E-nose for Basal Stem Rot Detection

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INTRODUCTION

An electronic nose is an intelligent device, able to mimic human olfaction functions and may be used for detection, recognition and classification of volatile compounds and odours. An e-nose consists of an array of sensors, signal collecting unit(s) and suitable pattern recognition algorithm. The possible implementations of these devices are wide ranging, from agricultural applications to solving environmental issues. In terms of agricultural applications, e-nose systems have been used successfully to assist product quality monitoring, fruit ripeness determination as well as inspection of fish. The e-nose has also been used to detect the causal agent or element of plant disease such as fungi and bacteria. Fungi produce mycotoxins on agricultural commodities during plant growth or after harvest during storage and shipment, which could be detrimental to living organisms when ingested. Also, the growth of the moulds in grains reduces their nutritional quality and subsequent decrease in germination results in economic loss. The disease is a threat to the oil palm industry causing an estimated annual lost of RM80 million. Hence a novel feasibility study to use an e-nose to detect plant disease, specifically the basal stem rot (BSR) disease, is executed, with a commercial e-nose, Cyranose 320 incorporated artificial neural networks.

Basal stem rot disease

The oil palm tree is a leading source of edible vegetable oil production in the world and in Malaysia, palm oil as a cash crop has superceded natural rubber, and its importance has been further boosted with the introduction of bio-diesel. Its cultivation, in much of South-East Asia, is threatened by BSR caused by G. boninense, where losses can reach 80% after repeated planting cycles. BSR has been causing serious damage to oil palm plantations in Malaysia for more than 50 years and is currently the most important disease of economical importance causing large amount of losses in revenue. In severe infestation situations, more than 50% of oil palm stands can be lost to the disease. The Federal Land Development Authority (FELDA) recorded a high incidence of the disease in Peninsular Malaysia, about 50%, from 1994 to 2005. The disease does not indicate early infection when it progresses from the base. Visible symptoms appear at a very late stage of infection, when more than half of the root tissues have decayed, thus eliminating cure. The causal agent, G. boninense, a white-rot basidiomycete, is a saprophyte or weak parasite that infects living palms if there are massive inoculums as shown in Fig.1. G. boninense produces enzymes that degrade the palm tissue. As the fungus destroys internal palm tissues, it affects the palm xylem, causing serious problems to the distribution of water and other nutrients to the palm tree top, eventually leading to its death. The incidence increases rapidly by the time the palms are 15 years old, the disease levels can reach between 40 and 50 percent of the palm. In severe cases, up to 85 percent of the standing palms succumb to BSR by the time the palms are 25 years old. There are two biochemistry processes used to detect ganoderma infection. The first is culture, such as Ganoderma Selective Medium (GSM).

Fig. 1. Ganoderma boninense fruiting body.

The second category is molecular DNA, such as a polymerase chain reaction (PCR). However, both require stem collection for further tests in the laboratories. There has yet to be a method able to provide real time or in-situ results.

Cyranose 320

The Cyranose 320 (C-320) is a handheld e-nose instrument widely used in quality control, process measurement, hazardous material identification and biomedical sample discrimination. The sensing component consists of an array of 32 conduction-based polymer sensor elements. Each sensor has a different response specificity to a broad range of compounds, and is able to produce limitless numbers of output signals, referred to as the signal pattern or fingerprint.

Pattern recognition
Artificial neural networks (ANNs), an interconnected group of artificial neurons that use a mathematical or computational model for data processing, have been widely used as a pattern recognition tool. It produces a good performance with promising results in chemical vapour recognition. A Levenberg–Marquardt algorithm is chosen because it offers the best performance in terms of speed and efficiency. It has a faster convergence leading to faster optimisation.

Data and sample collection
The ganoderma odour data collection, is performed at FELDA Besout 7 oil palm plantation, Sungkai, Perak, Malaysia. The area of interest is divided into two sections; the first is of normal or healthy plants while the second is the infected area. Three types of odour samples are selected - odour of the air surrounding the tree, odour of bored tree trunk and odour of soil surrounding the base of the tree trunks, which represent different parameters of the tree odour. Three trees are chosen randomly from each section and, three points for each odour parameter are marked as shown in Fig. 2. The tree odours are collected, as are samples, for laboratory analysis. The C-320 readings of these samples are also performed in the laboratory for comparison purposes. The comparison between on-site and laboratory readings enable verification of any physiological change of the samples that may alter its odour profile. Also, the results of this test will dictate whether the odour readings taken on site and in the laboratory are interchangeable.

