Investigation of the ripeness of oil palm fresh fruit bunches using bio-speckle imaging

R Salambue¹, A Adnan² and M Shiddiq³
¹ Department of Information System, Universitas Riau
² Department of Statistic, Universitas Riau
³ Department of Physics, Universitas Riau
roni.salambue@lecturer.unri.ac.id

Abstract. The ripeness of the oil palm Fresh Fruit Bunches (FFB) determines the yield of the oil produced. Traditionally there are two ways to determine FFB ripeness which are the number of loose fruits and the color changes. Nevertheless, one drawback of visual determination is subjective and qualitative judgment. In this study, the FFB ripeness was investigated using laser based image processing technique. The advantages of using this technique are non-destructive, simple and quantitative. The working principle of the investigation is that a FFB is inserted into a light tight box which contains a laser diode and a CMOS camera, the FFB is illuminated, and then an image is recorded. The FFB image recorder was performed on four FFB fractions i.e. F0, F3, F4 and F5 on the front and rear surfaces at three sections. The recorded images are speckled granules that have light intensity variation (bio-speckle imaging). The feature extracted from the speckled image is the contrast value obtained from the average gray value intensity and the standard deviation. Based on the contrast values, the four fractions of FFB can be grouped into three levels of ripeness of unripe (F0), ripe (F3) and overripe (F4 and F5) on the front surface of base section of FFB by 75%.

1. Introduction
In the last few decades the problem of determining the maturity and ripeness level of oil palm fresh fruit bunches (FFB) has become a popular research topic in the palm oil industry. Indonesia, which is one of the largest Crude Palm Oil producing and exporting countries in the world, makes palm oil the main source of foreign exchange in Indonesia. Fruit maturity and ripeness determine the yield of oil produced [1], therefore the determination of FFB maturity and ripeness is one of the problems for farmers and oil palm companies in Indonesia. The determination of FFB ripeness before harvested or in sorting and grading process is still done manually or traditionally using the vision (human vision) by trained and experienced workers. Several studies on FFB ripeness have been conducted in the last decade, one of which is a review of several techniques for predicting maturity of oil palm fruit based on visual observation, oil content and image processing [2].

FFB ripeness is classified by several standards. In general, there are three categories of FFB ripeness those are unripe, ripe, and overripe. Traditionally there are two ways to determine the ripeness stages of FFB that are base on the number of fruits that detached and fell from a FFB and based on the color of FFB. However, one drawback of visual determination is subjective and qualitative judgment. This research investigates FFB ripeness categories using a laser based image processing technique. In order to get the image, a FFB is inserted into a light tight box containing a 650 nm laser diodes and a CMOS camera. The diode laser illuminates the FFB and the FFB speckle image is recorded using the
camera. The resulting image has a light and dark speckle pattern. In the field of biological science, the activity of biological matter such as a fruit which is irradiated by a laser beam is called Bio-speckle. Bio-speckle imaging and image processing techniques are potential combination to analyze and classified ripeness of oil palm FFBs.

2. Literature Review

The use of laser light in agriculture become intensive in last decade because it is non-destructive, simple, and fast. The optical method is potential to substitute or accompany laboratory test methods that are expensive, invasive, and time consuming. Laser Speckle Imaging (LSI) is an optical method that can be used to detect the level of ripeness and abnormalities in the fruit. This technique relies on the interaction of light and the fruit material and monochromatic light. When laser light illuminates the fruit surface, light can be absorbed, reflected, transmitted, and scattered by the surface of the material. Fruit has several physical properties which are represented by physical parameters such as density, porosity, surface roughness, diameter, and color. Light that concerns uneven surfaces will experience two types of reflections that are specular reflections and diffuse reflections. The reflected light beams will have different phases that will cause constructive and destructive interference resulting in some light and dark speckle granules. The method of speckling pattern caused by biological material such as fruit is called Bio-speckle. The bio-speckle phenomenon occurs when biological matter is irradiated by coherent light (laser light). The diffused light from surface roughness is optically recorded and produces the image with light and dark speckles of light [3].

There are two type of speckle pattern: static and dynamic. The static pattern is derived from the static part of the fruit network, while the dynamic pattern comes from particles or molecules that move in the tissues i.e in the process of maturity or ripeness. The dynamics of this speckle pattern can be statistically analyzed. This method is based on variations of laser light intensity or contrast dissipated by biological samples. Fruit is a complex element consisting of molecules of fruit tissue built of various sizes depending on the level of maturity and ripeness. These molecular sizes will affect the optical properties of the fruit associated with the skin's ability and the fruit tissue to absorb and scatter light so that it can be used to monitor fruit maturity levels [4].

