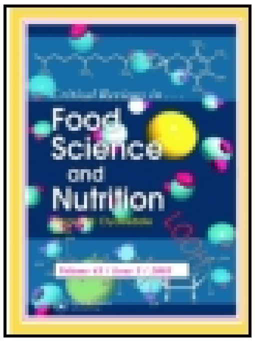

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**Smart Storage Technologies Applied to Fresh Foods: A Review**

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**ABSTRACT**

Fresh foods are perishable, seasonal and regional in nature and their storage, transportation and preservation of freshness are quite challenging .Smart storage technologies can online detection and monitor the changes of quality parameters and storage environment of fresh foods during storage, so that operators can make timely adjustments to reduce the loss. This article reviews the smart storage technologies from two aspects: online detection technologies and smartly monitoring technologies for fresh foods. Online detection technologies include electronic nose, nuclear magnetic resonance (NMR), near infrared spectroscopy (NIRS), hyperspectral imaging and computer vision. Smartly monitoring technologies mainly include some intelligent indicators for monitoring the change of storage environment. Smart storage technologies applied to fresh foods need to be highly efficient and nondestructive and need to be competitively priced. In this work, we have critically reviewed the principles, applications, and development trends of smart storage technologies.

**Keywords**

Fresh foods smart storage technology cold chain

 

*INTRODUCTION*

The term 'fresh foods' usually refers to fruits and vegetables, carcass meat and fresh aquatic products. Fresh foods have high water content, short shelf-life, and highly perishable nature and require special care during storage, transportation and product formulation. They are also characteristically seasonal and regional in nature. The quality of fresh foods continues deteriorate from the point of harvest to consumption due to environmental factors such as temperature, relative humidity and growth of microorganisms. The loss of quantity and quality of fresh foods is quite high especially when the environmental stress is high. In some cases, inadequate and suboptimal storage of this class of food materials can lead to food poisoning and personal injury (Kim et al., 2015). Postharvest decay of foods during their passage through the supply chain has been identified as one of the main factors causing postharvest loss, which results in significant economic loss, particularly in horticulture supply chain (Dayer, 1986). Therefore, rigorous monitoring of quality parameters and their control are essential to ensure the quality of fresh foods during storage and transportation to long distance or to make fresh foods available in off season. The volatile and nonvolatile substances are constantly undergoing changes during storage and transportation. Hence, the quantification and analysis of these changes can help determine the degree of maturity, freshness and deterioration of fruits and vegetables and help predict their shelf life.

Contemporary fresh foods preservation technologies include closely interrelated postharvest pretreatment, storage and cold chain logistics. The slowing down or control of respiratory


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metabolism, minimizing the loss of water from transpiration and providing defense against microbial invasion are at the heart of fresh food preservation technologies. Thus the fresh food preservation technologies help keep the quality as close as that of freshly harvested produce, and minimize the loss of nutritional attributes and extend the shelf-life.

Postharvest pretreatment includes operations such as washing, grading/classification, packaging and precooling. These operations are mechanized or automated in industrial production lines. Sorting is an important unit operation which directly affects the effectiveness of downstream packaging, transportation, storage and sales,etc., and it is also an essential upstream step for standardization and meeting the regulatory requirement (Peng and Zhang, 2012). The demand of fresh foods in global market has increased quite substantially in recent years. In order to meet this demand and also to avoid the negative impact of operations involved during pretreatment on fresh foods, industry is now replacing traditional manual sorting/classification with intelligent sorting(Diao et al., 2014). The sorting methods based on external quality parameters are being replaced by those using the internal and combined (internal+external) parameters. For example, machine vision based online fruit grading systems are commonly used by food industries in European countries and the United States(Aleixos et al., 2002; Leemans et al., 1998; Molto et al., 1998).

Global food waste is estimated to be of the order of 1.3 billon tons per year (Gustavsson et al., 2011). Fresh products are mostly transported through carefully considered cold chain logistics to ensure that each component of the supply chain, i.e., harvesting, storage, transportation, and sale,

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etc. operate within allowable temperature range. This level of temperature control in a supply chain minimizes the risk of food borne diseases, helps maintain the quality by slowing down several physiological and microbial activities(Aung and Chang, 2014; Rediers et al., 2009). It is well known that the product temperature, storage relative humidity and headspace gas composition are some of the most important factors affecting food quality and safety (Ovca and Jevšnik, 2009; Montanari, 2008). An online real-time monitoring of these environmental indicators should be made before the fresh foods reach to consumers. The online monitoring enables operators to know if and when the storage environment changes so that they can make timely adjustments or corrections. Online monitoring also allows tracking of quality parameters of a produce in the entirety of the supply chain.

In the above context, the aim of this article was to systematically and critically review the latest developments in smart storage technologies applied to fresh foods. We can expect to see a rise in commercialized sophisticated smart storage technologies appearing on various fresh foods in coming years, and these technologies can achieve higher food safety and quality.

***ONLINE DETECTION TECHNOLOGIES***

Postharvest processing of fresh foods involves operations such as selection, grading, dressing, cleaning, pre-cooling, packaging and storage. The deterioration of internal quality attributes occurring during the long-term storage of fresh foods can cause substantial economic loss as such deterioration is difficult to observe from outside (Franck et al., 2007). Postharvest pretreatments can reduce the product damage and water loss, prevent the spread of diseases and pests, and


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preserve the freshness and nutritional value of products. Postharvest pretreatment also reduces the loss of quantity and quality of products during storage, transportation, distribution and sale. For example, the quality inspection and grading of fresh foods, can ensure the quality of products in the supply chain (Teena et al., 2013).

