The Electronic Smell of the Orchard Fruit

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Abstract

Assessing fruit maturity at the end of the season is a hard task for fruit growers. This task is either made by visual inspection – which is tedious and time consuming - or using destructive procedures for measuring biophysical properties of the fruits, such as the sugar content. An alternative to measure the ripeness of fruits is measuring the volatile organic compounds emitted by the fruits. An important compound produced by the fruits in this stage is ethylene (C_2H_4). The recent advances in electrochemical semiconductors have enabled the rapid growth of electronic noses technologies and applications. Nevertheless, the research reported where its characteristics and limitations are explored only addresses experiments in controlled and indoor settings. Therefore, many questions remain regarding the electronic noses applicability in outdoor environments. This work presents preliminary evidences that there are good chances that ethylene can be detected outdoors via an electronic nose placed within an orchard field. The results presented are measurements acquired in a Conference pear (*Pyrus communis*) orchard in September 2017. The measurements where acquired on several points within the field, and the maximum ethylene detection shows an increase of 10% over 400 seconds. These results were contrasted with a theoretical study where gas dispersion patterns can be appreciated when subject to the wind speeds recorded in the field. The simulation results indicated a good correlation between the practical and the theoretical simulation results. To the best of our knowledge this work is the first to report results from measurements using electronic noses in a non-controlled environment, and detecting spatial-temporal variability of natural gas sources.

Keywords: Electronic nose, Fruit orchard management, Fruit maturity, Ethylene detection, Uncontrolled setups

1. Introduction

The worldwide population is increasing so fast that we will not be able to produce food to everyone. This unbalance chain has triggered the alarms from industrials and academics. Many collaborations between the two parties have been carried out over the last years where the aim is to find agrotechnologic solutions that aim to increase food production and preserve its natural quality.

For farmers, to determine the best time for harvesting is key. This time must take into consideration some marketing flexibility, i.e. shelf-life, and reaching a sufficient quality for the consumer. While harvesting immature fruits results in poor quality when ripe and higher susceptibility to mechanical damage, harvesting overripe fruits results in soft and flavourless product, with a very short shelf-life (Kader 1997).

To develop an effective marketing strategy and to increase the efficiency of the use of labour and resources, maturity indices exist to support farmer's decision making. These indices should in theory be simple enough to be performed by farmers, fruit handlers and quality control personnel. Moreover, the samples should be easy to acquire in the field and in inspection points, be objective, i.e., a measurement instead of a subjective evaluation, and be non-destructive.

As fruit matures and ripens, several Volatile Organic Compounds (VOC) are synthesized and emitted by fruits which yield the characteristic aroma of the fruit. In Baietto and Wilson (2015) several fruit aroma characteristic VOC are described. The aroma, as perceived by the human nose is a very simple maturity assessment but as with visual inspection, is a very subjective method. The VOC can also be detected using digital sensors, electronic noses or gas sensors, that can measure the concentration of a certain VOC or a mixture of different VOC and with that infer on the maturity of the fruit.

The first non-destructive attempt for monitoring fruit ripeness using electronic noses is reported in the work from Brezmes et al. (2000). The authors proposed an alternative method in a controlled setup that skip the conventional fruit decomposition. In the following years, several other attempts using similar approaches have been reported (e.g., Gomez et al. 2006, Esser et al. 2012, Ma et al. 2016). Those studies demonstrate that it's possible to classify fruit maturity at several levels, e.g., unripe, half-ripe, ripe, and overripe., using electronic noses, but in a controlled setup through a chamber. To the best of our knowledge, there is no evidence of any attempt for sensing ethylene concentrations within an uncontrolled facility like a fruit orchard field.

The overall goal of this works is to investigate the potential use of electronic noses for inferring the fruit maturity of fruit orchards: 1) Design a low cost and easily replicable ethylene sensor system; 2) Define an experimental setup for testing it within an uncontrolled environment; 3) Substantiate the practical results with a theoretical model; and 4) Discuss the experimental setup re-design.