The efforts of finding nondestructive methods for the detection of fruits for both pre- and post-harvest conditions have been widely practiced. The nondestructive method for estimating mango maturity uses color as one of the characteristics of maturity [5]. In addition, the use of image processing algorithm has also been developed for sorting and grading in fruits and vegetables [6]. A study of the determination of FFB maturity and ripeness has also been done and many methods have been developed. Identification of nondestructive maturity generally uses computer vision and image processing techniques. The characteristic of the extraction is the color of the image. The CCD camera recording is then processed using software to classify FFB maturity [7]. This technique provides classification accuracy between 83.5% - 94%. In addition, a grading system using a computer-based photogrammetric method, has been conducted in which the FFB is illuminated by a homogeneous light bulb in a box [8]. Furthermore, the ripeness category is determined from the Color Digital Number (DN). Automatic FFB grading systems have also been developed in estimating the ripeness fraction, oil content and free fatty acids of FFB using two statistical methods of forward stepwise multiple linear regression and multilayer-perceptron artificial neural network analysis. The estimation accuracy of both statistical methods is about 90%[9].

3. Material and Methodology

3.1 Tools and materials

The tools used in this research are a diode laser, a CMOS sensor camera, biconcave lenses, image processing software, and data processing as well as other optical components. The sample material studied was FFB of varieties of Tenera (Lonsum clone). FFBs are selected by four maturity fractions
(representing three levels of maturity) i.e. F0 (unripe), F3 (ripe), F4 and F5 (overripe). The tools and materials used are presented in the following table

| Tool and materials         | Information        |
|----------------------------|--------------------|
| Oil palm FFB               | Tenera Variety     |
| Optical bench              | Thorlabs           |
| Diode laser 650 nm         | Roithner           |
| Monochrome CMOS camera     | Imaging Source     |
| Camera lens Kamera 1.4/12mm| Navitar            |
| Biconcave lens f = -50 mm  | Roithner           |
| Laptop                     | Sony               |
| IC Capture 2.4             | Imaging Source     |
| Matlab                     | http://mathworks.com|

3.2 Data
The FFB samples used represented three levels of ripeness and were selected from trees under the age of eight years. The ripeness stages of harvested FFBs were determined by an experience harvester. The FFBs were then brought to Lab and cleaned. The measurements were completed in 24 hours after harvest. The image recording is performed on two FFB surfaces, the rear and front surfaces. The rear surface is the surface facing the palm tree while the front surface is facing sunlight. The surface of FFB is irradiated in three parts, namely the base, the middle and the tip, so that each FFB gets six specimen images. A specimen image of each FFB was analyzed using MATLAB software to obtain average gray value intensities and standard deviation values on all parts of each surface. Both values are computed to obtain the value of the contrast that represents the ripeness level of each FFB.

3.3 Method
To observe the bio-speckle activity at three levels of FFB ripeness, we have calculated the speckle modulation pattern expressed as contrast in the FFB image. The contrast equation is as follows:

\[
C = \frac{\sigma I}{\langle I \rangle}
\]

\[
I = \frac{\sum f(x,y)}{n}
\]

\[
\sigma I = \sqrt{\frac{\sum (f(x,y) - I)^2}{n-1}}
\]

where
- \(C\) = contrast
- \(\sigma I\) = standard deviation
- \(I\) = average of grey value intensity
- \(f(x, y)\) = grey value on spatial coordinates
- \(n\) = the number of spatial coordinates

The average gray value intensity shows the intensity distribution of the gray level, the standard deviation shows the intensity of gray and the contrast intensity levels represents variations in gray level intensity distribution. Equation (1) becomes the characteristic of extraction algorithm in this study.