There is a continuous push for making the detection technologies fully automatic, capable of detecting the internal quality attributes and making the detection instruments portable, digital and intelligent. Technologies capable of delivering real-time and *in situ* detection of various quality attributes of fresh foods are now available. These detection technologies include electronic nose, nuclear magnetic resonance (NMR), near infrared spectroscopy (NIRS), hyperspectral imaging and computer vision (Table 1).

***Electronic Nose***

Electronic nose (E-nose) is a bionic olfactory system developed in recent years. The application of E-nose is expected to increase in the future as the conventional detection technologies are time consuming, destructive, require expensive equipment, and are unsuitable for on-site monitoring. The use of human subject to detect and differentiate aroma compounds involves trained human subject that frequently suffers from sensory fatigue. E-nose has overcome some of these disadvantages and it is increasingly becoming a method of choice for nondestructively determining the sense of smell. E-nose is designed to simulate human's ability to recognize, analyze and judge the extent and nature of smell. It consists of sample handling, detection, and data processing systems (Peris and Escuder-Gilabert, 2009). A schematic diagram of a typical E-nose system is shown in Fig. 1. Due to its advantages of being sensitive, rapid and easy to operate, E-nose is being increasingly used in diverse fields such as disease diagnosis in agricultural products (Casalinuovo et al., 2006), freshness assessment in fruits and vegetables (Musatov et al., 2010), shelf-life assessment of fresh foods (Torri et al., 2010), monitoring of headspace gases (Capelli et al., 2014), and grading or classification of foods (Yu et al., 2008).

Gomez et al. (2006) used a specifically designed E-nose instrument (PEN 2) comprised of sensor array with 10 different metal oxide sensors and capable of pattern recognition which was reported to monitor the stages of maturity of mandarin. These authors analyzed the data during external validation by using principal component analysis (PCA) and linear discriminant analysis (LDA) built in the E-nose. Their results showed this E-nose system was able to distinguish the differences among different picking periods of mandarin when the LDA was used for analysis (Gómez et al., 2006b). Barbri et al. (2008) used an E-nose system to determine the freshness of sardine samples stored at 4°C in real-time, and also developed a model to predict the freshness level. When the E-nose system was combined with PCA and support vector machines (SVMs), it was able to evaluate the freshness of sardines stored at 4°C more effectively (Barbri et al., 2008). Sanaeifar et al. (2014) used an E-nose comprised of metal oxide gas sensors for real-time monitoring of concentration of volatile gases in banana during ripening. The concentration of volatile gases was analyzed by using PCA, LDA, soft independent modeling of class analogy (SIMCA) and SVMs which are critical components of E-nose systems. These analyses showed that

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the SVM model was better than other models, and the classification accuracy of SVM based E-nose was close to 99% (Sanaeifar et al., 2014).

There still are some notable limitations regarding the use of E-nose instruments for broader applications. For example, the detection performance and sensitivity of E-nose are quite significantly affected by the characteristics of the sensors used (Ghasemi-Varnamkhasti and Aghbashlo, 2014). Furthermore, there is no universally accepted pattern recognition technology and the available software is specific to a product or a process. The response signals of sensors are frequently affected by the changes in temperature and humidity of test chamber.

To be more effective, an E-nose system needs to overcome the above mentioned limitations. A real-time remote monitoring of the quality of agricultural products by E-nose instrument during storage and transportation will become more effective with continuous advances in sensor and communication technologies. When the sensitivity of E-nose system and the effectiveness of pattern recognition technologies are improved, the E-nose will mimic the human olfactory system more effectively.

***Nuclear Magnetic Resonance***

Nuclear magnetic resonance (NMR) technology is applied to determine water, fat, carbohydrate, protein contents and other quality parameters of foods (Chen et al., 2013). The concentration and nature of water, fat and carbohydrate components determine the degree and nature of molecular binding and organizational structure in foods. Thus, the NMR provides important information regarding the nature and extent of internal changes taking place during processing and storage. NMR can effectively determine the water content as well as the state of water in foods in relatively short time. NMR is a nondestructive technology which can be applied to a wide range of solid and liquid materials without physically or chemically altering the sample or producing hazardous waste (Marcone et al., 2013). Thus, this technology is suitable for monitoring the freshness of food materials during storage. This technology is also able to continuously monitor quality parameters (Zhang et al., 2012), progress of ripening (Musse et al., 2009) and browning (Vandendriessche et al., 2013),etc. of fresh foods during storage.

Otero and Prestamo (2009) used magnetic resonance imaging and NMR spectroscopy with magic-angle spinning to monitor the damage caused by high pressure (100--200 MPa) in strawberry. Results showed that this technology was able to effectively measure the changes in internal structure, pH and sugar content etc. occurring during high pressure processing(Otero and Prestamo, 2009). Galed et al. (2004) used magnetic resonance imaging (MRI) to monitor the processes of ripening and decay of citrus fruits treated with chitosan. The MRI technique showed that the chitosan coating slowed down the release of the embedded preservative, inhibited the growth of fungi, and maintained the fresh-like appearance of the fruits for longer time. MRI was able to detect the changes taking place in the interior of the tested citrus fruits during storage (Galed et al., 2004). Kerr et al. (1997) studied the chilling injury in kiwi fruit using NMR imaging. They observed the dynamic process of ice formation by freezing the kiwi fruit at - 40°C. Results showed that the relaxation times of the frozen and thawed fruits were significantly shorter compared to that of the fresh fruit. Therefore, the relaxation time of NMR imaging can be used for online classification and sorting of kiwi fruit. Thus, NMR imaging provides important information which can be effectively used to work out better storage conditions for fruits (Kerr et al., 1997).