2. Materials and Methods

Experimental setup

The first measurements performed with the sensor prototype were conducted in Houten in a commercial producer farm, applying a ground sampling methodology. The goal here was to check whether the sensor was capturing some signal and where hand held measurements in the ground, at breast height and in the line, were suitable for detecting ethylene concentrations.

The experiments were carried out in the very morning of the day that the pears were found ready to be harvested by experts and so where there was more probability to detect ethylene. A set of nine points were defined. Seven points where place equidistantly (each 5 meters) in the same row and two other points where placed equidistantly in adjacent rows on west. The measurements where obtained following the points and positions within the points order, i.e., 1-Ground, 2-Breast height (at 1.65 meters above the ground), 3-In line (in the branches). The experimental field and sample locations are displayed in Figure 1.

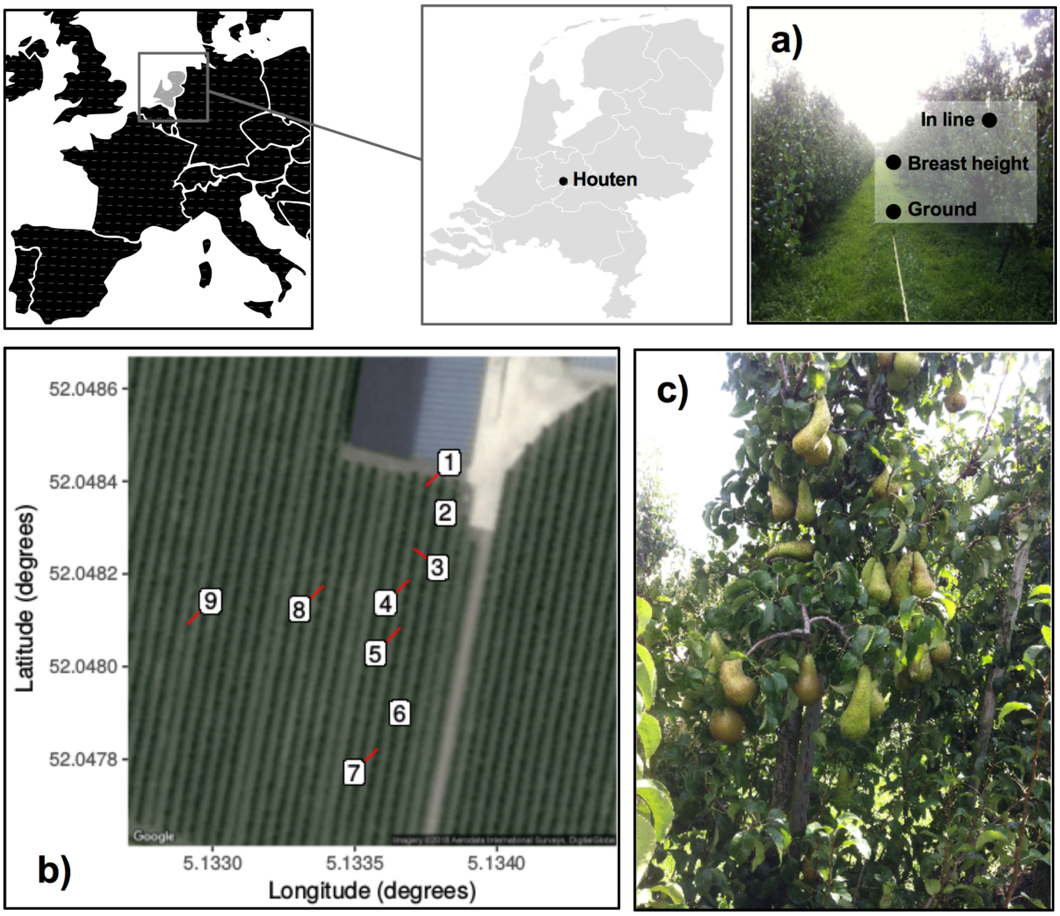

Figure 1. Experiment carrying out on September 12th, 2017 on the harvest day: a) Field measurement heights in each point; b) Geo-reference position from the field points; and c) Conference pear at the harvest time.

