Optical Sensor in the Measurement of Fruits Quality: A Review on an Innovative Approach

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***Abstract*—Agriculture industries are developing standards that evaluating on fruits intrinsic properties before it is put in the market for the consumer, unlike current standards that focuses only on the physical appearance of the fruits. To achieve this, there exist well established instruments to evaluate fruits intrinsic quality parameters such as firmness, acidity and sugar content. However, the current approach utilizes an invasive techniques and time consuming. Efforts have been delivered by various researchers world wide in making use of optical measurement techniques, specifically through spectrometer. While realizing that a specific biochemical composition is responsive the best at a certain wavelength, an effort is being made by researchers from University Science Malaysia in developing a specialize instrument in measuring fruits intrinsic quality. Besides, several works has also been accomplished in understanding optical phenomena in fruits to further enhance the current methodology in benefiting agriculture industry, especially farmers in producing only best quality of fruits to the market.**

***Index Terms*—agriculture, biochemical, fruit, optical, spectrometer**

I. Introduction

In expanding the globalization of fresh produce market, UN ECE has drawn standards for fresh fruits and vegetables, E.91.II.E.42, which every product in the market has to comply with. The properties of the product which could be standardized are based on the magnitude which can be measured such as size, shape, presence and size of external damages. Some other properties which may be included are based on the subjective assessment such as color and its distribution and also occurrence of off-shape. On the contrary, this regulation does not include properties which can not be measured with definite procedure. As a result, it is common that this situation has led the fresh produce market to a point where many fruits and vegetables do not satisfy the consumers' quality expectations. Therefore, growers and distributors are now developing the company specifications which ahead of the legal quality, summarizing the relevant intrinsic properties that the consumer will accept: such as firmness, sugar and acid contents, aromas (juice content has been established as a comparatively standard measurement) also Vitamins [1].

II. Technological Efforts in Agriculture Industry

There are many efforts is being made to establish the standard quality parameters for fresh produce and the instrumentations that meet these expectation. For instance, the Physical Properties Laboratory (LPF) directed by Prof. Margarita Ruiz-Altisent has been working on fruit quality assessment on theoretical and practical basis concerning the quality specifications as well as instrumental measurement of quality in fruits [2]. However, assessing internal quality of fruits usually involving destructive procedures which requiring much labor and time consumption. Currently, there already exist the well accepted tools for the measurement of fruits intrinsic properties. Refractometer is used for the measurement of soluble solids content, pH meter and titrator for the measurement of acidity and penetrometer for the measurement of firmness. However, these instruments will require the fruits to be physically destroyed during the measurement. This method takes longer time and at higher cost since sampling had to be made and the tested fruits will carry no more commercial values. Therefore, a much simpler, faster and highly accurate measurement method is required [3].

Employing nondestructive sensing techniques in fruits industry assure the quality and wholesomeness of fruit. This would increase consumer satisfaction and acceptance, and enhancing industry competitiveness and profitability. Various nondestructive sensing techniques have been studied and implemented for predicting internal quality of fresh fruits. For instance, light-based sensing techniques or so-called spectroscopy offer great prospect for measuring the firmness and sugar or soluble solids content (SSC) of fruits. The interaction between radiation and matter has been proven useful in many research labs [4]. Ultraviolet (10-400nm), Visible (400–750nm) and Near Infrared (750–2500nm) (UV-VIS-NIR) spectroscopy is gaining increased attention in the field of postharvest quality assessment of fruits. It is an established technique to examine chemical constituents in agricultural products which is comparable to that devoted to different physical methods [5]. The absorbance (or conversely, reflectance) spectrum are the result of complex pattern of scattering and absorption by various structural and biochemical composition of the fruits. The information content of a sample's UV-VIS-NIR spectrum is very high, because it provides a brief and rich summary of the overall biochemical components of the sample [6].

III. Spectroscopic Method in Fruits Quality Analysis

Spectroscopic measurement techniques have been performed by many researchers in the measurement of properties of fruits. There are techniques of measurement that usually being implemented in the measurement of commonly defined fruits' intrinsic properties, such as sugar content (soluble solids content), acid content and firmness. Here are some overviews on examples of research and experiment that have been conducted in implementing spectroscopic technique for the measurement of fruits quality.