NMR technology has the advantages of being nondestructive, fast and capable of accessing the internal information of samples. Hence, NMR technology can be an effective tool for the detecting, analyzing and ascertaining freshness in foods.

The main obstacles for broader and more wide spread use of NMR instrument are high cost, need of trained operator, and the safety issues associated with the maintenance of magnetic field (Marcone et al., 2013). The complexity associated with the signal analysis also limits its popular use. Therefore, future research expected to focus at solving the above constraints, improving the hardware and software of NMR technology. Continued improvements in instrument function and reducing the cost will favor much more extensive use of this technology. It is expected that NMR technology will experience more extensive application in fresh food industry especially for rapid detection and analysis of internal defects and other quality parameters.

***Near Infrared Spectroscopy***

Near infrared spectroscopy(NIRS) covers 780 nm to 2500 nm wavelength range. When the NIR illuminates objects, hydrogen-containing functional groups of the organic and some inorganic molecules absorb enough energy to generate complex spectra. The NIR spectra represent the chemical composition of the product and depend on the light scattering properties of the test

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material (Nicolaï et al., 2007).Thus, the characteristic information of a test material can be obtained by analyzing its NIR absorption spectrum. The type and content of various components such as sugar, acid, protein, and water can be determined by analyzing the absorption and transmission of NIR by a test material. This method neither requires the pre-treatment of a sample nor does it require addition of any chemical during the test. NIRS is convenient, fast, non-invasive, suitable for online detection and also allows multiple and simultaneous detection and analysis (Jie et al., 2014). NIRS is suitable for most fresh food materials as they contain high proportion of hydrogen containing groups.

Kawamura et al. (2007) developed a NIR system for on-line monitoring of quality of milk. This instrument was able to obtain the NIR spectrum of milk between 1050 nm and 600 nm. They developed models to predict fat, protein, lactose and milk urea nitrogen contents and somatic cell count in milk. This work showed that NIR spectrum sensing system can be used to monitor the quality of milk in real time(Kawamura et al., 2007). Wang & Xie (2014) developed mathematical models to determine soluble solid content of citrus fruits using NIRS. They used a number of variable selection methods such as genetic algorithm (GA), uninformative variable elimination (UVE), Monte Carlo UVE, successive projection algorithm (SPA), stepwise multiple linear regression (SMLR), regression coefficient analysis (RCA), x-loading weights analysis(x-LWA) and their different combinations to select the most effective wavelengths. The effective wavelengths selected by SPA, SMLR, RCA and x-LWA were used for multiple linear regression (MLR) models. A GA-SPA-MLR model was found to be suitable for on-line measurement for

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soluble solid content in citrus fruits (Wang and Xie, 2014). Beghi et al. (2014) used VIS-NIR spectroscopy to monitor the long-term storage ability of apples in a refrigerated warehouse. Storage-life of two cultivars of apples was determined by using a VIS-NIR apparatus (600-1200 nm) by correlating with totals soluble solids determined through VIS-NIR. This work showed that the spectroscopic technique can be used for non-destructive classification of apples(Beghi et al., 2014).

At present, the research efforts regarding the application of NIRS are mostly confined to laboratory. One of the limitations of transfer of NIRS technology to industry is that it cannot handle the higher volume and frequent sampling needs of industrial scale production. Besides, the stability of the instrument and repeatability of data are poor in dynamic online detection mode. The acquired spectrum can be easily affected by the environmental factors such as fluctuation of temperature and movement of samples; both of these factors negatively affect the measurement accuracy and increase the measurement error (Porep et al., 2015). Thus, there is a need of improving the predicting power and data handling ability of the models or software used. Research is also needed to build better feedback system and real time monitoring of temperature and humidity of the surrounding.

***Hyperspectral imaging technology***

Hyperspectral imaging technology integrates the advantages of spectral imaging and spectroscopic techniques (Lorente et al., 2012). It integrates the spatial information and spectral signals of a test object. Thus, this technology can be used to assess the internal and external quality of food and other agricultural products (Iqbal et al., 2014; Pu et al., 2015). This technology has notable ability of pattern recognition through imaging and ability acquire unique chemical fingerprint using spectra; hence, it has great promise for nondestructive testing of fresh meat (Barbin et al., 2012), fruits and vegetables (Cen et al., 2016; Pan et al., 2016), and seafood (Cheng and Sun, 2014).

Qin et al. (2012) developed a real-time, small scale citrus canker detection and fruit sorting machine using two important IR bands of 730 nm and 830 nm. This two-band spectral imaging and sorting functions enabled a complete online detection of the canker. This instrument achieved a classification accuracy of 95.3%, indicating that this two-band spectral imaging system is effective detection of citrus canker in real-time. Fecal contamination is one of the most commonly encountered food safety problems (Qin et al., 2012). Kim et al. (2007) developed a hyperspectral line-scan imaging system and applied to a commercial apple-sorting machine to inspect fecal contamination and other defects. This instrument was able to detect the apple defect with 99.5% classification accuracy and with a false positive rate of only 2% (Kim et al., 2007). Chao et al., (2009) developed an online line-scan spectral imaging system to identify the changes caused by pathological microorganisms in slaughtered chicken which included hyperspectral and multispectral Vis/NIR imaging. The system was able to identify over 99% of wholesome and over 96% of unwholesome chickens(Chao et al., 2009).