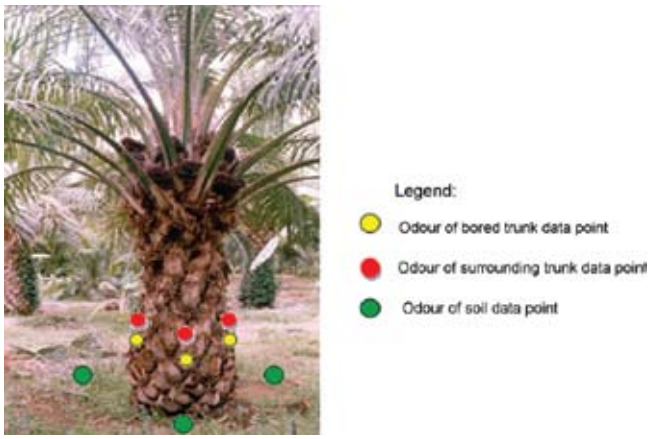

Fig. 2 : Ganoderma boninense fruiting body.

Dimension reduction
Dimension reduction is a process of identifying the most effective subset of the original features to use in the classification process that should lead to a higher classification accuracy. In this study, Principle Component Analysis (PCA) is chosen as it is commonly used in e-nose signal processing. A reduced number of sensors input to the ANN improves the system performance, increases accuracy and efficiency. Only eight significant sensor responses of the 32 will be considered to be ANN's inputs.

Normalisation and ANN analysis
The collected data, normalized to ensure no dominance of any specific sensor to the ANN output, are divided for training and testing. Different network sizes are tested, with the number of inputs and outputs set to eight and one, respectively, since these are determined by implementation. Since eight sensors are input to the ANN after feature selection, the network has the same number of inputs. Since sample implementation only determines healthy or infected sample, a single output is sufficient, with a 1 indicating positive recognition and 0 for negative.

Network testing
Network testing is performed using the test data set, which tests the accuracy of the trained ANN model in discriminating and hence classifying the samples.

Results and discussions

Comparison on in-situ and laboratory data
Graphs are plotted for the mean sensors response against the number of sensors for both data taken in the laboratory as well as on-site, as seen in Fig. 3. The graphs do not show any similarity whereby there must be some physiological changes during transit which caused different odour profiles to be recorded by the sensors of C-320. Hence, only in-situ data samples are used.

The data profile
All tested trees have the same sensor responses. This means that regardless of the tree where the odour was captured, the odour profile of the same parameter remains consistent. This indicates that the data collected are reliable to be used for the ANN training. The best graphical method to present the profile or fingerprint, instead of a bar chart, is a radar plot as shown in Fig. 4 (a–c) which shows that healthy and infected samples have their own odour profile.

Dimension reduction
PCA method expresses the response vectors in terms of a linear combination of orthogonal vectors that account for a certain amount of variance in the data. As a result of applying PCA to an array of 32 sensors when applied to three types of BSR disease environment parameters, two principle components are kept, which account for 99.32% of the variance in the data set (PC1 and PC2 accounted for 74.67% and 24.65% of the variance, respectively).

Sensors selection
The selection of sensors is taken from the eight high valued PCA coefficients. Sensors are chosen based on the presented high responses to the samples for all parameters. Only the data from these sensors will be used as the input to the ANN.

Results from the ANN training and testing
The training of the ANN showed that the e-nose was able to discriminate healthy and infected tree trunk samples. After the completion of the network training phase, a hundred data of each sample is tested using the resulting ANN model, with a 100% accuracy.

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Conclusions

A successful application of an electronic nose, Cyranose 320, as a frontend sensor with artificial neural networks for the discrimination of oil palm trees infected by G. boninense has been shown. This is the first step in proving the feasibility of using an e-nose for plant disease detection. The next phase of the research will study the ability of the proposed e-nose setup to differentiate the different levels of infection stages of the fungus. This will lead to the implementation of the system for early infection detection application.

The odour profiles recorded are consistent for each tree, and the 32 different sensors in Cyranose 320 are able to give individual odour fingerprints of healthy and infected trees. The PCA used as feature selection, has successfully to reduced the execution time of ANN training as well as to improve the accuracy of classification. These results are valuable as they proved the feasibility of using an electronic nose with artificial intelligence to discriminate healthy and infected plants, hence the detection of plant diseases. The system can be easily adopted for different diseases, and this approach holds promise for a better plant disease detection and monitoring.