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Temme et al (2002), have used Near Infrared (NIR) spectroscopy to determine the sugar content of apples and apples juice. The experiment was conducted at room temperature using Pacific Scientific Model 6250 system and the measurement wavelength region was from 680 to 1235nm. In this experiment, the reflectance spectrum was calculated by comparing the NIR intensity (energy) reflected from the sample with a standard reference. From this research, Temma et al (2002) concludes that a standard error of prediction (SEP) value obtained for four varieties of apples (Fuji, Star King Delicious, Jonagold and Golden Delicious) is 0.546^{o}Bx at most with correlation coefficients above 0.94. While the measurement of sugar content for two kinds of apple juice, leads to a maximum SEP value of 0.439^{o}Bx and correlation coefficients above 0.97. Furthermore, it was identified that 912 nm was an important wavelength for determining sugar content of apples and apple juice [3].

In the other experiment, due to the realization that there is a high correlation between soluble solids content (SSC) and tomato flavor quality, Slaughter et al (1996), have performed a non destructive optical technique in the measurement of SSC in tomato using NIR spectroscopy. The study focused on the measurement of light spectrum within the range of 800 to 1000nm. Experiment which was conducted on 400 tomatoes produced a SEP of 0.33^{o}Bx and correlation coefficient of 0.89 [7]. Besides the measurement of soluble solids content in fruits through spectroscopy techniques, there are also researches conducted in determining other intrinsic properties of fruits. For instance, Mahayothee et al (2002) have perform NIR spectroscopy (650 to 2500nm) measurement to identify the soluble solids content, total acid (titrate citric acid) and firmness of Thai mango [8]. There are also efforts done to apply visible spectroscopy (VIS) for the measurement of fruits properties. This has been done by Li and He (2006) in interpreting the acidity (in pH) of Chinese bayberry using VIS-NIR spectroscopy with the range of wavelength from 325 to 1075nm [9]. Carlini et al (2000) has conducted the same technique but for the measurement of soluble solids contents in apricot and cherry using analysis on wavelength from 600 to 1100nm [5].

Typically, many research related to spectroscopy measurement has been conducted using standard spectrometer that are having range of functioning wavelength from ultraviolet to near infrared, depending on brand and model. However, there are also applications of spectroscopy using different instruments and measurement techniques. Yan-de et al (2007) have used the Fourier Transform Near Infrared (FT-NIR) spectrometer to predict the sugar content in apples. FT-NIR method has the capability to improve spectra reproducibility and wavenumber precision which is expected to minimize the effects of solvent interference during measurement [10]. Lu (2007) in the other hand has performed measurement of firmness and soluble solids content for apple using hyperspectral scattering images. The experiment was conducted using CCD camera and imaging spectrograph which covers the spectral region from 450 nm to 1050 nm [11]. There are also optical instrumentations available in the market for the agriculture industry. For instance, Agro-Technologie has successfully develop and commercialize IRS 3000 which is a laboratory NIR spectrometer that able to measure various parameters of fruit quality such as sugar rate, acidity, firmness in a non destructive way [12].

IV. Spectral Mathematical Analysis

Typically, spectrometers will produce the spectral signature of a measured sample as the output. Measured sample normally consists of a few biochemical compositions which have tendency to absorb different wavelength of light at different capacity. This output is considered as raw and often undergo multiple mathematical, commonly statistical analysis before it is extracted as final data. The intention of all this mathematical treatment to the original light spectrum is to find the possible linear correlation (R^2) between the wavelength and the expected bio-chemical composition and its magnitude in the examined material. The resultant computed linear correlation coefficient, R^2 of 1 is considered to be the perfect fit for linear measurement. Besides, Root Mean Square Error of Prediction (RMSEP) is often computed along side to the R^2. The raw spectrum retrieved from the spectrometer usually will be in the form of either reflectance or transmission value. However, when the calculation is performed, the raw optical data will be converted into absorption values. Absorption, A is represented by log(1/T) or log(1/R), where T and R are the spectral values of transmittance and reflectance of the sample, respectively.
Absorbance is therefore defined as:

$$A = - \log (I/I_o) \qquad \text{…Eq. 2.1}$$

Where, I is the signal from the sample relative to the signal from a reference, I_o. The reference can be an empty transmission sample cell for liquids or a broadband spectral reflector, such as a white ceramic, for reflectance measurements of solids [13;14]

