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Research Article

Review: Application of Non-destructive Techniques for Fruit Quality Classification

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Abstract: A review is given of different non-destructive techniques for fruit quality classification. As a hot research topic in the field of International Agricultural and Food Engineering, fruit quality classification has great influence on meeting consumers' requirements for food quality and safety. Recently, a range of non-destructive techniques has been used for evaluating fruit quality. The main non-destructive techniques for fruit classification include using electrical properties, acoustic properties, optical properties, sonic vibration properties of fruits or THz, NMR, x-rays, electronic nose, machine vision technology, near-infrared spectroscopy and hyperspectral imaging to evaluate fruits without destruction. This review focus on summing up different types of non-destructive fruit classification techniques, including their pros and cons. Hyperspectral imaging techniques which were developed in recent years has been involved.

Keywords: Fruit classification, hyperspectral, non-destructive techniques

INTRODUCTION

China becomes the great producer of fruit in the world because of the vast territory, but in the same time our exports did not match the huge production. In recent years China has joined the front ranks of the world fruit production, however, the food exports of our country takes only 3% of the total production because of the low-level processing standards (Ying and Liu, 2003). With the frequent occurrence of problems in food quality and safety, domestic and foreign consumers are more and more concerned about the quality of fruit. This condition leads to a more serious situation and an increasingly intense competitive pressure in fruit exports (Hu *et al*., 2014).

The traditional methods we used in our country not only waste time, money and energy but also destruct the fruit. In order to overcome disadvantages of these methods, lots of scholars began to study non-destructive techniques for fruit classification. Novel and emerging non-destructive techniques for fruit quality measurement include near infrared spectroscopy, hyperspectral imaging, thermal imaging, nuclear magnetic resonance imaging, etc. Compared to those traditional methods, these new non-destructive techniques can be used to classify fruit not only according to external features (e.g., color, texture, size, shape, surface defects, etc.) (Oranusi and Wesley, 2012; Liu *et al*., 2014; Yang and Li, 2015) but also some internal features (e.g., sugar content, acidity, firmness, soluble solids content, starch content, moisture, maturity, etc.) (Lu *et al*., 2000; Ying and Yu, 2007).

Thus it can be seen that non-destructive techniques for fruit quality play an important role in fruit production and market. The aim of this article is to provide a review of recent non-destructive technological developments in fruit classification. Then the pros and cons of differences techniques will be presented. Discussion of these techniques will be given in the final section.

METHODS

The electrical characteristics techniques: This section is variously called Methods or Methods and Materials. It should give essential details, including experimental design and statistical analysis. A large number of charged particles inside the fruit form the biological electric field. The biochemical reactions of fruit go with the material and energy conversion when fruit grow, mature, damage and spoilage which lead to changes of electrical voltage and spatial distribution inside the fruit. This process will affect the electrical characteristics of fruit macroscopically (Sun and Jiang, 2010). Fruit can be classified according to the relationship between macroscopic quality and electrical characteristics. Figure 1 shows a basic program of electrical characteristics in fruit classification.

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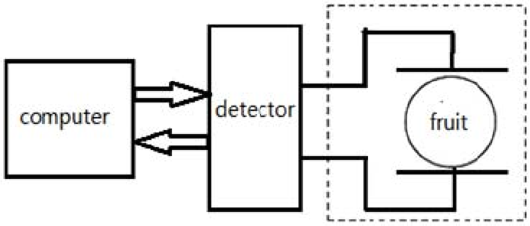

Fig. 1: Basic program of electrical characteristics in fruit classification

Thompson and Zechariah (1971) found that the maturation of fruit and its electrical characteristics are closely related in the band between 300 and 900 MHZ. Nelson (1980) showed the moisture of fruit has some connection with electrical characteristics by using his own system detecting slice of *soybean*, *date palm* and *pecan* in the band between 0.2 and 20 GHz. The first fruit electrical characteristics testing system was created by Kato (1987). He used an impedance analyzer based on bridge method (YHP, 4192A). However, because of the sparse sampling frequency, his system cannot accurately reflect the frequency characteristics of the parameters and reach the test requirements. Compared with foreign research, the study of non-destructive techniques for fruit quality is still in its infancy in China. Zhang and Xu (1996) used Intelligent Inductance-Capacitance-Resistance Tester and Flat electrode studied electrical characteristics of apple, pear and peach in a low frequency range firstly. Sun (2007）suggested the deeper a fruit rot is, the bigger its equivalent impedance became. Chen (2007) studied the relation between electrical characteristics of tomato and its maturity, storage time and extent of damage. The result showed that complex impedance, inductance, relative permittivity, conductivity and resistance of fruit have closely relations with these parameters.

