Title Sensor fusion models to integrate electronic nose and surface acoustic wave sensor for apple quality evaluation

Author Changying Li and Paul H Heinemann

Citation Thesis, Doctor of Philosophy (Agricultural and Biological Engineering). The Pennsylvania State University.319 pages. 2006.

Keywords Sensor fusion; Electronic nose; Surface acoustic wave sensor; Apple

Abstract

Because of the importance of fresh produce in the U.S. to both the economy and people's health, it is essential to maintain the quality of this valuable resource. In this project, sensor fusion technology was applied to two artificial noses: the Cyranose 320 electronic nose (Enose) and a surface acoustic wave sensor (zNose(TM)), in order to develop a system for non-destructive, rapid detection the safety and quality of fresh produce.

Dominant volatile compounds associated with healthy apples and physically damaged apples were identified by gas chromatography and mass spectrometry (GC-MS). The results proved that the volatile compounds from healthy apples and damaged apples are different both qualitatively and quantitatively.

The Enose and zNose(TM) were firstly independently studied. Different statistical models, such as PLS-DA and PLS-CVA, were developed and performed on the data on individual days and one single month. It was found that statistical models were effective for separating healthy from damaged apples when individual days or single month data were analyzed. When data from different months were combined, statistical models could not give desirable results due to the non-linearity of this problem. In order to improve the system classification performance, artificial neural networks (ANN) were used to develop classification models. Three ANN models (back-propagation, probabilistic, and learning vector quantification networks) were developed and tested on data sets collected in three different months. Results showed that all three ANN models achieved better classification performance than statistical models when data from different months were pooled together for both the Enose and zNose(TM) data. Among these three ANN models, the PNN was superior, considering the classification quality (85% and 77% classification accuracy for the Enose and zNose(TM) respectively) and efficiency (training was faster than BP and LVQ).

Another focus of this research was to reduce data dimensionality of the Enose and zNose(TM). Various methods were investigated towards this end. Although methods such as the PCA loadings method, F-value selection and sequential forward/backward search reduced data dimensionality to various degrees,

evolutionary algorithms were proven to be a more powerful and robust search approach. Evolutionary algorithms reduced data dimensionality 75% and 50% for the Enose and zNose(TM) respectively, and the classification error rate for the two instruments was reduced by 10% for the Enose and 20% for the zNose(TM).

Multisensor data fusion models both at the feature and decision levels were developed to combine the Enose and zNose(TM) data to improve classification performance. At the feature level, ANN-based fusion models (dynamic selective fusion) reduced the classification error rate to 1.8% on average in 30 independent runs, and at the same time only about 50% of the sensors from the Enose and zNose(TM) were used for input. At the decision level fusion, a Bayesian network was developed to combine classification decisions made by the Enose and zNose(TM) classifiers independently. It was found that using soft evidence produced by the BP classifier either with or without prior performance knowledge gave the best improvement of classification performance.

Finally, trained models were tested on new data sets which were collected by measuring the presence of one bad apple placed amongst three good apples in a 4 L concentration chamber. Sensor fusion models could achieve 81% and 82% classification accuracy at the feature level and decision level; when selected sensors were updated, the classification accuracy of sensor fusion models were improved to 97% at the feature level and 91% at the decision level.

This study introduced three artificial intelligent technologies into food quality and safety evaluation: artificial neural networks, evolutionary algorithms, and multisensor data fusion, utilizing information from two advanced volatile detection instruments. Sophisticated algorithms improved the performance of two artificial noses and showed promise of eventually achieving non-destructive detection of physically damaged and fungi-diseased apples.