Derivatives are one of the common methods in manipulating NIR spectrum for qualitative analysis and for quantification. This technique which is also known as derivative spectroscopy uses first or higher derivatives of absorbance with respect to wavelength. The first derivative will removes the baseline or offset produced by the scattering effects. In the other hand, the second derivative eliminates the gradient of the spectrum [15;16]. For instance, Temma et al using second derivative spectra in measuring sugar content of apple and apple juice. The application of second derivative by Temma et al is to separate any overlapping absorption peaks with the intention that the selection of appropriate peak for measurement and analysis can be done [3]. However, this technique introduce a problem since derivatives does amplify spectral curvature. This scenario often desired, but it may also increase the random noise to the spectrum. This will become an important setback as soon as the spectrophotometer reached its detection limit. The effect of increasing random noise however can be reduced by smoothing the spectra prior to differentiation [16].

V. Current Research at University Science Malaysia

Omar and Matjafri (2008) from University Science Malaysia have introduced new techniques to manipulate spectral waveform. In an experiment conducted in monitoring apples and pears decay, two techniques, named as NIR Spectral Reflectance Linearization and Gradient Shift has been introduced. These two techniques were done to the range of NIR wavelength from 920 to 980nm. The data of the spectral linearity and gradient have been measured and correlate with the time of measurement (every one hour) to monitor the effect of the fruits decay of to the light spectrum. This technique has able to produce a better linear correlation, R^2 (0.8456 to 0.9851) if compared to the measurement of a raw reflectance data at a single wavelength (0.4256 and 0.9564). The response of the NIR wavelengths in this experiment is expected due to the reduction of fruits water content [17;18]. The experimental setup is shown in Figure 1 while the entire results are tabulated in Table 1.

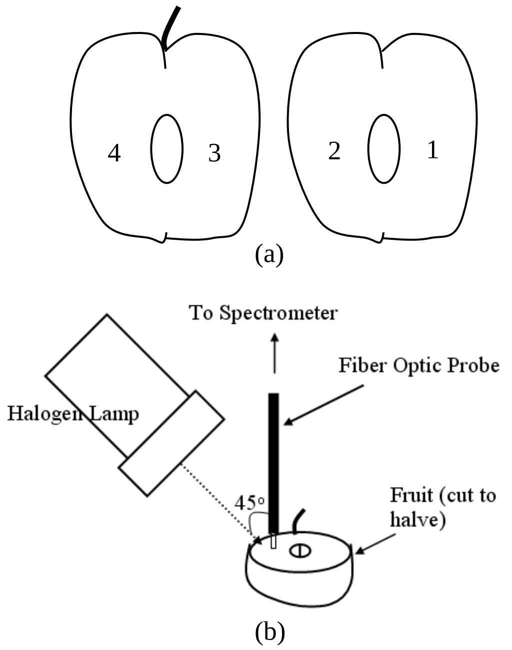

FIGURE 1: (a) Four parts of fruit that have be examined (b) Measurement of reflectance from fruits surface [17].

TABLE 1: Results obtained from the spectral response of four varieties of fruits [17;18]

Red Apple	Part 1	Part 2	Part 3	Part 4
R^2 (at single wavelength)	0.6739 (970nm)	0.8421 (975nm)	0.7909 (975nm)	0.8725 (970nm)
R^2 (Gradient vs Time)	0.9756	0.9042	0.945	0.935
R^2 (Linear Correlation Coefficient vs Time)	0.9299	0.9421	0.9391	0.9527
Green Apple	Part 1	Part 2	Part 3	Part 4
R^2 (at single wavelength)	0.7542 (975nm)	0.6711 (975nm)	0.4256 (975nm)	0.7815 (975nm)
R^2 (Gradient vs Time)	0.9411	0.8456	0.9602	0.9651
R^2 (Linear Correlation Coefficient vs Time)	0.9459	0.8869	0.9161	0.9647
Yellow Pear	Part 1	Part 2	Part 3	Part 4
R^2 (at single wavelength)	0.8016 (965nm)	0.9564 (965nm)	0.823 (960nm)	0.8466 (970nm)
R^2 (Gradient vs Time)	0.9106	0.9578	0.9506	0.9559
R^2 (Linear Correlation Coefficient vs Time)	0.8659	0.8528	0.8936	0.8735
Green Pear	Part 1	Part 2	Part 3	Part 4
R^2 (at single wavelength)	0.8983 (965nm)	0.7273 (980nm)	0.863 (965nm)	0.8224 (980nm)
R^2 (Gradient vs Time)	0.9319	0.9407	0.9851	0.951
R^2 (Linear Correlation Coefficient vs Time)	0.8787	0.882	0.9775	0.896

