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Classification of oil palm fresh fruit bunches utilising multiband optical sensors: A review

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ABSTRACT

Indonesia, as the world's largest palm oil producer, faces the challenge of improving crude palm oil production efficiency through the classification of fresh fruit bunch (FFB) maturity levels. This study aims to develop a FFB classification system using multiband optical sensors based on visible light and near-infrared spectra. A total of 191 FFB samples were classified into two categories, namely ripe and unripe, using the reflectance of the near-infrared (NIR) spectrum. Results show that the combination of visible and NIR spectra at a wavelength of 660 nm has high accuracy in detecting oil content in FFB. The classification model based on oil content showed an accuracy of 66.7%, better than the visual inspection model (52.1%). This study shows the great potential of optical sensor technology to improve the efficiency and quality of the palm oil industry in Indonesia.

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1. INTRODUCTION

Indonesia is the preeminent producer of palm oil globally, with a significant increase in demand for palm fruit corresponding to the rising need for crude palm oil (CPO). Consequently, the prospects for oil palm farms and the palm oil processing industry remain highly promising. Nonetheless, global rivalry is intensifying along with the proliferation of plantation enterprises. In the era of globalisation, plantation enterprises must enhance their effectiveness and efficiency [1].

Fresh fruit bunches (FFBs) possess a maturity level that directly influences both harvest quality and palm oil quality, categorised into three classifications: unripe, ripe, and overripe. Fruits appropriate for shipment are those in ripe and near-ripe stages, as both yield quality oil. Conversely, unripe fruits are unsuitable for processing and must not be delivered to the mill. Nevertheless, immature fruit is frequently transported, resulting in losses for the producer due to the absence of oil production. Consequently, it is essential to perform a precise categorisation of FFB maturity levels before shipment to reduce losses and enhance palm oil production efficiency [2].

Today, enterprises strive to substitute human labour with machinery to enhance productivity and output quality. The initial manual stage in the production process involves choosing ripe palm fruits. These manual procedures are labour-intensive and time-consuming, relying on human observation and necessitating considerable effort. Consequently, errors frequently arise during the verification process, necessitating. Consequently, the utilisation of machines can enhance this procedure, minimise errors, and augment overall efficiency [3].

In response to the aforementioned issues, a study was undertaken employing chemometric analysis of visible and near-infrared spectra to ascertain the internal characteristics of FFB. Introducing the latest technology in the palm oil business is essential. The primary aim is to enhance palm oil crops and processing facilities [4].

2. THEORITICAL REVIEW

2.1. Multiband Optical Sensor

Multiband optical sensors are instruments that utilise visible and infrared light to detect and quantify numerous physical properties [5]. Visible light and infrared light are distinct segments of the electromagnetic spectrum, each with unique qualities and applications. Visible light, perceivable by the human eye, has a wavelength ranging from 380 – 750 nm. Conversely, infrared light is electromagnetic radiation with a wavelength exceeding that of visible light, ranging from 700 nm to 1 mm. The wavelength of infrared light is imperceptible to the human eye, yet its thermal radiation is detectable. Infrared is classified into three categories: near infrared (0.75 – 1.5 μm), mid infrared (1.5 – 10 μm), and far infrared (10 – 100 μm) [6, 7].