Online hyperspectral imaging system can achieve very high accuracy detection of problems/defects in fresh foods. However, the noise can be high and it can be easily affected by the environmental noise. Hence, provisions for noise reduction can be very helpful in improving the accuracy of hyperspectral imaging systems. Moreover, hyperspectral images contain immensely large amount of data and the processing of this large body of data can take unusually long time. Any technological improvements regarding band selection and algorithms for removing noise and processing the data faster can make the detection more efficient. In due course, the hyperspectral system has potential of being fast, non-destructive online testing method suitable for fresh foods.

***Computer Vision***

The computer vision technology is effectively replacing the manual inspection of agricultural and food products (Zhang et al., 2014). Computer vision technology mimics or makes use of human image processing ability. Images are captured digitally and are processed using computers. This technology makes use of captured image to obtain important information about a product's quality or defect without a physical contact (Brosnan and Sun, 2004). It has the advantages of being rapid, economic, accurate, consistent (Sun, 2000). A typical machine vision system consists of an image acquisition system, image processing and statistical analysis program as shown in Fig.2. The basic components of an image acquisition system include: a camera, a light source, an image acquisition card, and computer system complete with essential hardware and software (Wang and Sun, 2002).

Pourdarbani et al. (2015) developed a machine vision based online sorting system for date fruit according to different stages of maturity. This system was comprised of a conveying unit, lighting and image capture unit and a sorting unit (Pourdarbani et al., 2015).Yang et al. (2009) developed an online machine vision system comprised of an imaging spectrograph, a charge-coupled-device camera, and light-emitting-diode based lighting unit. This system was able to automatically check and distinguish between healthy and diseased slaughtered chickens at a speed of 140 chickens per minute. The results showed that the machine vision system can be successfully applied to inspect the healthy and defective of chicken online (Yang et al., 2009).

There are some difficulties regarding the application of computer vision in food industry. For example, there is no standardized detection index. Due to lack of classification standards, there is no uniformity across industry regarding the application of machine vision. Davenel et al. (1988) developed a computer vision based apple classification system using size, weight and appearance of apples as input parameters and achieved a classification accuracy of 85.1%(Davenel et al., 1988). In addition, the computer vision systems developed so far are sample specific; a system developed for a particular fruit type cannot be used for some others. Zwiggelaar et al. (1996) examined the handling damage in apricot and peach and found that the detection accuracy of peach was significantly higher than that of apricot(Zwiggelaar et al., 1996). The detection performance of computer vision is also affected by the environmental factors as most of the available systems are validated against stationary agricultural products. It is expected that the future research on computer vision systems will focus on improving detection accuracy and making these systems more suitable for online detection. Computer vision technology will be more commonly used for quality inspection and control of fresh foods.

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***SMARTLY MONITORING TECHNOLOGIES***

Food supply chain handles fast moving goods and it is a dynamic and complex operation (Trienekens et al., 2012). The loss of foods in terms of quality and quantity during transportation and storage is a major global problem impacting food security. Food materials are affected by environmental factors (temperature, relative humidity, overhead gas composition) in every stage of supply chain lose their original quality. Therefore, it is essential to establish uninterrupted cold chain and maintain suitable environmental conditions during the entire logistics (Aung and Chang, 2014). The pre-cooling, suitably temperature controlled storage and suitably temperature controlled transportation are three important components of cold chain.

Fresh-keeping is to preserve the freshness of vegetables, fruits, meat and other perishable foods. Different preservation technologies have to be adapted to preserve the original texture, flavor and color, reduce the loss of water and nutrients, and prolong the shelf-life of foods. The major fresh keeping methods include cold storage, controlled or modified atmospheric storage coupled with the upstream irradiation and/or chemical treatment. The integration of fresh-keeping technologies listed above and the internet technologies such as wireless sensor networks (WSN) (Fig.3), radio frequency identification (RFID) system (Fig.4), sensors, ZigBee wireless transmission, etc. (Table 2) can monitor the storage and transportation environments of fresh foods. This combination can help reduce the product loss due to spoilage and prolong the shelf-life. This combined technology can effectively track the use-by date of foods and prevent the expired foods entering the market. By reducing the losses occurring during storage and transportation, this combined technology can play an important role in ensuring food security.

***Temperature***

Fresh foods need to be stored at appropriate low temperature to realize longer shelf-life. Temperature control is one of the core requirements of cold chain logistics. Even a small change of temperature away from a specific optimal temperature range for even a very short time can lead to bacterial growth and then reduce the quality of the product. Temperature is also considered to be one of the main critical control points affecting the food safety

(Jedermann et al., 2009; Kreyenschmidt et al., 2010). Despite the importance of strict control of temperature, fresh foods are often exposed to undesired level of temperature fluctuation during in the food supply chain(Laguerre et al., 2002; Labuza and Fu, 1995; Raab et al., 2008; Brecht et al., 2003).