Low-cost ethylene sensing system

A prototype ethylene sensor has been developed based in an electrochemical gas sensors, also referred as a Taguchi gas sensors (TGS) and more often electronic nose (e-nose). The prototype, as illustrated in Figure 2 has four main components: 1) Arduino UNO; 2) Adafruit Assembled Data Logging shield for Arduino; 3) Winsen ME4-C2H4 electrochemical gas sensor; and 4) Power source.

The electronic nose sensor specification sheet reports a sensing range of 0 to 100ppm of C2H4 and a response (amount of time it takes the sensor to detect the presence of ethylene) and recovery time of 100s. The sensor prototype is equipped with a memory card when the device is on, with a configurable measurement frequency, measurements are recorded with the respective time-stamp and output signal from the sensor. In these experiments one measurement per second (1Hz) was set as the measurement frequency.

The overall prototype working current is less than 100 mA. The autonomy using a 9 volts' battery is less than 4 hours, while with a 1400 mAh LiPo battery we can increase autonomy up to 14 hours.

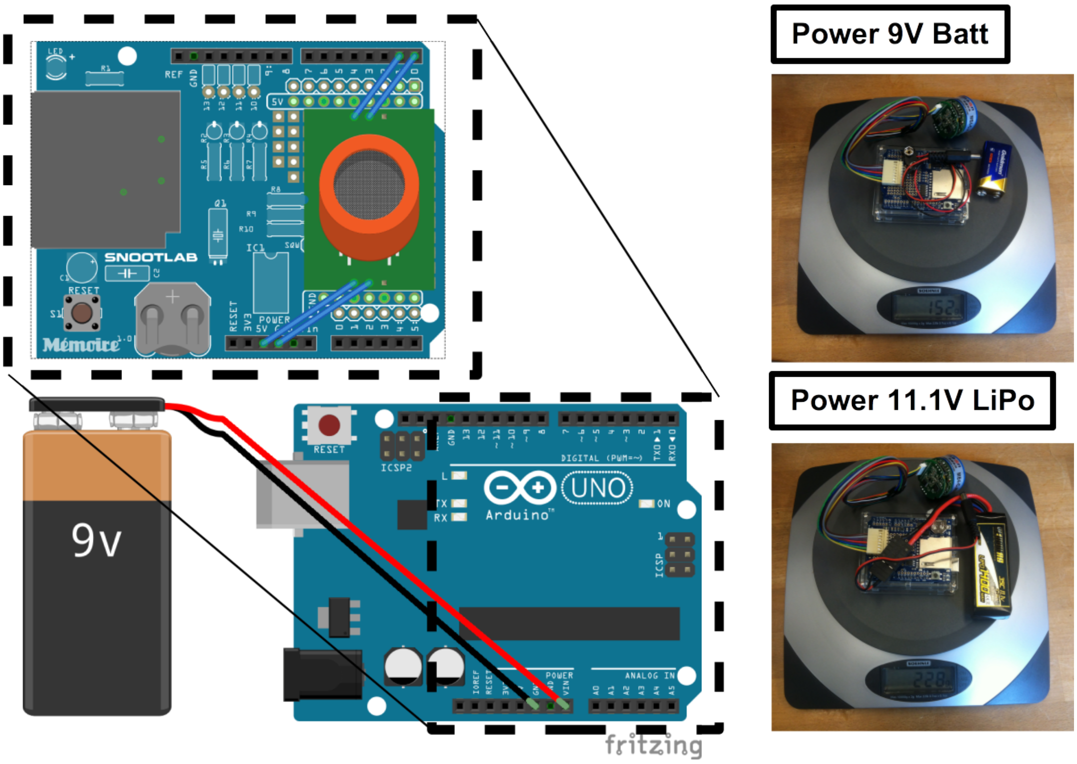

Figure 2. First prototype of the low-cost sensor prototype for detecting ethylene: The assemblage schematic using Arduino-based electronic boards; and final prototype with different power sources (rechargeable and non-rechargeable).