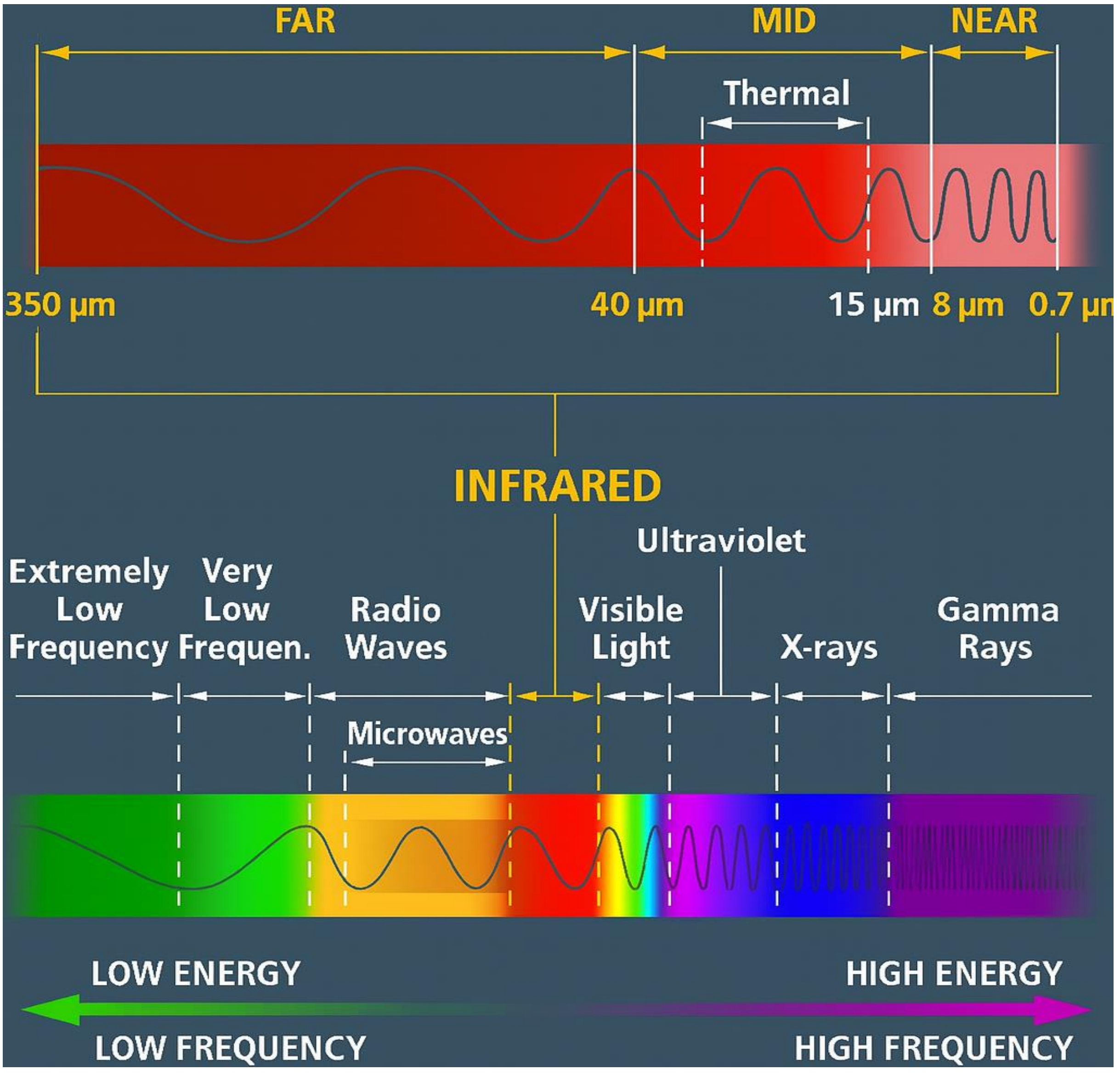

Figure 1. Depiction of the infrared segment of the spectrum.

2.2. Analysis of Spectral Data

Spectral data analysis is a method employed to evaluate and analyse information derived from spectral measurements. This technique is crucial in various domains, including remote sensing, meteorology, and product quality assessment. Spectral measuring is a method employed to examine the interaction of light with things, specifically oil palm FFBs. Utilising a light source, such as an LED, at a specified wavelength enables the acquisition of relative reflectance data, which yields significant insights into the physical attributes and maturity of FFB [8, 9].

3. RESEARCH METHODS

3.1. Multiband Optical Sensor Work

The following outlines the fundamental procedures by which multiband optical sensors operate:

- Illumination Provision
  The sensor radiates visible or infrared light towards the thing being measured. This light may originate from an LED or laser beam.
- Engagement with Objects
  When light strikes an item, a portion is reflected, while the remainder is either absorbed or transmitted, contingent upon the object's material qualities.
- Photonic Detection
  Light reflected to the sensor is caught by a detector, such as a photodiode. This detector transforms the incoming light intensity into an electrical signal.
- Signal Processing
  The resultant electrical signal is further analysed to ascertain the measured parameter, including material concentration, temperature, or liquid level. This method frequently entails boosting and conditioning the signal to enhance measurement precision [4].

