Fresh Fruit Bunch Ripeness Evaluation Methods

Subjects: Agricultural Engineering

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There are two types of methods to analyse the ripeness of fresh fruit bunches (FFBs), destructive methods and nondestructive methods. The destructive methods require physical contact in ways that affect the integrity of the FFBs and severely reduce the amount of oil that can be extracted from the tested FFBs. Meanwhile, the nondestructive techniques can involve noncontact features that are either visual or nonvisual. Nonvisual methods include using physicochemical, electrical, magnetic, and electromagnetic properties to determine fruit maturity such as fluorescence sensor, microwave sensor, inductive sensor, and thermal sensor. However, most nondestructive methods are visual, in which the selected sensor can evaluate through the morphology, colour, and other physical characteristics of the fruit to identify their maturity stages through the analysis of specific modalities such as colour vision, light detection and ranging, spectral image, and near-infrared spectroscopy.

Keywords: oil palm ; ripeness ; detection

1. Nondestructive Methods

1.1. Colour Vision

Usually, a colour image forms and appears that combines the red, green, and blue (RGB) tristimulus values. When the fresh fruit bunches (FFBs) are captured using image processing, and the image captured undergoes analysis to evaluate ripeness by RGB colour [1]. After the image is captured, inspection begins using image processing software and data acquisition software. Recently, to enhance the performance of maturity classification on FFB, different segmentation methods were proposed using colour vision systems. Septiarini et al. [2] implemented the Otsu method to segmentize the area of the oil palm fruit from the background in the image and obtain an iterative threshold. Septiarini et al. [3] implement the Canny algorithm combined with several morphology operations to remove the noise in the image. Furthermore, a multispectral system was proposed for evaluating the ripeness grading. The multispectral system was able to select specific optical filters with different wavelengths for penetrating objects or blocking noise. Therefore, the internal components and properties in the fruit could be discovered. Using the hyperspectral camera to capture the image could verify the amount of water content in the oil palm fruitlets. The multispectral system could perform even higher spatial resolution and image quality compare to the traditional system [4].

1.2. Light Detection and Ranging (LiDAR)

Generally, light detection and ranging(LiDAR) is a remote sensing technology that is applied in precision agriculture, archaeology, and other applications. The use of LiDAR has the potential in the classification of FFB maturity since LiDAR can acquire the actual distance and intensity from the target object. The LiDAR sensor emits laser light to the targeted object and receives the reflected light signal to calculate the distance between the sensor and the object. LiDAR also calculates the intensity of the object, which is the key to distinguishing the ripeness stage of FFB [5]. Hashim et al. [6] verified the accuracy of using LiDAR sensors in FFB maturity. In the experiment, LiDAR Lite v2 sensor was used to experiment in the laboratory and on-field. The LiDAR Lite v2 emitted a pulse of light with a 905 nm wavelength, and the reflected signal was received and transmitted back. The data were used to plot the graphical representation of the point cloud 3D mapping representing different maturity stages. Husin et al. [7] also used LiDAR on FFB maturity classification. In the experiment, LiDAR Lite v3 was used, and it received the reflected light signal to calculate the mean of return intensity. The researchers enhanced the use of LiDAR technology by creating a distribution map based on received latitude and longitude location. This will pinpoint the location of the ripe FFBs that are ready for harvesting.

1.3. Optical Sensor—Spectral Image

Several different wavelengths can be used to capture FFB images. The ultimate goal of multispectral image analysis is to examine the image intensity at various wavelengths especially in the ultraviolet (UV), visible light, and infrared spectra.

One of the key benefits of this examination is that more information detail can be investigated; for instance, the object's chemical components can be retrieved. The hyperspectral camera is used to take multispectral images in order to measure the maturity level of palm oil FFB. The relative water content in palm oil FFBs can be determined using these images [4]. The hyperspectral camera is not the only appliance for building an optical sensor system. Others researchers used several LEDs with different wavelengths as their source light to capture images of the FFBs for determining the maturity stage [8]. Moreover, the FFB image data were collected using a handheld four-band active sensor [9]. Four narrow-band (active optic) light sources and reflectance sensor components of various wavelengths were used in the system: two in the visible area (at 570 and 670 nm), one in the red-edge region (750 nm), and one in the near-infrared region (870 nm). For four bands, the spectral band width was around 50 nm. Each spectral area indicated distinct qualities that could be used to classify palm oil FFB maturity.

1.4. Near-Infrared Spectroscopy (NIR)

Near-infrared spectroscopy (NIR) is applied in the agriculture industry. The advantages of this method are nondestructive, and both physical and chemical substances can be measured. NIR spectroscopy analyses the chemical composition of fruit such as aqueous mixture, sugar level, firmness, and acidity. This method fills the gap in classifying FFB maturity. Traditionally, the harvester may make mistaken analyses of ripeness based on visual evaluation of features such as shape, size, and colour. Usually, the maturity stage of fruit can be identified by wavelength between 750 nm to 2500 nm. The electromagnetic spectrum in the near-infrared region can penetrate the organic substance because it has low absorption and low reflection . Through the process, the substance properties allow for distinguishing the maturity grades of fruit, as the chemical composition of fruit changes significantly from unripe to ripe. Silalahi et al. pointed out NIR spectroscopy as an alternative method for grading the ripeness of FFB by analysing the chemical composition of fruits. The samples were scanned under a near-infrared sensor with wavelengths of 1108–2500 nm. The test results showed the ripening of mesocarp changes depending on the oil content and moisture content.

