FreshSurety

Analysis of Alternatives

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Introduction:

This paper describes any and all known alternatives to FreshSurety's Technology.

It is unfortunate that this is a highly technical subject, so this paper must also be technical, but this detail is required in order to correctly explain why over $95 million of venture capital has been wasted over the last 10 years attempting to predict food senescence (aging).

Perishable products are different:

Unlike most other products in supply chains, fruits and vegetables are living biological entities performing a number of metabolic functions which can be divided into three major stages: growth, maturation, and senescence. Supply chains are most concerned with senescence, the period when chemical synthesizing pathways give way to degradative processes, leading to aging and death of tissue. Fruit ripening is the result of many complex changes, some interactive but many independent of one another.

Two metabolic functions of particular importance in fruit and vegetables are respiration (the breaking down of carbohydrates, giving off carbon dioxide and heat) and transpiration (the giving off of moisture). Once the fruit is harvested, respiration and transpiration continue, but only for as long as the fruit can draw on its own food reserves and moisture. It is this limited ability to continue vital metabolic functions that defines fruit as perishable.

Post-harvest, processing, package, and supermarket shrink occur because of changes that take place during storage, as fruits and vegetables begin to overripen and cause extreme color formation, development of strong off-flavors with intense aroma, softening of the flesh, onset of physiological disorders, and manifestations of disease. Many bacteria and fungi, for instance, are involved in decay after harvest. Typical fungi include Alternaria, Botrytis, Monilinia, Penicillium, and Rhizopus. These fungi are generally weak pathogens, in that they usually invest only in weak or damaged fruit and vegetables.

Background:

The current technology that FreshSurety is using is not the technology upon which the company was founded to commercialize. The original technology is based around chemical sensing inks which can be ink-jetted to create low-cost disposable sensors which could be used to detect changes in perishability dynamics of fresh foods using headspace gases. This technology is virtually identical to the technology employed by C2Sense https://www.c2sense.com/. (They use graphene nanotubes and we use titanium dioxide nanoparticles as an assembly support for emeraldine salt (ES)).

At the time of this company's founding no information was available concerning the real-world limits of headspace gases in actual food transport, so we constructed a probe designed to be inserted at a producer and collected at the end of the grocery distribution cycle. The technology used in these probes is based on metal oxide (MOX) sensors https://www.figaro.co.jp/en/technicalinfo/principle/mos-type.html. Importantly, commercially available sensors of this type use a catalyst to select a particular chemical species they sense. For example, ethylene sensors have a catalyst which filter out most other chemical species which simplifies the associated electronics. This filter reduces the sensitivity of this type of sensor substantially. In fact, as we later discovered, to such a degree that they are useless to determine changes in perishability dynamics of fresh foods.

Because we had no idea what headspace gases were present and at what concentrations in the supply chain the MOX sensors used, our probes were specially constructed for us without a catalyst layer. These sensors could detect all chemical species present and record their response using post processing separation algorithms.

During these early missions into the fresh food value chain, we learned the following which are discoveries new to science.

1. **Food senescence must be modeled as a linear time variant, LTV, not a linear time invariant, LTI, process.** A time-variant system is a system whose output response depends on the moment of observation as well as the moment of input signal application. In other words, a time delay or time advance of input not only shifts the output signal in time but also changes other parameters and behaviors. Time variant systems respond differently to the same input at different times. Proof that food senescence is LTV can be readily found in our data looking at a food's response to step inputs (in the form of temperature steps), which, for a LTI process, must produce a deterministic response that is clearly not demonstrated by the data. Note that food senescence also cannot be fully defined by its impulse response.

2. In order accommodate these facts, we have chosen to model food senescence as an evolutionary process with Markovian dynamics as a function of respiration. We have developed a system of mathematics where food senescence can be accurately described by the chemical composition of its respiratory output as a hidden state variable (of which we can make noisy measurements). In our system, the state transition probabilities of the state variables (as a discrete state variable with arbitrary dynamics and arbitrary measurements) evolve as Hidden Markov Models (HMMs) which can be used to gauge freshness, net present value, and loss function. From these parameters food value chains may be optimized.

We apologize that this description may appear overly technical, but this is necessary to lay the proper foundation for our work. Nearly all statistics courses and tools presented at the undergraduate and even graduate level are based on the statistics of linear time invariant, LTI, processes. Based on our work, these tools are useless to describe food senescence. By extension, any measurement technique based on linear time invariant statistics are also useless to describe food senescence. Wrong tool, wrong answer.

3. Many foods require detection of 3 to 4 parts per billion of many gas species to correctly estimate food senescence based on respiration. The sensors used in our probes are 100 times better than anything we could achieve with chemical sensing inks due to fundamental quantum limits of the sensor ink.

   For this reason, we ceased work on the chemical sensing inks and disposable sensors. Instead, we concentrated on MOX sensors without a catalyst and developed a system of mathematics based on the evolution of state transition probabilities for Markov chains as a linear dynamical system to correctly model food senescence.