3. Results and discussion

Measured ethylene detections

The average wind speed during those measurements was of about 1.3ms^{-1} (west), measured with a hand-held anemometer. The ambient temperature was around the 19ºC.

Before starting the measurements, the system was turned on half an hour before to ensure the sensor is at the steady state during the measurements. The sampling time in each point was from 4-15 minutes, where the goals was to sample each position from 4-5 minutes.

The data acquired with the electronic nose sensing system is shown in Figure 3. This result seemed to show promise since at the time of the measurements, the harvest was under way and the measurements obtained suggest the absence of fruits in a fraction of the field. The picking started in the early morning going from the most east tree row until the latest row on the west. In the first measurements - point 1 to point 6 - some ethylene is detected, especially in the first point, where the sensor output reaches the maximum in this measurement set. In the vicinity of Point 6 to 9, which confirm the hypothesis that there was no signal because no fruits were on the tree since that area was already harvested.

The measurements from the three first points from the last row show stronger detection signals and special in point 1, where the signal shows an increase of 10% over 400 seconds. The difference of magnitudes between the sensors might explain because the first point was more protected from the wind because of the shed that was close to the row, or due to the shed itself since is a fruit storage facility.

Furthermore, a brief qualitative evaluation was performed considering three characteristics that were important to analyse: Settling time; detection time; and variance. The settled time is defined as the amount of time that the signal is settled (continuous); the detection time is defined as how long it takes for the first detection; and the variance regards to the peaks frequency in the signal. The results suggest that the ethylene concentrations are higher on the ground, and also at the breast height.