Although lots of experiments that domestic and foreign researchers did had demonstrated the feasibility of the fruit electrical characteristics for quality grading, there are still many shortcomings. Individual differences in size, physiological changes of fruit brings great difficulties in monitoring, besides, temperature, humidity, climatic conditions, the distance between the electrodes and the position of the fruit will affect the result of the experiments. These factors all led to inaccurate measurements and grading errors. In order to achieve a more accurate grading of fruit, we must keep the system from being affected by other factors. A strict hardware is required in this method.

The electronic nose techniques: One of the important evaluations of fruit quality is fruit smell; it is also one of the main factors that attract consumers' eyebrow. Different fruits have different smells because of various aromatic substances inside the fruit. Generally speaking, the content of aromatic substances in the fruit is rare, but it has a larger impact on fruit quality and will change in different varieties, maturity and storage time. The electronic nose is a novel artificial olfactory system which can be used to analyze, identify and detect complex odors and volatile components. Figure 2 shows the principle of Electronic Nose. No pretreatment, solvents required in this technique compared with other conventional methods of instrumental analysis. It is a kind of green bionic instrument which is easy to carry. It can carry out real-time detection and has been used in food chemical analysis (Tang, 2011).The application of electronic nose to detect and grade fruit is also one of the non-destructive techniques in recent years.

Zhu *et al.* (2006) developed embryonic electronic nose used conductance modulation odor and contact potential odor modulation. However, Persaud and Dodd (Richardson and Mash, 1988), professor of Warwick put forward the concept of electronic nose by mimicking the structure and mechanism of the mammalian olfactory system till 1982 and then they distinguished 21 kinds of complex volatile chemicals odor including *brain amines tree*, *rose oil*, *clove bud oil* using their own electronic nose system. Sarig and Beaumelle (1993)

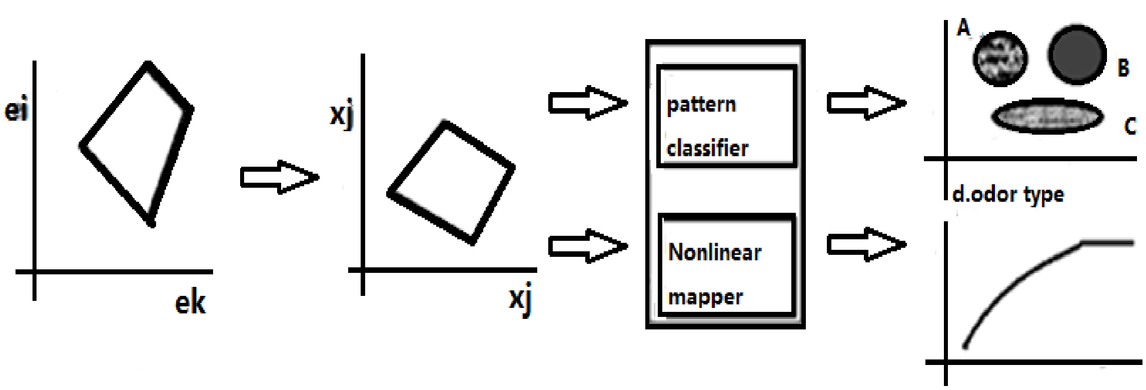

Fig. 2: Principle of electronic nose; (a): Odor component space; (b): Sensor respondence space (c): Intelligent explainer; (d): Odor intensity

generalized relationships between indicators of fruit and the output of the system which he used for detecting. This system was designed by Japanese and has the ability of distinguishing fruit from over-mature, mature and immature, as a result, its detection accuracy is around 99%.The Fruit maturity sensor used to judge mature or immature based on there was smell of volatile or not which developed by Benady *et al*. (1995) could detect fruit with a correct rate of more than 90%. Simon *et al*. (1996) used semiconductor gas sensor to evaluate *bilberry* quality and reached a conclusion that response of the sensor will be increased with the addition of firmness, pH, acid titration value and color value. Since then, he also used the *tin* oxide gas sensor researched on aromatic vegetation. Osborn *et al*. (2001) used electronic nose to distinguish the pear which was picked in different time and divided into 3 groups, the experiment result showed that electronic nose could clearly distinguish three different maturity periods of pear. Natale *et al*. (2001) discussed the quality of apple and reached the conclusion that electronic nose could easily distinguish the types of apples and forecast the extent of injury. Saevels *et al*. (2003) predicted and optimized the best apple harvest time using electronic nose. Their study showed that electronic nose signals could predict optimal harvest time. Zhao *et al*. (2004) proved the quality of apples could be distinguished by using electronic nose with training set and test set and the correct rate is 100 and 96.4%, respectively.