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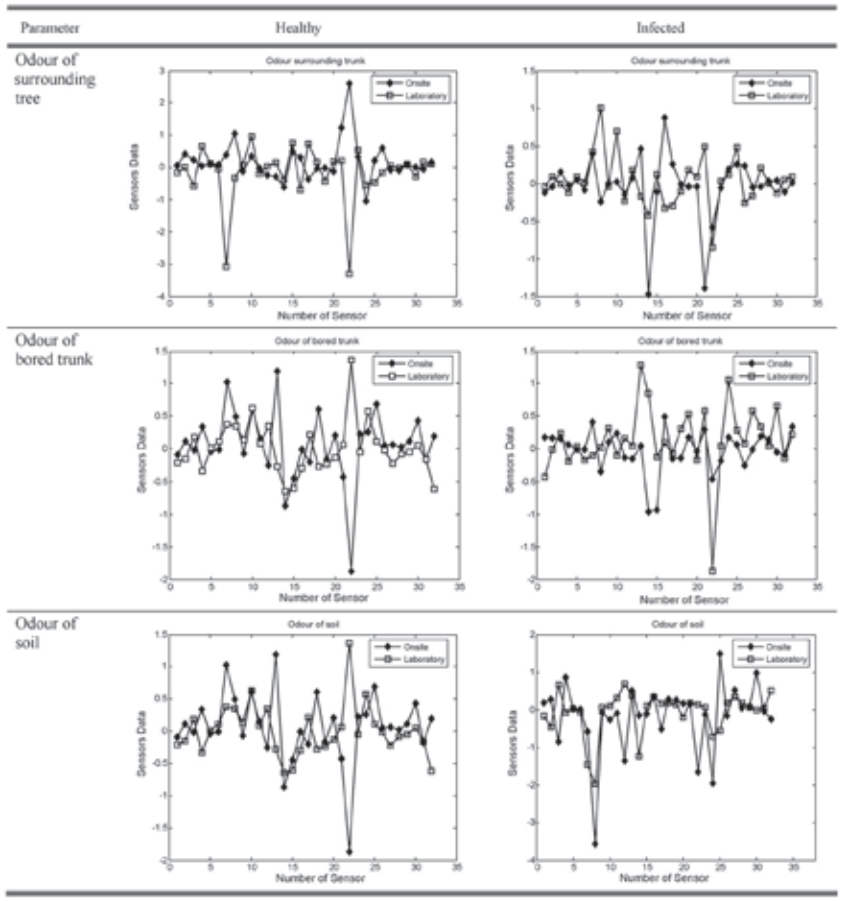

Fig. 3 : Onsite and laboratory data comparison.

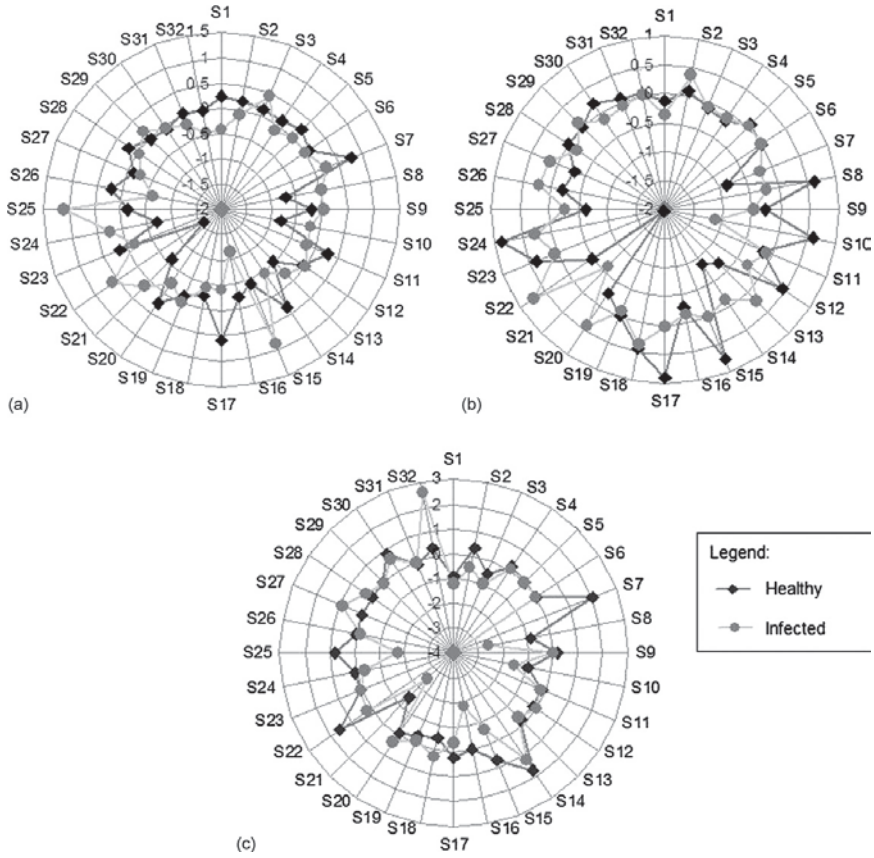

Fig. 4 : (a) Profile of healthy and infected data for odour surrounding the trunk.
(b) Profile of healthy and infected data for odour of bored trunk.
(c) Profile of healthy and infected for odour of soil.