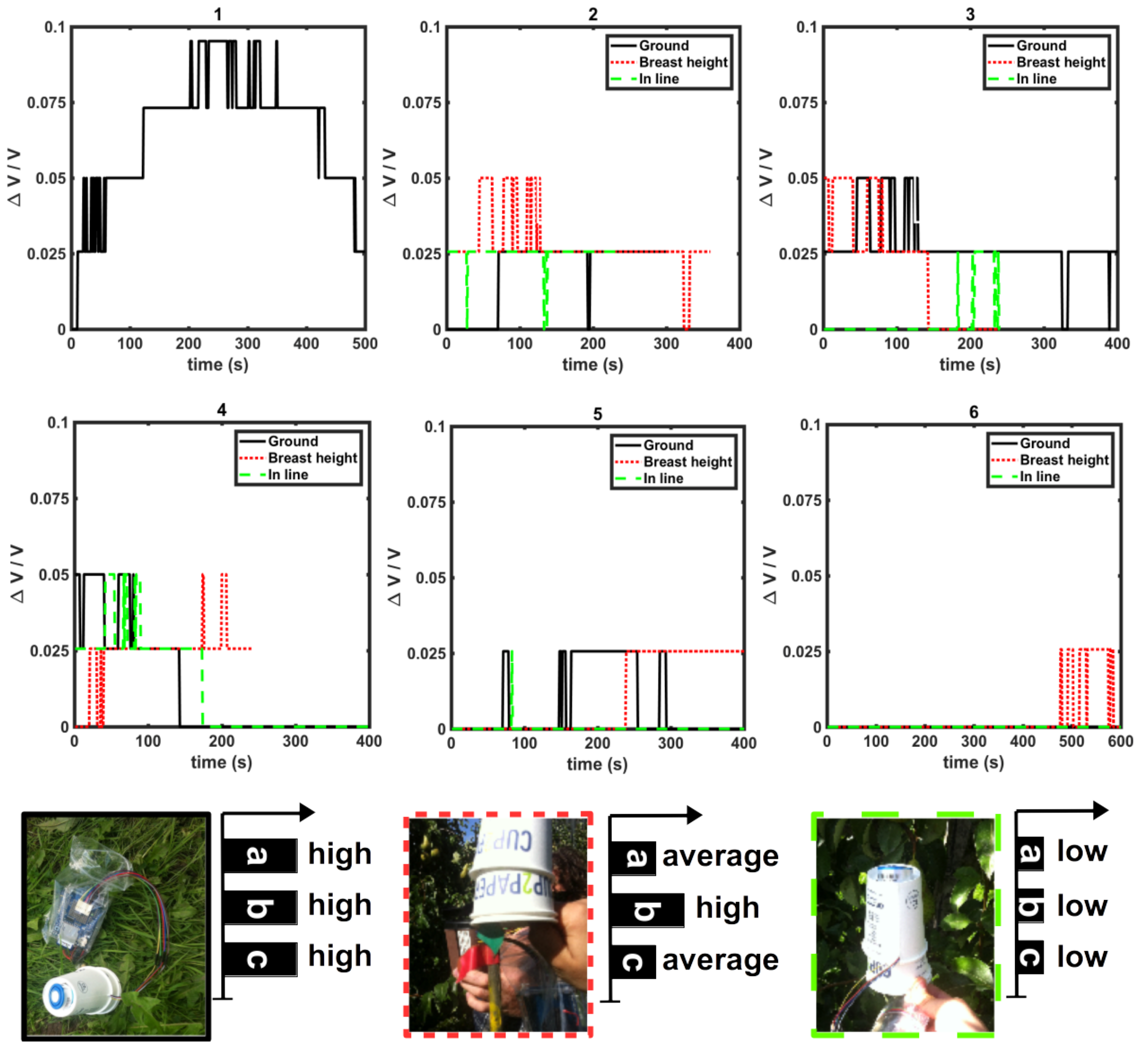

Figure 3. Ethylene measurements from point 1 to 6 at the different positions within the field. The qualitative assessment of the performance o: a-Settling time; b-detection time; and c) c-Peaks frequency.

Simulated ethylene emissions subject to wind speed

The experiments shown in last section shown that the sensor can detect the presence of fruit, the ethylene emission source, although it's hard to draw conclusion about the amount of ethylene concentration measured. The detection and no detection of ethylene are not enough to infer on the pears maturity.

To obtain a model that could provide an estimation for the optimal harvest time we need a more descriptive signature from the ethylene concentrations on the field. There is a hypothesis that the environment changes like the wind during the measurements could had affected the sensor sensibility. Although the average during the measurements was about $1.3ms^{-1}$, a maximum wind speed from $3.3ms^{-1}$ was registered.

The dispersion of the ethylene was studied when subject to wind through a modelling and simulation approach using the as parameters the physical properties from the orchard and from the fruits. For that purpose, the GADEN gas dispersion simulation framework was employed. GADEN is a gas dispersion simulation framework that not only emulates the gas dispersion on a three-dimensional space but also considers obstacles and air flow dynamics (Monroy et al., 2017).

In the orchard model four different zones (volumes) have been defined: Environment (it compresses all the simulated area); Main volume (bounding area around the overall modelled field); In rows (bounding volume corresponding to the orchard rows); and In-between rows (bounding volume corresponding to the orchard in-between rows).

The impact of wind speed in the average ethylene concentration is summed up in Figure 4. The results indicate clearly that the ethylene concentration is higher when not subject to wind speeds higher than $1ms^{-1}$ and that concentration values drops significantly between $1\text{-}2ms^{-1}$. For an increase of $1ms^{-1}$ we get between 67%-92% decrease in the average ethylene detection.