1.5. Raman Spectra

Raman spectroscopy has been used to determine the maturity and freshness of tomatoes [12] and citrus fruits [13] by detecting the molecular vibrations of carotenoids and other chemical components found in the fruit's skin. Both a confocal Raman spectrometer and a portable Raman spectrometer were used to demonstrate these findings. A Raman-based device measures inelastic scattering from a compound's surface, which is then used as a molecular fingerprint. A leaf-clip-based Raman probe successfully proved to provide real-time monitoring for early identification of nutritional insufficiency. Recently, Raj et al. [14] used Raman spectroscopy to determine the maturity of oil palm fruitlets. The organic characteristics of the exocarp of oil palm fruitlets were studied using a confocal Raman spectroscopy device. They led to the realization that carotene content is one of the most important factors in determining the maturity of oil palm fruits. They showed that the Raman spectrum's carotene peak may be further deconvoluted and processed to identify four carotenoid components: carotene, lycopene, lutein, and neoxanthin. These elements and their derivations are used as features in machine-learning-based classification algorithms to automatically identify the maturity state of oil palm fruits.

1.6. Fluorescence Sensing

The use of fluorescence sensing on FFB classification was introduced by Hazir et al. [15]. The researchers measured the content of flavonoids and anthocyanin in the plant cell system using fluorescence methods. The flavonoids and anthocyanin are the phenolic content in the plant system that protect them from insect attack, and the phenolic content is important for attracting animals for seed dispersal. The researchers applied the fluorescence based on the phenolic content in the fruit. When UV light hits the epidermis, the flavonoids absorb the UV light. At the same time, the chlorophyll from mesophyll emits near-infrared fluorescence on the plant leaf. Meanwhile, anthocyanins are produced in the epidermis by absorbing the green light. Therefore, the phenolic content in FFBs can be measured to identify different maturity stages on the FFB after fluorescence scanning. Hazir et al. [16] used fluorescence sensors to classify the ripeness of FFB. The researchers investigated the implementation of the blue-to-red fluorescence ratio (BRR_FRF) as a parameter to differentiate the maturity of FFB and they used the Multiplex*3 sensor in the experiment.

1.7. Microwave Method

Yeow et al. [17] developed a low-cost coaxial moisture sensor to classify the maturity stage of oil palm fruit by determining its moisture content. This method was applicable because the water molecules in the fruit are sensitive when exposed to the microwave. This is because the water molecules have the intention to absorb microwave energy. When the microwave sensor emitted light to the targeted oil palm fruitlet, the light was interrupted. The receiver observed the changes in the light and measured moisture content. The microwave sensor detected the moisture content significantly under the frequency range from 300 MHz to 300 GHz. The moisture content in the fruitlet had the highest amount during the unripe stage and the lowest amount when overripe. This is due to the water content diminished and oil content produced after the anthesis in the mesocarp. Using a microwave, the relative complex permittivity ε_r to the agriculture product is shown in equation 1:

$$\varepsilon_r = \varepsilon_r' - j\,\varepsilon_r'' \qquad (1)$$

The variable ε_r' is the dielectric constant, and ε_r'' is the dielectric loss factor. Both ε_r' and ε_r'' are related to the moisture content because it absorbs the microwave energy. The dielectric constant affects the electric field distribution. Additionally, the energy absorption of the material is induced by the loss factor. The relative permittivity of water and oil also has a huge difference; their relative permittivity is 80 and 2.5 respectively. Hence, the microwave sensor can detect a slight difference in resonant frequency [18].

1.8. Inductive Sensing

Inductive sensing technology was first proposed by Harun et al.[19]. They tested with the frequency from 100 Hz to 100 MHz on unripe and ripe oil palm fruitlets. The result showed a significant difference between unripe and ripe oil palm fruitlets regarding the inductance and resonant characteristics. In addition, after testing with the variation in coil diameter, the single air coil with 24 mm coil diameter showed obvious differences between unripe and ripe fruitlets based on the resonant frequency. Harun et al. [20] continued their study on inductive sensing. They investigated the inductive sensor replacing the single air coil to the dual flat-type shape of air coil and found that it improved the sensitivity up to 167% of the determination of FFB ripeness. Lately, the ripeness of FFB can be proved by resonance frequency against time as the result showed it has a linear relationship. Additionally, the moisture content of the fruitlets reduced in a negative logarithm function was investigated. The analysis showed that the resonance frequencies acquired for unripe and ripe fruitlets are around 8.5 MHz and 9.8 MHz [21]. The inductive sensing method demonstrates the potential for determining the FFB ripeness. The design structure of the inductive sensor is improving to obtain more sensitive and precise results. Aliteh et al. [22] proposed using the triple flat-type air coil inductive sensor to identify the maturity of FFB. The researchers found that the coil with a fixed number of turns with different lengths was more sensitive because the inductive sensor is of sufficient length to attach to the fruit surface area. Currently, the inductive-based concept was implemented in the application for determining the ripeness of FFB. An inductive sensor system was developed and applied in the field [23].