4. Results and Discussion
Image of speckled FFB captured uses a monochrome CMOS camera with 650 nm diode laser wavelength. Supporting components are camera lens, biconcave lens -50 mm. The camera lens is used to adjust the focus and camera aperture and bi-concave lenses are used to spread the laser beam. Biconcave lens arrangement focuses the laser beam only on 2-5 pieces on FFB fruits because
illuminating the entire surfaces of FFB will produce dark dominant speckles. FFS objects are irradiated alternately in three parts of the base, middle and ends of the front and back surfaces of FFB. Each fraction is represented by three FFB, so that for each part on the surface 12 images are produced. CMOS cameras are installed as far as 44.3 cm and perpendicular to FFB. The laser distance to FFB is 58.6 cm, and the distance of the laser to the camera is 17.5 cm. The distances between these components is kept constant, so the width of the beam of laser beams on the surface of the FFB remains constant. The system is built in black box with size 60 cm x 60 cm x 90 cm. The black box function is to eliminate outside light interference during the recording process. Illustration of illumination and recording of FFB and FFB biospeckle results is presented in the following figure.

![Radiation system and bio-speckle image recording](image)

**Figure 1.** Radiation system and bio-speckle image recording

Image recording is done experimentally at different levels of FFB ripeness. The sample used was four fractions of FFB with three variations of ripeness level i.e. F0 (unripe), F3 (ripe), F4 and F5 (overripe). The speckled data retrieval is taken from the front and back surfaces of FFB. The fruits on the back surface of FFB have a variety of different shape and size. The backbone FFB base has many spikelet and many small fruits. Rear surface fruits have fewer gaps than the front surface. The front surface of FFB has uniform fruits on all parts. The front surface FFB tip has a smaller size than the rear end FFB tip.

![The pattern of the frontal specimen of FFB fraction F4](image)

**Figure 2.** The pattern of the frontal specimen of FFB fraction F4 (a) base (b) middle (c) top

![The pattern of the backside FFB specimen fraction F4](image)

**Figure 3.** The pattern of the backside FFB specimen fraction F4 (a) base (b) middle (c) top
Speckle image data processing is done using MATLAB. Via this software, the average features of gray value and standard deviation intensity are extracted using equations (2) and (3). Then both values are entered into equation (1) to obtain a contrast value. Based on the observation of contrast value on 72 image data, it can be determined that the contrast value for F0 ≤ 1.4, F3 ≤ 1.5, F4 and F5 > 1.5. The results of the feature extraction, computation and category of FFB speckle patterns are presented in the following table.

Table 2. The results of feature extraction and category of front surface FFB

| No | Label   | (l)  | (σl) | (C)  | Category | Results | Remarks          |
|----|---------|------|------|------|----------|---------|------------------|
| 1  | F0S1 DP | 9.2335 | 11.7414 | 1.2716 | F0       | True    | DP:              |
| 2  | F0S2 DP | 9.1673 | 12.3662 | 1.3489 | F0       | True    | Front surface    |
| 3  | F0S3 DP | 9.7634 | 10.5114 | 1.3716 | F0       | True    | of base section  |
| 4  | F3S1 DP | 11.2172 | 16.1706 | 1.4416 | F3       | True    | F3              |
| 5  | F3S2 DP | 11.1350 | 16.0150 | 1.4383 | F3       | True    | F3 section       |
| 6  | F3S3 DP | 10.7062 | 15.9368 | 1.4886 | F3       | True    |                  |
| 7  | F4S1 DP | 16.0704 | 24.4794 | 1.5233 | F4/F5    | True    |                  |
| 8  | F4S2 DP | 12.0800 | 17.3519 | 1.4334 | F3       | False   |                  |
| 9  | F4S3 DP | 9.8844 | 13.1788 | 1.3333 | F0       | False   |                  |
| 10 | F5S1 DP | 12.0197 | 18.4556 | 1.5354 | F4/F5    | True    |                  |
| 11 | F5S2 DP | 12.0103 | 17.2111 | 1.4330 | F3       | False   |                  |
| 12 | F5S3 DP | 17.3642 | 27.2451 | 1.5690 | F4/F5    | True    |                  |
| 13 | F0S1 DT | 7.9177 | 10.8452 | 1.3697 | F0       | True    | DT: Front surface of middle section |
| 14 | F0S2 DT | 7.6918 | 10.9207 | 1.4198 | F3       | False   |                  |
| 15 | F0S3 DT | 7.3038 | 10.5891 | 1.4498 | F3       | False   |                  |
| 16 | F3S1 DT | 11.8859 | 15.3337 | 1.2901 | F0       | False   |                  |
| 17 | F3S2 DT | 9.8199 | 12.8930 | 1.3129 | F0       | False   |                  |
| 18 | F3S3 DT | 10.9066 | 15.5500 | 1.4257 | F3       | False   |                  |
| 19 | F4S1 DT | 15.7896 | 21.9578 | 1.3907 | F3       | False   |                  |
| 20 | F4S2 DT | 12.9032 | 18.9321 | 1.4672 | F3       | False   |                  |
| 21 | F4S3 DT | 9.2836 | 14.1572 | 1.5250 | F4/F5    | True    |                  |
| 22 | F5S1 DT | 9.7572 | 14.0671 | 1.4417 | F3       | False   |                  |
| 23 | F5S2 DT | 12.3533 | 18.9965 | 1.5378 | F4/F5    | True    | DU: Front surface of top section |
| 24 | F5S3 DT | 10.9792 | 17.1891 | 1.5656 | F4/F5    | True    |                  |
| 25 | F0S1 DU | 7.8667 | 11.6992 | 1.4872 | F3       | False   |                  |
| 26 | F0S2 DU | 7.5373 | 11.1222 | 1.4756 | F4       | False   |                  |
| 27 | F0S3 DU | 7.4140 | 11.1486 | 1.5037 | F4/F5    | True    |                  |
| 28 | F3S1 DU | 13.8776 | 19.4875 | 1.4042 | F3       | False   |                  |
| 29 | F3S2 DU | 10.0506 | 13.5783 | 1.3510 | F0       | False   |                  |
| 30 | F3S3 DU | 8.9027 | 12.2714 | 1.3784 | F3       | True    |                  |
| 31 | F4S1 DU | 12.0523 | 16.7271 | 1.3879 | F3       | False   |                  |
| 32 | F4S2 DU | 11.2896 | 15.5545 | 1.3778 | F3       | False   |                  |
| 33 | F4S3 DU | 8.8804 | 13.8123 | 1.5554 | F4/F5    | True    |                  |
| 34 | F5S1 DU | 8.2798 | 11.6025 | 1.4013 | F3       | False   |                  |
| 35 | F5S2 DU | 8.9208 | 12.6784 | 1.4212 | F3       | False   |                  |
| 36 | F5S3 DU | 8.4947 | 12.3973 | 1.4594 | F3       | False   |                  |