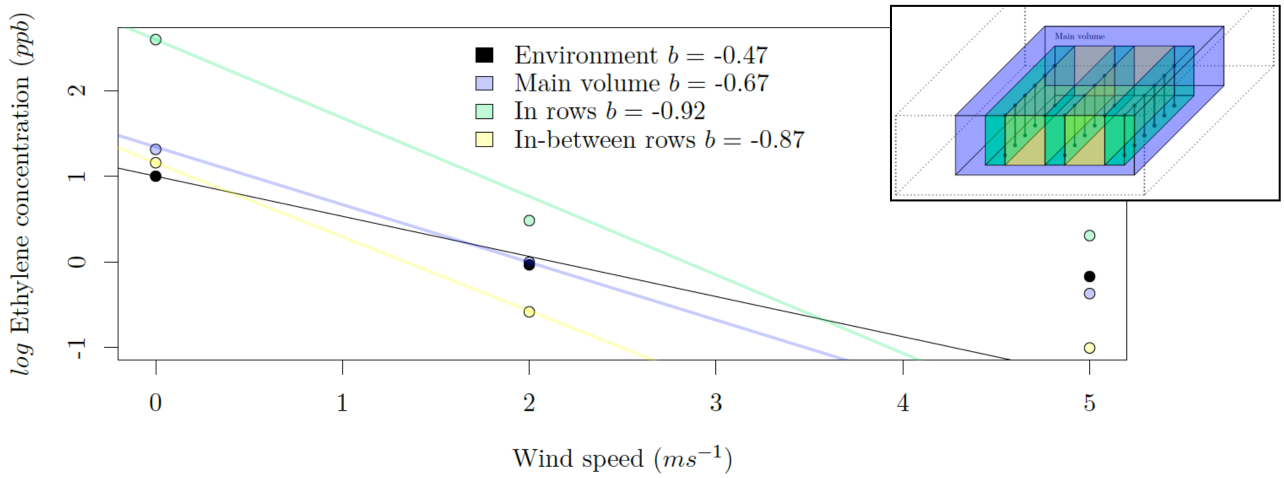

Figure 4. Relation between wind speed and average ethylene concentration in the 4 different zones within the model orchard. The coloured lines represent the trend line for each zone, as given by the equation y = a+bx where b is the decrease in log(ppb) per additional unit of wind speed (ms^{-1}).

The results reported in the previous section are a starting point to carry out further experiments that can yield more meaningful conclusions. What is clear from the field measurements performed is that detecting and measuring ethylene in an uncontrolled environment is a difficult challenge. Furthermore, several lessons were learned regarding to the instrumentation used and the environment conditions:

Sensitivity: In these experiments only one type of sensors was used. It's important to provide from other ethylene gas sensors to exclude all the hypothesis of mal functioning of the current sensors system and have additional ground truth. Look for more sensible sensors if available. Introducing the sensor in an air inlet-outlet camera following the hypothesis that might help to increase the sensor sensibility.

Sampling: The sampling scheme must be upgraded. It is important to have system that is able to increase effective sampling area and the sampling frequency. The sampling time should also be increase to the order of hours. The time series must take longer to increase the probability of detection and to get more informative signals.

Robustness: The sensor system must be robust enough to record data in reliable way. The developing of a new prototype weather proofed should be considered. Important to protect and increase the lifetime of the system. Additionally, the design should be oriented to portability and to be easy to be use in the field.

Environment condition: Wind conditions in the orchard are an important variable in the ethylene concentration dynamics within the orchard, but other variable such like humidity and temperature most probably increase the uncertainty from the measurements. Therefore, in next experiment is important to monitor those variable during the experiment and have it into account in each sample.

Calibration: The raw data outputted from the sensor is not quantifiable until a proper calibration is done. It's important to define a zero-measurement reference in order to understand more about the magnitude from the measurements. This should be achieved in next trial in a controlled environment with an ethylene gas source.

4. Conclusions

This paper report what might be the first tentative to measure ethylene emissions in a ripped fruit orchard by an electrochemical sensor. Although, the concentrations registered were not enough to infer in the fruit maturity, there is a good indication that ripe and not ripe fruit areas are detectable within the field.

Moreover, a theoretical model from the orchard was provided to understand how the wind speed could affect the ethylene concentrations and thus the detection. The simulations show that to carry out further research and ensure reliable detection signatures it's important to avoid wind in the target environment.

Finally, a set of major challenges in measuring ethylene in an uncontrolled environment are identified to continue with this study.

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