4. There is no “magic” gas that indicates food senescence based on respiration, though millions of dollars have been spent looking for one. Multiple gases are needed; it is not possible to narrow the selection down to just a few gases. Food headspaces have a rich abundance of gases, all of which we use in our predictions.

Our innovation is using the same advanced machine learning technology found in SRI International’s SIRI, a technology later sold to Apple, so we can turn an inexpensive sensor into an amazing device to help retailers understand their supply chains better for fresher food and far less shrink.

Alternative technologies:

Time and temperature-based technologies

- The vast majority of our former competitors (they are now out of business) attempted to use measurements of time or time combined with temperature to predict food senescence. Their premise is simple. Food senescence is a chemical reaction which takes place over time, and high school chemistry teaches that the hotter the reagents, the faster the reaction proceeds.

This explanation totally ignores the fact that food is composed of a complex mixture of multiple chemical reactions, and thus a mixture of different reaction rates. There exist lags because of variable starting concentrations enclosed within a non-homogeneous boundary.

As a result, food senescence can be observed to temporarily lag in one state (the transition probabilities clearly do not depend on the time parameter) with a given probability at multiple (sometimes overlapping) steady state points on the food’s complex biochemical landscape. Any attempt to predict the output of such a process by measuring the inputs (time and temperature) to such a process is mathematically absurd. Based on our own data collection, about 33% of all losses are due to mechanical damage, over-the-road vibration, and rough handling. 15% of all losses are due to cool down stress at the producer and about 8% of all losses are due to picking stress (handedness).

12% of all losses are due to field stress (transport and local storage) and 15% of all losses are due to inter-field micro-climate variations. The rest of all losses are due to inter-cultivar variations.

Despite all evidence to the contrary, this has not stopped people from trying to use time and temperature technologies because it is perceived to be "simpler". FreshSurety's technology measures the actual output of the food senescence process in the form of headspace gases in order to determine the changes in perishability dynamics of fresh foods.

In 2018, Walmart conducted trials with 6 vendors on their offerings of time and temperature-based technologies for a "winner take all" to supply Walmart with a supply chain visibility solution for fresh produce. After 6 months, Walmart concluded that none of these technologies worked and all of these vendors promptly went out of business including Zest Labs https://www.zestlabs.com/ (Note: They are back in business only in order to sue Walmart.).

The misuse of this technology applied to food senescence has cost venture capital at least $85 million that we know of.

E-noses (MOX)

– Predicting food senescence using respiration requires measurement of more than one gas due to the complexity of the process and the great variability between different food products. Therefore, gas measurement arrays called electronic noses or E-noses using MOX technologies similar to FreshSurety have long been in development for this purpose. The majority of E-noses utilize an array of metal oxide (MOX) or conducting polymer (CP) gas sensors.

Any chemical measurement system is a compromise between sensitivity, selectivity ,and accuracy. E-nose arrays of MOX sensors where each sensor uses a different catalyst in order to select different species is a great illustration of this fact. An example is https://interestingengineering.com/gadgets-could-sense-smells-with-new-electronic-nose-chip. The basic problem with this technology is that the catalysts unavoidably reduce the sensitivity in order to achieve the required selectivity, deadening the sensitivity to the point that the sensor array is not useful to solve any real-world problem. Gas concentrators can be added but these increase the cost and power draw to the point that they offer no market advantage over conventional gas chromatography or flame ionization detector spectroscopy.

FreshSurety's key innovation is the development of a catalyst free sensor with outstanding sensitivity combined with the use of post processing algorithms to achieve both high selectivity and high precision. We do not characterize our sensors for accuracy, because the relative distribution of particular gas species in the food headspace is important to determine the changes in perishability dynamics of fresh foods and not the absolute concentration of the gas.

E-noses (NDIR)

– Not yet on the market are optical non-dispersive infrared (NDIR) E-noses, which consist of an array of tunable detectors, able to scan a range of wavelengths (3.1–10.5 µm). The functionality of these devices has been demonstrated with good discrimination in university laboratories. Optical E-nose technology therefore demonstrates significant potential as a portable and low-cost solution for a number of E-nose applications including observing changes in perishability dynamics of fresh foods, but we estimate practical products are at least 5 years away.

Gas Sensitive Inks – The original FreshSurety technology. As discussed above this technology suffers from a fundamental quantum lower limit that is over 100 times too high to measure the relevant gases involved in food senescence. Many foods require a limit of detection about 3 to 4 parts per billion to correctly estimate food senescence. FreshSurety's currently technology has an independently verified limit of detection below a part per billion.

This technology also suffers from the fact that irreversible chemical reactions occur within the inks which limits the lifetime of the sensor. Unfortunately, in real operational environments, chemical reaction "poisons" also regularly occur, making it almost impossible to state with any degree of certainty the lifetime of the sensor making them not economically viable.

Membrane-type Surface-stress Sensors (MSS) - These new mechanical sensors are a cross between MOX technologies similar to FreshSurety and gas sensitive inks (above). These sensors detect a change in mass of a very light weight membrane coated with a gas sensitive inks which as it absorbs a particular chemical species. We cannot think of a single advantage of this technology which: 1) must be employed in arrays like the MOX sensor with a catalyst, 2) is sensitive to chemical reaction "poisons" like gas sensitive inks, and 3) is much less sensitive than the MOX sensor.