1.9. Laser Light Backscattering

Laser-light backscattering was lately proposed to classify the ripeness of FFB and applied for determining the maturity of such as apricot [24], banana [25], and macaw oil palm [26]. Laser-light backscattering can determine the textural and mechanical properties of the fruit. The physical properties in the fruit can be acquired by tuning the wavelength of the laser diode. In addition, the backscattering profile is correlated to the scattering properties and absorption of the fruit [27]. The laser-light backscattering is supported by Utom et al. [28], who discovered that chlorophyll act as a photoreceptor. It absorbs light with a wavelength in the region of 400 to 700 nm. Therefore, the carotenoids and chlorophyll contents can be an indicator to classify the maturity of FFB. In the past, this method was implemented in the different agricultural crops for monitoring fruit quality. For example, Babazadeh et al.[29] applied laser light backscattering imaging to distinguish the potatoes that only contained α-solanine taxicant. Ali et al. [30] developed a backscattering images system to classify seeded and seedless watermelons. In 2020, Ali et al. [31] combined backscattering imaging and computer vision to determine the maturity level of FFB. The authors used discriminant analysis and quadratic discriminant analysis to carry out the classification with the combination of backscattering parameters and RGB values. The experimental research demonstrated this method achieved above 85% accuracies for classifying the ripeness of oil palm FFB.

1.10. Thermal Sensing

The maturity grading of FFB using thermal vision was first proposed by Fauziah et al. [32]. The authors found that the traditional FFB harvesting method was inappropriate due to the environmental condition and animal disturbances. In addition, the FFB harvesting with long-range detection and nondestructive method was usually affected by lighting environment. Therefore, the authors introduced using thermal vision since the lighting has no explicit effect on the thermal principle's outcomes. The object temperature emission was used to carry out the testing procedure. The oil content had an effect on the thermal characteristics (heat) of the object. The oil content of the fruit increases as it ripens: the higher the ripeness level, the less water content and the higher the oil content. This phenomenon could be seen using a thermal camera's image. This camera is monochromatic, meaning it cannot observe the colours but can detect the strength of radiation. The strength of the radiation is directly proportional to the ripeness degree of the fruit, as seen in the picture extraction outcomes. The picture extraction results are the elements of redness, greenish, and bluish, which are transformed into temperatures. The FFB surface temperature can be utilised to predict greater ripeness. As the fruit ripens, the heat level rises. The temperature will fall after optimum ripeness. The authors further improved the thermal vision method implemented in a device. They discovered that two quality parameters had higher coefficients of determination related to FFB surface temperature: carotene content and oil and moisture ratio. Therefore, a linear and multiple regression model could be employed to predict the ripeness of oil palm FFB at the pre-harvest stage using a thermal imaging system. This method can also be used to estimate the time it will take to harvest the oil palm FFB [33].

2. Destructive Methods

Fruit Battery

The estimation of ripeness of FFB using fruit battery was first proposed by Minakata et al. [34]. The authors designed the fruit battery using copper and zinc electrode. These metal electrodes pricked through the surface of oil palm fruitlets, and ionization occurred. Zinc experiences oxidation by leaving two electrons as zinc has a higher level of activity series compared with copper. The copper electrode received electrons from the zinc electrode. The electron will combine with a hydrogen ion since the fruitlets contain moisture, and hydrogen gas is produced. The half-equations are shown below. A small current produced due to the movement of electrons had a potential difference in the mesocarp.

This is the half equation of the zinc and hydrogen equations [34]:

$$Zn \rightarrow Zn^{2+} + 2e^{-}, \qquad (2)$$

$$2H^{+} + 2e^{-} \rightarrow H_2 \qquad (3)$$

A load of electromotive force generated in the mesocarp confines in the proportion of moisture in oil palm fruitlets. The moisture and lipid content in unripe fruitlets occupy 80.1% and 5.9% of content percentage, which has a significant difference compared with a ripe fruitlet. The moisture content converts to lipid content during the maturation of the fruitlet. The ripe fruitlet has only 24.7% and 58.3% content [21].

The characteristic of moisture and lipid content in the fruitlet become an indicator for designating the maturity stage of oil palm fruitlets. For instance, Misron et al. [35] implemented the concept of fruit battery in an application to inspect the maturity of FFB at the mill. The authors proposed a fruit battery sensor with a charging concept to gain steady-state condition, which is to avoid inaccurate results from unstable load voltage. Moreover, the authors proposed the sensor by implementing different adequate parameters. The parameters included load resistance, charging voltage, and charging time. These parameters were tested with a variant of data from the experiment to deliver important information. An investigation found that the sensitivity performance increased where the load resistance, charging voltage, and charging time increased. Additionally, the fruit battery sensor improved the accuracy of screening the maturity stage of FFB when combined with computer vision [36].

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