Temperature monitoring and control are two important operations of cold chain management. A real-time temperature monitoring system helps an operator know when and by how much temperature is fluctuating and this information can be used to prevent the fluctuation exceeding the optimal temperature range. Currently, an Electronic Product Code Information Services (EPCIS) based real-time and online temperature monitoring system is preferred by supply chain industry as it allows an effective monitoring of temperature (Thakur and Forås, 2015). Time temperature indicator (TTI) makes it possible to continuously record and monitor the temperature history of a sample in an entire supply chain in a simple and cost effective way(Taoukis and Labuza, 1989; Kim et al., 2016). Nga et al. (2011) used a photochromic TTI to simulate a scenario of temperature variation of fresh fish in a distribution chain. The results showed that the TTI was able to reliably simulate the freshness index of fish discoloration. TTI has shown a great potential for real-time and continuous monitoring of temperature of fresh fish in fish supply chain(Nga et al., 2011). Mai et al. (2011) used the above mentioned photochromic TTI to continuously monitor the quality and shelf life of fresh cod loins under different storage conditions(Mai et al., 2011).

***Relative Humidity***

Loss of water content in fruits and vegetables during storage is one of the main factors for their quality deterioration. A loss of water can lead to sever change in texture, color, taste and also undesirable shrinkage or change in shape. Relative humidity values below an optimum range give rise to hard appearance in animal tissues and the wilting of fruits and vegetables. The loss of mass in the form of water loss also leads to economic loss on top of the loss caused by quality deterioration. When the harvested products lose water by 3 ~ 6%, they begin to wither and likely become inedible (Mahajan et al., 2008). Therefore, the relative humidity of the environment or the storage enclosure should be monitored and controlled during the storage and transportation of fresh foods to avoid quality deterioration.

Hübert & Lang (2011) used an autofocus sensor system to obtain relative humidity or water activity of fruits and vegetables and the data was transmitted by radio transmission. These relative humidity data can be used to estimate transpiration and shelf-life of fruits and vegetables (Hübert

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and Lang, 2012). Kim et al. (2015) introduced a freshness gauge to evaluate the quality of fresh produce making use of an algorithm that used temperature and relative humidity as main inputs. The algorithm considered the cost, shelf-life, and quality of a product, and applied the center of gravity model and genetic algorithm. Besides, the radio frequency identification and sensor technologies were used to generate data real time movement of a product in the entire supply chain. This freshness gauge concept can be applied to minimize water loss during cold storage and to work out the best storage conditions for perishable products (Kim et al., 2015). Abad et al. (2009) developed and tested a radio frequency identification (RFID) smart tag which integrated relative humidity and temperature sensors with RFID communication capabilities for food traceability and cold chain monitoring. The RFID tags were also capable of measuring temperatures below 0°C; hence, they could be used in frozen food systems. The authors(Abad et al., 2009) demonstrated the capability and effectiveness of this system using it in an intercontinental fresh fish logistic chain.

***$CO_2$***

$CO_2$ is often produced during the storage of fresh foods due to metabolic activity and also due to microbial activities. Therefore, the rise in $CO_2$ level indicates to a decline in food freshness. However, certain high concentration of $CO_2$ can be effectively used to extend the shelf-life of meat and fruits and vegetables because it can inhibit growth of aerobic microorganisms and reduce the respiration rate of fresh fruits and vegetables(Gill and Tan, 1980; Boskou and Debevere, 1997; Jacxsens et al., 1999). Hence, certain high concentration of $CO_2$ (20-80%) is used to preserve the freshness of meat, poultry, fish, cheese, strawberries and some other food materials. However, if the concentration of $CO_2$ is too high, it will initiate the glycolysis early on and leads to a rapid decline in fruit quality. Therefore, monitoring and control of $CO_2$ concentration is important to ensure proper adequately long shelf-life of fresh foods.

Liu et al. (2005) introduced an intelligent as well as highly precise monitoring and control system for head space gases such as $CO_2$, $O_2$. The system made use of a single chip microcomputer as the core, carried out the data acquisition and transmission using a sensing element and an analog to digital converter and controlled the parameters of cold storage by applying fuzzy logic(Liu et al., 2005). Borchert et al. (2013) designed and tested an optochemical $CO_2$ sensor which used phosphorescent Pt-porphyrin dye prepared using Förster Resonance Energy Transfer (FRET). The reaction between the platinum porphyrin and carbon dioxide produced color and the intensity of this color was used to characterize the freshness of fresh cut fruits and vegetables successfully. They evaluated the operational stability and sensor behavior in packaged foods during storage. In this research it was shown that the sensor can maintain the sensitivity to $CO_2$ for 21 days at 4°C in modified atmosphere environment, which is important for food packaging and shelf life studies(Borchert et al., 2013).

***Ethylene***

Ethylene causes ripening and senescence in fruits (Burg and Burg, 1962). This gas is produced in increased amount after fruits are picked (Emmel and Hersch, 2000). Biale & Young (1954) also showed that a mere $0.1 \times 10^{-6}$ volume fraction of ethylene is capable of accelerating the ripening of fruits(Biale and Young, 1954). Ethylene is not only used for ripening of fruits and vegetables it is also used to accelerate the decomposition of chlorophyll and turn the green pigment to yellow and promote senescence of tissues (Jang and Allebach, 2006). Hence, it is of practical importance to do real-time monitoring and removal of ethylene in order to slow down the ripening of fruits and vegetables.