The electronic nose as an emerging technology can detect volatile substances and grad fruit, but odor is not the only standard for fruit quality measurement. Only using fruit odor resulted in single classification parameters. Besides, the electronic nose measurement data will be affected greatly by the great changes of volatile substances. Although the electronic nose detection technology has many shortcomings, it can be used with other techniques, such as machine vision technology and spectroscopy.

The NMR techniques: The basic principle of Nuclear Magnetic Resonance (NMR) is using electromagnetic irradiation to irradiate nuclear spin in the external magnetic field at the proper frequency, at this time the low-energy nuclear spin will absorb electromagnetic energy transit from low energy to high energy, this phenomenon called magnetic resonance and the nuclear magnetic resonance signal called NMR. We can know the state of atoms according to NMR spectrum (Pang and Wang, 2006). It can be acquired through NMR spectrometer. Figure 3 shows the compositions of NMR spectrometer.

The moisture, soluble solids contend and some other ingredient, which changes all the time during fruit growth, can be measured by NMR. They can be used to judge the quality of the fruit. Chen *et al*. (1996) proved that single pulse spectrum analysis can be used to analyze the internal quality of fruit and suitable for quick online detection. Its materials transport speed run up to 0.25m/s. The correlation coefficient between formant ratios and dry matter content of fruit is 0.98. Kim *et al*. (1999) designed and tested NMR online grading equipment. The experiments showed that the correlation coefficient between avocado resonance peak and maturity is 0.970. Chaughule *et al*. (2002) tested the SSC of *manilkarazapota* by using FID(free induction decay), the result showed that, for mature fruit, *glucose* and *fructose* NMR each has one peak, but for immature fruit, only one peak on *fructose* NMR. Zion *et al*. (1995) proposed a method to sort apple based on NMR and achieved good results. Kerr *et al*. (1997) studied NMR image of *kiwifruit* cold damage and singled out the damaged *kiwifruit* successfully. Sonego *et al*. (1995) studied NMR image of peach and *nectarine* lignification. Studies showed that in the serious damaged area, the NMR of proton signal intensity decreased. Barreiro *et al*. (2000) divided apples into three groups using NMR and arrived an accuracy rate of 87.5%. Besides, Gonzalez *et al*.