3.2. Analysis of Spectral Data

Spectral measuring techniques often entail the interaction between emitted light and the sample material. When light encounters an object, it may be reflected, transmitted, or absorbed by the material. This procedure yields a spectrum that is subsequently transformed into data. This interaction transpires as the molecules within the material vibrate upon exposure to light, resulting in the reflection or absorption of the light. The spectrum of light interacting with the product's chemical constituents yields significant insights into the material's qualities.

3.3. Methods of Oil Extraction

Thirty-three data samples were gathered for subsequent analysis. Immature fruits were detached from the cluster and subsequently weighed. Thirty juvenile fruits were randomly chosen: 10 from the exterior, 10 from the centre, and 10 from the interior of the little fruit. Subsequently, these little fruits were sliced to extract the pulp. The mesocarp was subsequently desiccated to eliminate physical moisture from it. The oil from the mesocarp was extracted utilising a Soxhlet extractor with hexane as the solvent. The residual fibres and solvent were dehydrated and chilled in a desiccator. Samples at each stage were measured by weight. The oil content in the mesocarp (Oil_m) was determined using the following equation:

$$\%Oil_m = \frac{W_2 - W_3}{W_1} \times 100\% \quad (1)$$

where, W_1 denotes the weight of the mesocarp sample (g), W_2 represents the weight of the mesocarp post-drying (g), and W_3 indicates the weight of the mesocarp subsequent to extraction (g). The yield of crude palm oil from FFB samples was determined using the subsequent equation:

$$\%Oil\ content = \frac{\sum W_f}{W_{FFB}} \times \%W_m \times \%Oil_m \quad (2)$$

where, W_{FFB} denotes the weight of FFB (g), W_f represents the weight of fruit (g), $\%W_m$ indicates the percentage of mesocarp weight of young fruit (%), and $\%Oil_m$ signifies the percentage of mesocarp oil (%).

4. RESULTS AND DISCUSSIONS

The mean relative reflectance voltage of the 16 LEDs is employed to differentiate between two types of fresh fruit bunch (FFB) maturity: ripe and immature. Outliers, shown by dots on box and line diagrams, were excluded from the dataset. Consequently, the aggregate number of samples for the ripe and immature categories is 57 and 52, respectively. The training dataset for FFB oil content comprises 17 FFB with oil content over 17.5% (high oil content) and 4 FFB with oil content below 17.5% (low oil content).

Four outlier data points with elevated oil content were excluded from the dataset. The voltage disparity between the two maturity classifications was observed in nearly all LEDs. Figure 2 displays box and line diagrams for wavelengths of 615 nm, 635 nm, 660 nm, and 830 nm.