Giberti et al. (2004) used tin oxide ($SnO_2$) gas sensors to monitor ethylene concentration during fruit ripening. They quantified the effect of atmospheric humidity on the sensitivity (electrical conductivity) of $SiO_2$ in measuring ethylene using a relative humidity compensating algorithm. The results showed that the application this type of chemical sensors are quite effective in monitoring the ethylene gas concentration in agricultural products (Giberti et al., 2004). Lang & Hubert (2012) developed a color indicator to monitor ethylene emission from apples. The color of molybdenum (Mo) chromophores changed when they come in contact with ethylene. The color spectrum of these chromophores changed from white/light yellow to blue due to a partial reduction of Mo (VI) to Mo (V). The intensity of change in color was found to be associated with the amount of ethylene release and the time of exposure. This study showed that Mo chromophore is an effective and stable indicator for in situ detection of ethylene released from apples and could be used to monitor the ripening or maturity of apples during storage (Lang and Hubert, 2012).

***Hydrogen sulphide***

Hydrogen sulfide and some other sulfur containing compounds are produced by the bacterial decomposition of food materials. The volatile sulfide is considered as the main reason for rancid

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smell of chicken. Hydrogen sulfide can also be produced by some lactic acid bacteria in vacuum packaged meat products (Kalinowski and Tompkin, 1999). Hydrogen sulfide and other sulfur containing compounds can be produced in meat by clostridium and other pathogenic microorganisms (Eeckhaut et al., 2012). Serio et al. (2014) found that the increase of sulfide concentration released by tuna and other seafood due to bacterial spoilage gradually increased due to the growth of *Shewanella* (Serio et al., 2014). Thus, the presence or absence of hydrogen sulfide can be linked to the freshness of meat and it can be used as an effective indicator of freshness of meat.

Smolander et al. (2002) found that the bacterial spoilage of myoglobin in poultry produces large amounts of hydrogen sulfide and hence can be used as an indicator of spoilage or freshness of poultry. They developed a myoglobin-based indicator to determine the freshness of poultry packaged in modified atmosphere packaging by detecting the concentration of hydrogen sulfide(Smolander et al., 2002). Koskela et al. (2015) developed a copper acetate based low-cost sensor to monitor the quality of raw broiler meat. This sensor had an excellent sensitivity to hydrogen sulfide. This sensor was found to accurately monitored hydrogen sulfide produced by the bacterial deterioration of meat packaged in modified atmosphere. The authors reported that this sensor could be easily used in commercial scale(Koskela et al., 2015).

***Total Volatile Basic Nitrogen (TVB-N)***

The color, pH, texture, freshness and tenderness can be used separately or in combination as indicators of quality of meat(Kamruzzaman et al., 2012; Cai et al., 2011; Tao et al., 2012). The

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breakdown of meat protein by enzymatic or bacterial action produces basic nitrogen compounds such as $(CH3)_2NH$ (dimethylamine), $(CH3)_3N$ (trimethylamine),and $NH_3$ (ammonia) which are collectively known as total volatile basic nitrogen (TVB-N) (Pacquit et al., 2006). The concentration of TVB-N correlates well with the extent of bacterial spoilage of meat and hence it can be a good indicator of meat freshness.

The spoilage of fish produces basic volatile amines which can be detected by monitoring the change of a pH sensor. Pacquit et al. (2006, 2007) developed a colorimetric dye-based sensor to monitor spoilage making use of pH sensing. The on-package sensor was comprised of a pH sensitive dye, bromocresol green which changes from yellow to blue color depending on the concentration of TVB-N. This color based simple freshness indicator enables the real-time monitoring of spoilage of a number of fish species(Pacquit et al., 2007; Pacquit et al., 2006). Kuswandi et al. (2012) developed a simple colorimetric sensor based on TVB-N sensitive polyaniline films to monitor real time freshness of fish products inside sealed fish packages. The reaction between the polyaniline film and the TVB-N released during fish spoilage changes the color of the film from green to blue and enables determination of degree of spoilage of fish. These polyaniline film based sensors are considered to be low-cost yet effective sensors as well as important component of smart packaging (Kuswandi et al., 2012).

***Conclusions and future outlook***

Detection and monitoring of quality of fresh foods using smart storage technology have been researched and are put in practice. However, further research is required to achieve fast, reliable

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and real-time online detection and monitoring. For example, the performance and sensitivity of electronic nose are easily influenced by the nature of the sensors used and prevailing environmental conditions. The acquired NIR spectra are easily affected by temperature fluctuation or movement of a sample. The high cost of equipment coupled with prevailing slow rate of image capture and analysis are impeding wider application of NMR equipment. The hyperspectral imaging system is still suffering from difficulty in data acquisition and relatively high cost. The computer vision systems, so far, has not been adapted to wide spectrum in mobile food samples and the speed of image processing is still slow. It is also largely confined to monitoring and recording of external quality parameters. Improving the accuracy of analysis and speed of detection technologies and making these systems fully digital and intelligent will be the direction of future research. The intelligent fresh food storage and supply chain technologies will have a huge impact on the preservation of fresh foods.

The smartly monitoring technologies have the ability of rapid detection, real-time online monitoring. They are nondestructive and greatly save human and financial resources. With continued research in sensor, communication and networking technologies the smartly monitoring technologies of fresh foods can achieve better monitoring of the internal and external quality attributes and enables seamless connection between logistic nodes. These developments will enable the supply chain industry to deliver high quality fresh foods to consumers in the shortest possible time and the lowest possible cost.