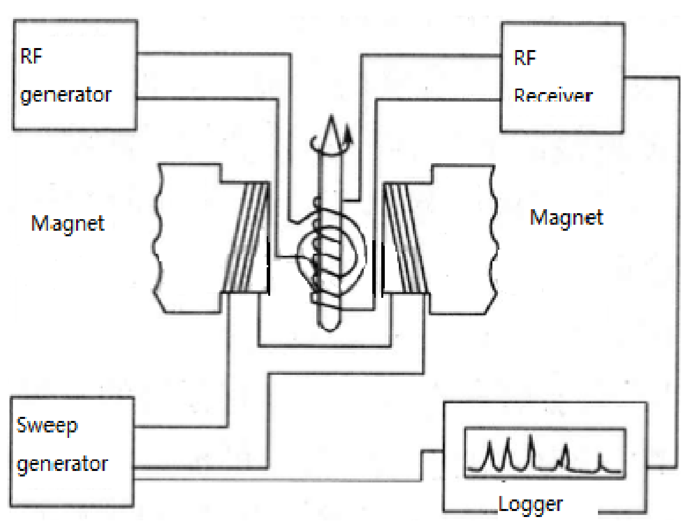

Fig. 3: Compositions of NMR spectrometer

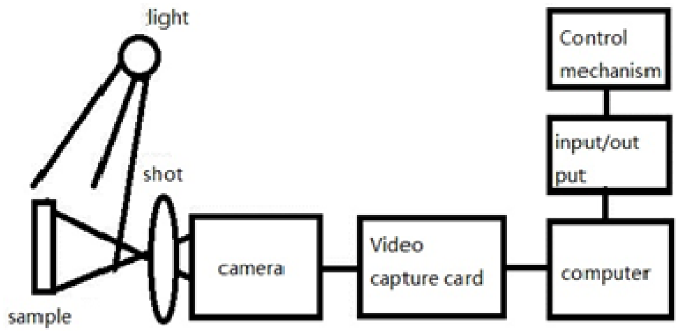

Fig. 4: Parts of machine vision

(2001) and Lammertyn *et al*. (2003) examined the internal browning of apple and moldy pears by the same method respectively. All of them reached the grading standards. In addition, many reports have indicated that NMR technique is widely used in fruit grading. It can also be applied to predict diseases, as well as the existence of fruit stone.

NMR technology has advantages over other technologies in non-destructive testing of fruit. First it has strong penetration and the ability of obtaining internal features of fruit is more accurate compare with optical detection method. Second, It will not cause potential damage to the fruit internal organization compare with X-ray detection method (Lammertyn *et al*., 2003). Although NMR has lots of advantages, it cannot be applied in some particular fruit with complex internal components such as tomato (Clark and Macfall, 2003, 1996; Clark and Forbes, 1994).Wasting too much time is another reason why it cannot be widely used.

The machine vision techniques: The principle of machine vision is to use the correlation between the color of fruit and its internal characteristics and then determining the internal characteristics of fruit by its color. The machine vision system consist of CCD camera, video capture card, monitor, light box and computer, Fig. 4 shows these parts. The main testing steps including: Setting the background color of the light box; Image acquisition; Color recognition method (Ying *et al*., 2004).

Applications of the machine vision in evaluation of non-destructive techniques for fruit focus on two areas: hardware, namely, how to obtain a more accurate pictures; software, namely, color processing and classification.

Japanese scholars used light-reflecting properties of citrus to study its skin color as early as 1980 (Ying *et al*., 2004). Paulsen and McClure (1986) studied what kind of light and what kind of background images collected precise image. Bowers *et al*. (1988) detected peach combining ultrasound imaging technology and machine vision. Miller and Delwiche (1989) developed a set of machine vision system being used to detect and classify fresh peach. The maturity classification and color identification of this system matched the manual inspection although the index of correlation was 56 and 92%, respectively. Throop *et al*. (1989) could accurately measure whether the stone exist or not by confirming visible light transmittance capability in apples using machine vision. Chen and Sun (1991) and Chen (1993) summarized some methods be used to non-destructive testing and grading from 1991 to 1993. Singh and Delwiche (1994) developed defect segmentation and image processing methods using histogram of peach. Tao (1996) identified the surface color of potato and apple using machine vision, then he also realized testing surface defects and damage of apple at a great speed using spherical transform algorithm. Diaz *et al*. (2004) detected olive using three methods including the neural network with a hidden layer, PLS (Partial Least Squares) and Mahalanobis distance method. Zhao *et al*. (2004) developed a new method based on three-camera system determining defects. This system obtained nine consecutive images in three different position using cameras. If there are two or more suspicious area split out in one image, the apple was defective. The result showed that the accuracy of defect recognition is 89.14%. Li *et al*. (2008) proposed "Size-evaluative metering value" space model and “number-degree” space model and classified fruit based on those new models. Wang (2011) studied Northwestern melon external damage using *Otus* algorithm to split suspicious area.

Currently, the research objectives of machine vision focus on shape, color, appearance and color-related defects and quality, such as maturity. Although compared with other methods, this system is simpler with more accurate results, it does not work with non-color related characters.

The spectroscopy and hyperspectral techniques: Because of the limitation of these four methods we can hardly use one of them to detect both physical and chemical properties of fruit. For example, we can use electrical characteristics of fruit, Electronic Nose and NMR to test internal substance but for size, color and shape these methods are useless. As for machine vision, it cannot recognize non-color related characters.