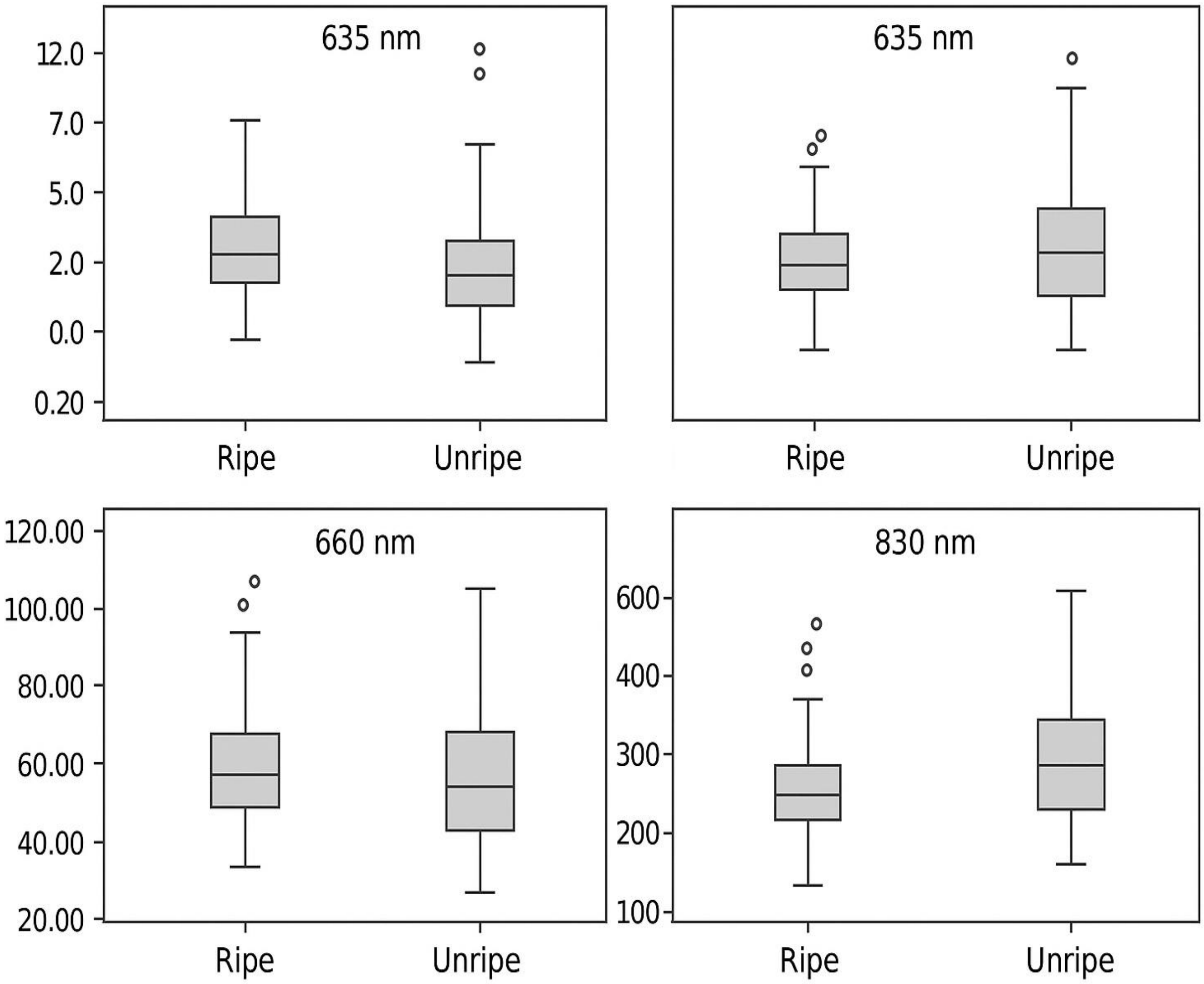

Figure 2. Box-and-whisker plot illustrating the comparative reflectance voltage values of mature and immature oil palm fresh fruit bunches.

The variation in voltage levels in the visible spectrum corresponds to the colour change attributed to chlorophyll, which exhibits absorbance at 660 nm. The hue of oil palm FFB intensifies to a more reddish tone during. Ikemefuna and Adamson assert that the primary pigment alterations linked to the ripening process include a reduction in chlorophyll and a significant increase in carotene.

Table 1. A summary of the outcomes from the stepwise method.

LED wavelengths (nm)	Tolerance	Significance of F for removal	Minimum D squared
LED 765 nm	1.000	0.000	0.000
LED 765 nm	0.619	0.000	0.078
LED 680 nm	0.619	0.000	0.883
LED 765 nm	0.152	0.000	0.954
LED 680 nm	0.558	0.000	0.930
LED 890 nm	0.201	0.016	2.076
LED 765 nm	0.150	0.000	1.061
LED 680 nm	0.036	0.001	2.039
LED 890 nm	0.201	0.014	2.293
LED 660 nm	0.040	0.046	2.419

In this study, the LED wavelength selection was established at 0.05 for the inclusion variable and 0.1 for the exclusion variable. Table 1 presents a summary of the outcomes from the stepwise method, including wavelength selection. These wavelengths were identified as the most significant for differentiating between treatments. Various wavelengths were acquired for classification according to FFB oil content. Only the 660 nm LED was incorporated into the model.

Linear discriminant analysis utilising Mahalanobis distance was employed to assess the quality of FFBs from smallholders, yielding accuracies of 52.1% for external feature criteria and 66.7% for FFB oil content. The model derived from FFB oil content exhibited superior accuracy.

5. CONCLUSION

The integration of visible and near-infrared spectra inside the sensor system exhibits promise for assessing the quality of oil palm FFB. Of the chosen wavelengths, the 660 nm LED was recognised as useful for assessing FFB oil content due to its robust capacity to detect oil levels and its correlation with pigment absorbance, such as chlorophyll, which varies with the fruit's maturity. The classification model based on FFB oil content data demonstrated superior accuracy compared to the model reliant on eye examination, with a classification accuracy of 66.7% versus 52.1%.

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