The common focus of the current research on spectroscopy application for fruits intrinsic quality measurement is through spectrometer. The spectrometer is considered as universal optical instrument to measure varieties of biochemical composition of a material. This can be done by performing various analyses towards the resultant light spectrum and correlate it with the capacity of element that we are interested to figure out. However, it is clear that specific biochemical composition is actually response better at a certain wavelength only. This has been proven by multiple experiments conducted previously. Specialized optical instrument has been developed for other application before by utilizing specifically a wavelength that response the best for the variable of interest. As an example to that, Apogee Instruments has successfully commercialize their Chlorophyll Concentration Meter by dividing the magnitude of light transmitted at wavelength 931nm by light transmitted at wavelength 653nm [19]. Inspired from this scenario, it is clear that the intrinsic fruits quality measurement system, which currently still concentrated as a lab procedure, shall be taken to the next step. This may require the development of a specialized optical instrument with specific parameters.

VI. OPTICAL DESIGN AND PARAMETERS

In the development of optical sensor in quality analysis, the major task assigned is in the quantification of the quality parameters and this will rely on the sensitivity of the optical system. The sensitivity of an optical system is defined as the minimum number of photons detectable during absorption or emission on a transition process. In other words, this is also a measurement for the minimum number of atoms or molecules which can be monitored by the spectroscopic system [20]. The introduction of fiber optic cable has light transferring medium from light source to the sample and from the sample to the spectrometer able to produce a flexibility in the overall measuring technique. The fiber optic spectroscopy system able to perform on-line analysis and it is the most effective means for obtaining process feedback and control. Reactant and product concentrations are quickly determined and the process is not disturbed by sampling [21]. The optical fiber sensor will be designed with a capability to measure range of UV-VIS-NIR wavelengths which this research introduces as Ultra Violet System, Visible System and Near Infra Red System. Individual optical sensor will be selected based on their peak responsivity and sensitivity. Sensor that having a higher sensitivity is more desirable since it can interpret small changes in light intensity resolution. While for the light source, device that can output the highest intensity is preferred. This selection is due to the understanding that the reflected light retrieved by an optical fiber cable is very small. Therefore, good optical devices are essential in the development of optical fiber sensor. Figure 2 shows the conceptual design for the Visible System.

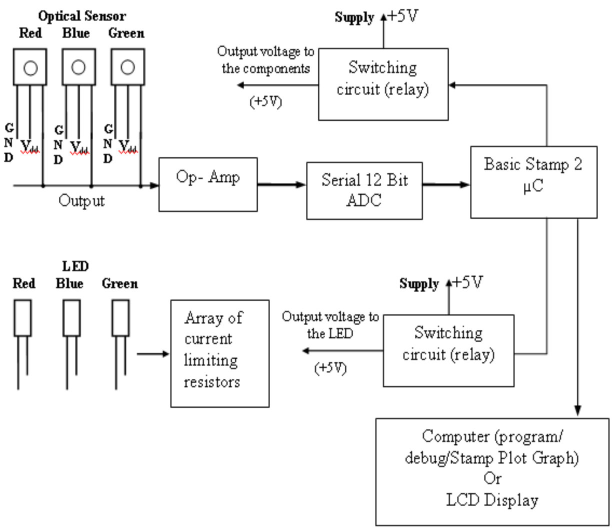

FIGURE 2: Conceptual design for Visible System

This system consist of a 12-bit receiver circuitry that is attached to a three different optical sensors that having peak responsivity at 470nm (blue), 524nm (green) and 635nm (red). The design of the Ultra Violet System and Near Infra Red System also will follow the same structure of design. But the selection of optical devices parameters will rely on its suitability to measure biochemical composition of fruits which will be measured throughout the research. The final data retrieved from the measurement will be displayed either in the graphical form on the computer (using Stamp Plot Graph) or through LCD Display.

VII. CONCLUSION

The current development of novel optical instrumentations and measuring techniques by researchers from University Science Malaysia is targeted to benefits the agriculture industry, especially among farmer in ensuring the high and consistent quality of fresh produce that are delivered to the market and consumer. The analysis on the previous works and initial experiment conducted does show the reliability of these new ideas which will be executed and calibrated with the established instrument in current market.

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