Optical Methods – What is old is new again. We have been in this business long enough to see both the failure and rebirth of this technology used to measure food perishability dynamics. This technology failed because: 1) it is impossible for light energy to penetrate the surface of food more than a few millimeters creating unknown regions and 2) the sugars used as a basis for estimating senescence are not uniformly distributed within foods (literally one side of the product will produce a different answer than the other).

There is new capital flowing into this optical technology, particularly attempting to combine it with smartphone cameras which have even less chance of working due the fact that any available light source does not have the spectral characteristics required to detect the sugars.

An alternative method is under development by Nanyang Technological University which is a hybrid between an optical method and the gas sensitive inks method. This device used colorimetry to read a bar code which changes color based on the absorption of specific gas species. FreshSurety's original technology also changed colors because our gas sensitive inks are based on dye chemistry, but this effect is secondary to a change in electron hole mobility (like a transistor). We cannot think of a single advantage of this technology which: 1) is sensitive to both the ambient light source and phone camera with unknown spectral characteristics, 2) is sensitive to chemical reaction "poisons" like gas sensitive inks, and 3) is much less sensitive than required to observe changes in perishability dynamics of fresh foods.

Photo Acoustic Spectroscopy (PAS) - These are commercially available single gas sensors based on photo acoustic spectroscopy, PAS. We have been looking at this technology very aggressively.

In this technology, a laser (fixed wavelength) is used to excite a chamber containing the target gas sample. The wavelength of the laser is tuned to the absorption of a specific target gas molecule. The absorbed energy of the molecules causes molecular vibrations, which result in an increased translational energy of the molecules and, due to the closed measuring cell, in an increase of pressure in the cell. A modulation of the light source causes a periodic pressure change in the measuring cell, which can be measured with a microphone. The signal of the microphone can thus serve as a measure of the number of target molecules present in the measuring cell and can be used to calculate the target gas concentration. This technology has been known since 1880.

FreshSurety is interested in the CO_2 detector for post-harvest measurement of bulk potatoes and onions, because it adds CO_2 to our measurement of C2 to C12's gases. We do not see further application for three reasons: 1) even though "miniature" the measurement chamber is much too large to create arrays, 2) it can only measure a single target gas per chamber, and 3) the sensitivity is directly related to the sensitivity of the microphone which imposes a fundamental lower limit of detection that is too high to measure food senescence.

Biological Sensors – A very new competitor is Koniku https://koniku.com/technology which is also using spiking neural AI networks just like FreshSurety does. However, they are using actual living neurons from mice stem cells combined with modified DNA material as the detector. We are fascinated by this technology but aside from the slick web page we have no idea what is real and what is vapor. We tend to fall on the side of vaporware, because we have not figured out how to keep the mice stem cells and DNA alive. We also have no idea how the FDA is going to handle the concept of living mice stem cells and mutant DNA in close proximity to food.

Conclusion:

The Founders of FreshSurety learned at SRI International, Menlo Park CA, to find a solution to an important problem using any available technology, rather than taking a technology and finding a problem to solve with it. Note that as demonstrated in this paper, FreshSurety is not wedded to a particular technology. We are continually monitoring the market for a better sensor, and, in fact, will use any technology if it is better or more cost effective. We simply believe we have found the best solution possible to predict food senescence.

About the Founders

FreshSurety founders John W Hodges and Marc Rippen Patented the GFET device in 2010. https://patents.google.com/patent/US8653510. This device is a novel gas-sensing scheme using a single graphene field-effect transistor (GFET) and machine learning to realize gas selectivity under particular conditions by combining the unique properties of the GFET and E-nose concept. Instead of using multiple functional materials, the gas-sensing conductivity profiles of a GFET are recorded and decoupled into four distinctive physical properties and projected onto a feature space as 4D output vectors and classified to differentiated target gases by using machine-learning analyses. Our single-GFET approach coupled with trained pattern recognition algorithms was able to classify water, methanol, and ethanol vapors with high accuracy quantitatively when they were tested individually. Furthermore, the gas-sensing patterns of methanol were qualitatively distinguished from those of water vapor in a binary mixture condition, suggesting that the proposed scheme is capable of differentiating a gas from the realistic scenario of an ambient environment with background humidity. As such, this work offers a new class of gas-sensing schemes using a single GFET without multiple functional materials toward miniaturized e-noses.

Further on February 16, 2021 FreshSurety founders John W Hodges and Marc Rippen patent for APPARATUS FOR IN VIVO DIELECTRIC SPECTROSCOPY U.S. Patent No.: 10,921,274. was published. https://patents.google.com/patent/US20200217809A1/en?oq=2020%2f0217809

For more Information

See https://pitchbook.com/news/reports/q2-2021-pitchbook-analyst-note-ai-opportunities-in-foodtech

And

For Investors https://vimeo.com/531962691

How it works: https://vimeo.com/538864119

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