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Table 1 Online detection technologies used in the pretreatment of fresh foods

| Methods | products | Studied property | Ref. |
|---|---|---|---|
| Electronic Nose | apples | starch index, puncture strength | Pathangea et al. (2006) |
| | fish, vegetables, fruit and meat | quality detection | Liu (2015) |
| | fruit | the level of fruit freshness,food spoilage | Ying and Wang (2013) |
| NMR | avocados, cherries | oil/water ratio in avocados, Internal Quality Evaluation | Kim et al. (1999) |
| | pears | Internal browning | Hernández-Sánchez et al. (2007) |
| | apples | internal browning | Chayaprasert and Stroshine (2005) |
| NIR | Braeburn apples | brown heart | Mcglone et al. (2005) |
| | Orange | sugar content, acidity | Kondo (2010) |
| | apples | sugar content | Sun et al. (2012) |
| | apples | Firmness, SSC | Lu (2004) |
| Hyperspectral imaging technology | meat and poultry products | quality, safety, authentication assessment | Kamruzamman et al. (2015) |
| | broiler carcasses | surface fecal, food contaminants | Park and Lawrence (2006) |
| | beef | Tenderness, color parameters | Wu et al. (2012) |
| Computer Vision | Eggplant | size, shape, color, and defects but also gloss of fruit surface | Kondo (2010) |

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| | | | |
|---|---|---|---|
| | Citrus | Maturity(the surface color information,TSS/TA) | Ying et al. (2004) |
| | Oil Palm Fruit | ripeness | May et al. (2011) |
| | mango | quality classification | Razak et al. (2012) |

Table 2 Smartly monitoring technologies for fresh foods during storage

| products | Studied property | technology | Ref. |
|---|---|---|---|
| the stored fruit in cold storage | environment monitoring(temperature, humidity and gas concentration, etc.) | WSN, RFID | Junxiang and Jingtao (2011) |
| pineapple | temperature | RFID, Temperature sensors | Amador et al. (2009) |
| chilled lamb | temperature monitoring and traceability in a cold meat chain | Electronic traceability, EPCIS, RFID, temperature sensors, GSM/GPRS | Thakur and Forås (2015) |
| fish | freshness | Amine oxidase-based flow biosensor | Frébort et al. (2000) |
| chilled chicken | shelf life,quality control | TTI | Brizio and Prentice (2014) |
| modified atmosphere packaged broiler chicken cuts | the sensory and microbiological quality control | TTI | Smolander et al. (2004) |

WSN, wireless sensor networks;

RFID, radio frequency identification;

EPCIS, Electronic Product Code Information Services;

GSM, Global Systems for Mobile Communications;

 

GPRS, General Packet Radio Service;

TTI, Time temperature indicator;

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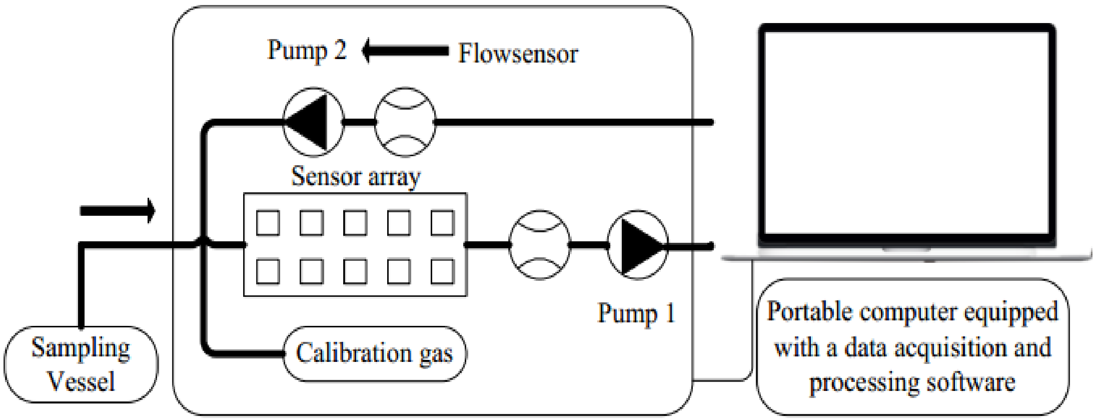


Fig.1 Schematic diagram of the e-nose system(Gómez et al., 2006a)

 