Table 3. The results of feature extraction and category of back surface FFB

| No | Label   | (l)  | (σl) | (C)  | Category | Results | Remarks          |
|----|---------|------|------|------|----------|---------|------------------|
| 1  | F0S1 BP | 17.8477 | 27.6307 | 1.5481 | F4/F5    | False   | BP: Rear surface of base section |
| 2  | F0S2 BP | 20.6675 | 29.5511 | 1.4298 | F3       | False   |                  |
| 3  | F0S3 BP | 15.7328 | 26.0196 | 1.6539 | F4/F5    | False   |                  |
| 4  | F3S1 BP | 18.8325 | 28.3307 | 1.5043 | F4/F5    | False   |                  |
| 5  | F3S2 BP | 15.0107 | 21.5276 | 1.4341 | F3       | True    |                  |
| 6  | F3S3 BP | 15.0268 | 22.9386 | 1.5265 | F4/F5    | False   |                  |
| 7  | F4S1 BP | 22.7972 | 37.5626 | 1.6477 | F4/F5    | True    |                  |
| 8  | F4S2 BP | 22.2380 | 34.5376 | 1.5531 | F4/F5    | True    |                  |
| 9  | F4S3 BP | 15.0004 | 20.5883 | 1.3725 | F0       | False   |                  |
| 10 | F5S1 BP | 20.2776 | 32.8684 | 1.6209 | F4/F5    | True    |                  |
| 11 | F5S2 BP | 16.9439 | 26.6742 | 1.5743 | F4/F5    | True    |                  |
| 12 | F5S3 BP | 24.0895 | 38.0983 | 1.5815 | F4/F5    | True    |                  |
Based on the tables, the most category is found on the front surface of base section of FFB by 75%, which means that the correct image is classified is 9 of 12 images. On the middle section, the category is 42% (5 of 12) and for the top section of the category result is 25% (3 of 12). Tests performed on the back surface of base and middle section, the classification success rate is 50% (6 of 12) and at the top section of the classification results only 33.3% (4 of 12).

The highest classification results produced by the front surface of base section, because the front surface has a fruit similarity on all parts so that it has a higher scattering intensity than the other parts. This higher scattering intensity is due to a more homogeneous scattering surface than any other surface. However, the lowest classification results are produced on the front surface of top section because it has smaller fruit sizes than the rest so that small scattering areas produce low scattering intensity.