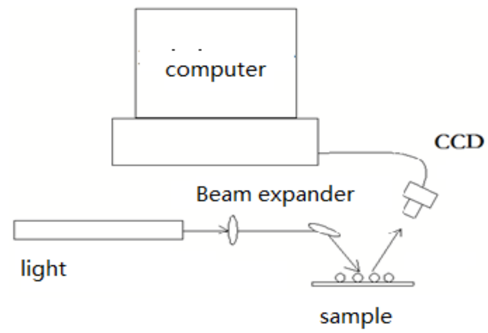

Fig. 5: Equipment components of spectroscopy test

It is a big problem that none of a method can classify fruit comprehensively, but with the development of technology, the appearance of Spectroscopy deal with this problem. Near-infrared spectroscopy (NIR) is soon applied to fruit classification. Infrared Spectroscopy (IR) includes three areas and NIR radiation covers the range of the electromagnetic spectrum between 780 and 2500nm. The spectral characteristics of subject changed with its scattering and absorption processes of light. These NIR characteristics can be used to analysis the complex subject (Nicolaï *et al*., 2007). The transmission, absorption and reflection characteristics of fruit is different from each other because of their internal tissue composition and external features. The peak of fruit reflection or absorption ratio will appear at a certain wavelength, the changes of these peaks have correlation to lots of characteristics of fruit, such as SSC, firmness and moisture (Jie, 2014). Figure 5 showed the equipment components of spectroscopy test.

NIR spectroscopy was first used in agricultural applications by Norris in 1964 to measure moisture of grain (Noh *et al*., 2006). Ito *et al*. (1993) found that diffuse transmittance acquisition mode were better for fruit with thick skin by studying the transmission and diffuse reflectance spectroscopy of watermelon. Guthrie *et al*. (1998) built a mode using watermelon covered the range of the electromagnetic spectrum between 650 and 1050 nm and found the fruit mode not all the same in different time. Factors such as number of light sources, spectral scan times which will affect fruit mode were studied by Walsh *et al*. (2000) using MMSI, S2000 and FICS. Ten modes have been created by (Greensill and Walsh, 2000; Greensill *et al*., 2001) using MMSI after analyzing the SSC (soluble solids content) of melon. The maturity and SSC of watermelon testing system was developed by Maruo *et al*. (2002) using transmission mode. Before that, Ito *et al*. (2001) used reflection mode studied the SSC of melon. Dull *et al*. (1989a) analyzed SSC of cantaloupe slices and the integral ones, which were different in maturity using the range of the electromagnetic spectrum between 800 and 1000nm and then, Dull *et al*. (1989b) also studied the effects that light, kinds of fruit and display angle had made. Besides the SSC and maturity, Tsuta *et al*. (2002) detected the *lycopene* content of watermelon using S2000 produced by US Ocean Optics.

At the same time, Spectroscopy technique has been also studied by scholars in China. Tao and Bao (2006), established PLSR-mode using Vis/NIR spectrometer produced by US ADS Company and tested the SSC of watermelon. Fan *et al*. (2007) analyzed the SSC and *cellulose* content of watermelon using spectroscopy.

The hyperspectral imaging has a great advantage over spectroscopy method because it can receive spatially distributed spectral responses at each pixel of fruit image but spectroscopy method only acquires the data from a single point from the fruit sample (Fan *et al*., 2007). It can conduct a more complex and comprehensive analysis of the fruit scene by acquiring a large set of monochromatic images correspond to consecutive wavelength just like a 3D cubic data.

The hyperspectral imaging has been used in many facets of non-destructive techniques for fruit (e.g., maturity, firmness, SSC). Polder *et al*. (2003) analyzed the maturity of tomato and divided samples into 5 classifications. The result showed that using hyperspectral image got a better classification compared with RGB image. Noh *et al*. (2006) developed a Golden delicious apple classification system combining hyperspectral and laser techniques. Nagata and Tallada (2005) also developed a classification system for detecting strawberry maturity. Besides, he studied the firmness of strawberry using MLR and selected 3 wavelength (685,985 and 865nm), then, established the preceding mode of SSC using 5 feature wavelength (915,765,870,695 and 860nm). Sivakumar *et al*. (2006) analyzed the moisture of mango and the result showed that the apposite wavelength were 831,932 and 950nm.

CONCLUSION

Several methods of non-destructive techniques for fruit quality classification are presented in this review. However, the first 4 methods have their own limitation in fruit detection. Compared to those methods, the hyperspectral imaging has its own important advantage with uncomplicated system and comprehensive data. But at the same time, large data also means redundancy information; as a result, a high level hardware is required.

In summary, the non-destructive techniques play a significant role in in fruit quality classification. At present, one way to deal with limitation of these methods is to combine them together and in order to obtain a certain commodity, more specific studies are required.

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