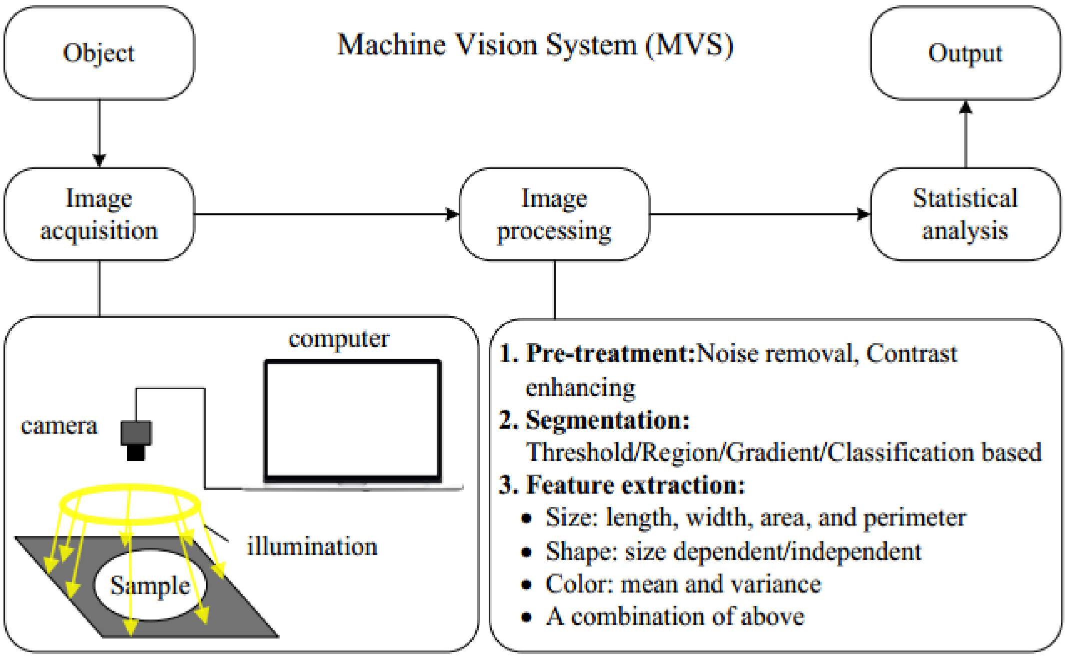


Fig.2 Essential elements of a machine vision system(Hong et al., 2014)

 

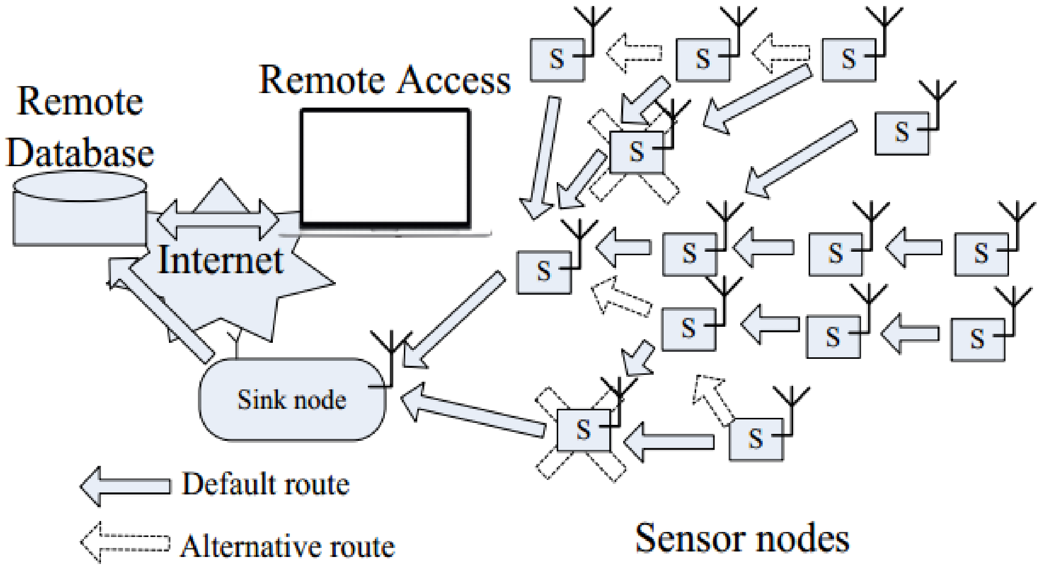


Fig.3 Architecture of a Wireless Sensor Network (Bonastre et al., 2012)

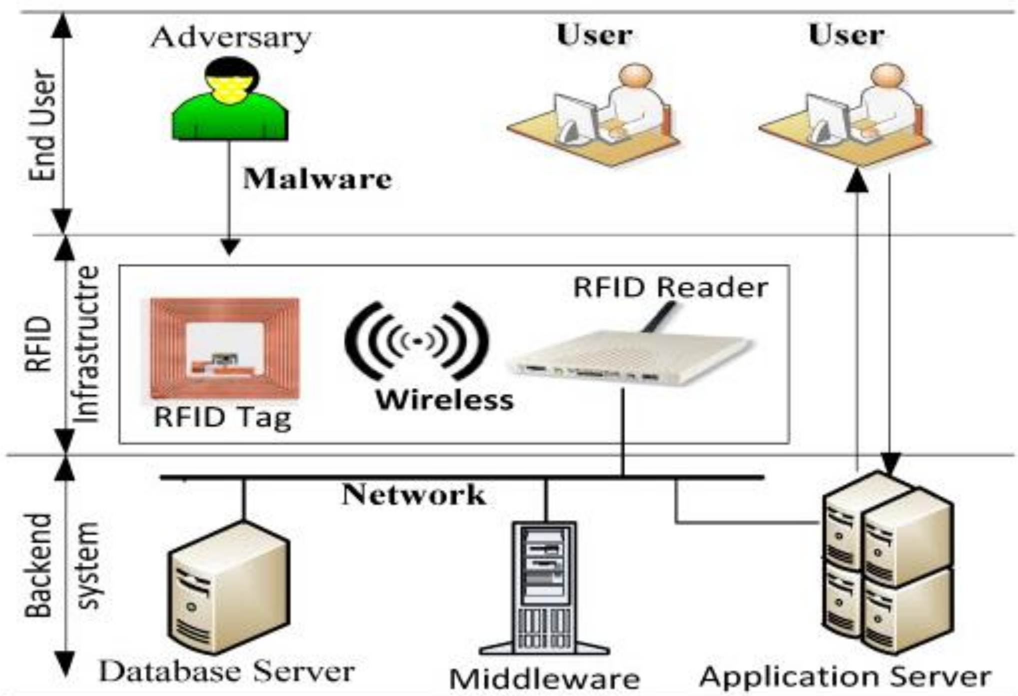


Fig.4 RFID system infrastructure(Abawajy, 2013)