5. Conclusion
Based on the implementation of research conducted we may conclude that:

1. The highest category is obtained on the front surface of FFB at the base of 75% because the front surface has a fruit similarity on all parts so the scatter intensity is higher than the other parts.
2. The lowest category is obtained on the front surface of the ends of the FFB i.e. 25% because the size of the fruit in this section is smaller than the other parts resulting in low scattering intensity.

References
[1] USAID 2009 Handbook of small-scale palm oil mills for the production of biofuel raw materials No. 497.
[2] M A H and Razali S R H and Somad A 2012 A Review on Crop Plant Production and Ripeness Forecasting,” Int. J. Agric. Crop Sci., vol. 4, no. 2, pp. 54–63.
[3] Zdunek A, Adamiak A and Pieczyrywe P M and Kurenda A 2013 The biospeckle method for the investigation of agricultural crops : A review Opt. Lasers Eng., pp. 1–10.
[4] Ansari M Z and Nirala A K 2014 Assessment of fruits during shelf-life storage using biospeckle laser vol. 16, no. 3, pp. 223–229.
[5] Slaughter D C 2009 Nondestructive Maturity Assessment Methods for Mango pp. 1–18.
[6] Mahendran R, Ge C and Alagusundaram K 2012 Application of Computer Vision Technique on Sorting and Grading of Fruits and Vegetables pp. 1–7.

| No. | FOS1 BU | FOS2 BU | FOS3 BU | F3S1 BU | F3S2 BU | F3S3 BU | F4S1 BU | F4S2 BU | F4S3 BU | F5S1 BU | F5S2 BU | F5S3 BU |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 13  | 14,1247 | 24,3208 | 1,7219  | F4/F5   | False   | BT: Rear |
| 14  | 14,3170 | 22,0723 | 1,5417  | F4/F5   | False   | surface |
| 15  | 8,2993  | 11,3388 | 1,3662  | F0      | True    | of middle |
| 16  | 19,2050 | 28,7487 | 1,4969  | F3      | True    | section |
| 17  | 13,2111 | 20,1834 | 1,5278  | F4/F5   | False   | |
| 18  | 15,0398 | 20,6931 | 1,3759  | F3      | True    | |
| 19  | 21,7583 | 29,4354 | 1,3528  | F3      | False   | |
| 20  | 17,2836 | 24,7171 | 1,4301  | F3      | False   | |
| 21  | 12,6097 | 16,0695 | 1,3314  | F0      | False   | |
| 22  | 12,9132 | 19,7892 | 1,5325  | F4/F5   | True    | |
| 23  | 13,3411 | 21,3701 | 1,6018  | F4/F5   | True    | |
| 24  | 14,4245 | 21,1381 | 1,4654  | F3      | False   | |
| 25  | 8,2519  | 11,5079 | 1,3946  | F3      | False   | BU: Rear |
| 26  | 7,9346  | 12,8586 | 1,6206  | F4/F5   | False   | surface |
| 27  | 7,6093  | 11,3591 | 1,4928  | F3      | False   | of top |
| 28  | 9,5628  | 13,6629 | 1,4287  | F3      | True    | section |
| 29  | 11,1023 | 15,4696 | 1,3934  | F3      | True    | |
| 30  | 9,7705  | 13,4804 | 1,3797  | F3      | True    | |
| 31  | 13,1232 | 19,3499 | 1,4745  | F3      | False   | |
| 32  | 11,6777 | 17,0577 | 1,4607  | F3      | False   | |
| 33  | 10,2687 | 14,3380 | 1,3963  | F3      | False   | |
| 34  | 8,9288  | 12,9348 | 1,4487  | F3      | False   | |
| 35  | 8,6688  | 12,7948 | 1,4760  | F3      | False   | |
| 36  | 8,9799  | 13,6102 | 1,5156  | F4/F5   | True    |
[7] Fadilah N and Mohamad-Saleh J 2014 Color feature extraction of oil palm fresh fruit bunch image for ripeness classification 13th Int. Conf. Appl. Comput. Appl. Comput. Sci., pp. 51–55.

[8] Roseleena J, Nursuriati J, Ahmed J and Low C Y 2011 Assessment of palm oil fresh fruit bunches using photogrammetric grading system Int. Food Res. J., vol. 18, no. 3, pp. 999–1005.

[9] Makky M, Soni P and Salokhe V M 2014 Automatic Non-destructive Quality Inspection System for Oil Palm Fruits Int. Agrophysics, vol. 28, no. 3, pp. 319–329.