in run for 1 minute. The data collected is stored on the device memory.

3.4. Pre-processing
Electronic noses are known to suffer from noise and drift. Hence, besides using software based filtering, the collected data also compensated for noise and drift. Compensation is done using a differential technique using equation (1).

\[ Y(t) = X(t) - X(0) \]  

(1)

where \( Y(t) \) is the Settle Point, \( X(t) \) is steady state value of a response signal and \( X(0) \) is the base or starting value of the response signal.

3.5. Post-processing
The collected labelled data set has two features for each observation, settle point and temperature. In post-processing the dataset formed is put through statistical analysis and various classifiers to achieve the results. All the post-processing was performed offline on a desktop computer.

3.6. Cleaning process
It is believed that nitrogen gas in some experiments [21] is necessary to “wash away” the odour from E-Nose as some of the gases leave very strong and pungent odour behind. However, in this study the principle of “Sniff and Purge” [22] which uses the ambient air as the “cleaner” to clean the sensor after every reading is applied. Ambient air was enough to clean the sensor as well as the chamber and the final result was not affected.

4. Results and Discussion
A scatter plot of the entire dataset is shown in figure 2. The dataset consists of 9 unique classes of 3 types of fat each experimented with 3 different temperatures. Each class consists of 10 observations. Each class is represented in the plot by a unique symbol and an abbreviation where the letter “L” represent a lard sample, “C” represents a chicken fat sample and “B” a beef fat sample. The numbers 40, 50 and 60 after the letters represent the temperature in degree Celsius. Three colours, red for lard, blue for chicken fat and green for beef fat have been used to help visualize the plot. The scatter plot shows the two features – temperature and settle point. Temperature implies the temperature of the peltier while the respective test was conducted. Settle Point signifies the overall response of the E-Nose sensor free of drift and noise. A clear separability can be seen overall in the plot as except classes “L40” and “C40” where there are no overlaps. This clarity in separability proves the potential of an E-Nose to distinguish between the three fats and identify lard. The chemical structure of a
chicken fat is very similar to lard and studies conducted with other techniques have proven that as well.

As mentioned before in Section III, temperature was expected to affect the sensor response due to the change in the chemical structure of the fat samples. Figure 3 shows the individual plot of the three classes and their responses at different temperatures. Linear regression lines in the background show an upward trend in sensor response, with lard having the highest gradient out of the three. To claim that this upward trend was due to the chemical changes that must have occurred in the fat sample cannot be explicitly made. The reason being that electronic noses collect only qualitative data and to prove that the chemical changes are responsible to a higher sensor response will require further study. However, due to increase in temperature the density and rate at which the odor fumes are produced must increase, thus giving rise to a higher sensor response. Besides, this lard has the lowest melting point among the three fats and will therefore melt and turn to gaseous state faster. The highest gradient in the upward trend proves this point as well. Chicken fat is supposed to have a lower melting point than beef fat. Even though the sensor response of beef fat has a higher gradient but the settle point values are still significantly lower. In terms of settle point values, chicken fat scored highest above the two as more evident from Figure 2. Melting points of fat vary depending on which part of the animal body it belongs to. This study did not take that into account. However, the higher settle point values of chicken fat can be explained by the fact that chicken fat melting points are very close to that of lard. While as lard fat melting points can vary from 25°C to 45°C, chicken fat melting points range only between 27°C to 35°C. Hence, less variance in the melting point could be a reason for higher settle point values overall.

| Classifier Name | Accuracy (%) |
|-----------------|--------------|
| KNN             | 95.6         |
| SVM             | 95.6         |
| Bagged Trees    | 93.3         |
| Simple Tree     | 91.1         |

Figure 2 - Scatter plot of the entire dataset
A study by Che Man [23] finds a differentiation regression model between palm oil and lard successfully. Another work by Man Che [24] could classify lard from lamb fat. Their work was only capable to classify a mixture of lard and lamb body fat up to 30% adulteration.

In this study, a classification between the three types of fats was also done. Table 2 lists the various classifiers applied with their respective accuracies in descending order.

Higher accuracies of KNN and SVM are expected because the scatter plot in Figure 2 showed clear and separate clusters of each classes overall. Furthermore, Figure 4 shows the confusion matrix of KNN and SVM. Both classifiers have the same confusion matrix results. Interestingly, the classes “L40” and “C40” are confused among each other. However, chicken is being classified as lard 3 out of 4 wrong predictions and lard as chicken as once. This can still be considered in our favour as we are more concerned about lard than chicken.

![Figure 3 - Response towards change in temperature](image)

![Figure 4 - Confusion matrix of KNN and SVM](image)
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5. Conclusion
The findings show that the E-Nose could successfully identify and differentiate lard among three different types of fats. The required sample preparation is simple. There is no need for additional chemical composition for lard detection. The required temperature for the experiment (40˚C to 60˚C) is easy to be achieved and the total testing time for each reading is 60 seconds only. The experiment, i.e. the detection does not need to be conducted in laboratory. The developed E-Nose is portable, light and cost effective. There were no errors in the conducted experiments which shows the device is reliable.

The direction of future work will be to conduct experiments on fats collected from different parts of the corresponding animal body so as to tune the classifiers further to accommodate that variable. Also, the range of temperature has to be increased, and the focus has to be to reduce the testing time further to around 30 seconds.

Nevertheless, so far, our developed E-Nose has been promising and has shown potential for many applications.

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